Application of Fuzzy Logic in Load Frequency Control of Two Area Power System

Suranjana Bharadwaj

Abstract— This paper presents the use of Fuzzy Logic Controller along with Proportional-Integral (PI) Controller to regulate the frequency deviations and change in tie-line loading of a two area thermal-thermal power system due to a step load change. The system is designed using MATLAB SIMULINK software. The system is first diagnosed using only PI controller but the response is not found satisfactory as it give huge oscillations and larger settling time. In the next step we incorporate Fuzzy Logic Controller (FLC) along with the PI controller. The result shows a satisfactory improvement in the frequency and tie-line loading deviations in both the areas and also reduces the settling time for all the oscillations. Hence system becomes more stable and reliable.

Index Terms— Load Frequency Control,Two Area System,Tie-line,Fuzzy Logic,Fuzzy Controller,Membership Function,Rule Base,PI Controller,MATLAB,SIMULINK

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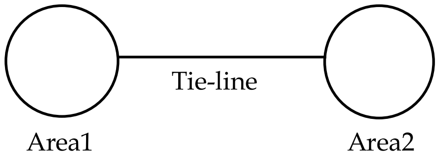
1 INTRODUCTION

Frequency regulation is one of the most important aspects of power system engineering[2]. It ensures supply of sufficient and reliable power with good quality. Load Frequency Control (LFC) is being used for several years as part of the Automatic Generation Control (AGC) scheme in electric power systems. The main objective of load frequency control(LFC) is to maintain the system frequency under prescribed limits and also check on the changes on tie-line loading in case of an interconnected power system. An interconnected power system can be considered as being divided into several control areas. In one particular area all the generators are assumed to form a coherent group which means that the group of generators are closely coupled internally and swing in unison [2]. Also, the generator turbines tend to have the same response characteristics. The several control areas are connected through tie-lines. The tie-line connection provides secure and economic operation. Under normal conditions, each area should be capable of supplying its own load and if this is not so, then it may purchase power from other areas to serve its demand. This purchase generally takes place over mutual agreements. A change in load or demand in any area of the interconnected power system is incorporated with change in frequency which is not desirable. Hence LFC is very essential which maintains the balance between the load on the generator and mechanical power input to the generator with the help of governor action [4]. Various types of controllers have been designed for LFC scheme till now. The controller should be such that apart from maintaining scheduled frequency and tie-line power it should also be able to give zero steady–state error. The controller should be robust and quick so that system comes back to its normal operating condition in minimum time after being subjected to load fluctuations. The controller that is applied in most cases is the conventional proportional integral (PI) controller [2], [10]. The inherent characteristic of a PI controller is that it adds a pole to the origin resulting in increasing the system type and reducing the steady state error to almost zero. But as the system complexity increases, response of PI controller is not satisfactory as it gives huge oscillations and larger settling time. To overcome these difficulties, intelligent controllers like fuzzy logic controllers, neural network controller etc came into picture. Fuzzy logic controllers provide a more realistic approach to the LFC problem. In this paper, a MATLAB SIMULINK model has been developed for a system with two areas connected through a tie-line [1]. First the system is diagnosed using only PI controller and after that fuzzy logic controller (FLC) has been incorporated with PI controller [5]. The result shows a satisfactory improvement with fuzzy plus PI controller as it reduces the system oscillations and improves the settling time [3].

2 FORMULATION OF LFC PROBLEM

2.1 Two Area System

In two-area system, two single areas are cnnected the tie line. Interconnection increases the overall system reliability. Generation failure in one area can be compensated by generators of other area to meet the load demand. The figure below shows a schematic of two areas connected through tie-line. Each area can be represented by its own equivalent turbine, generator and governor model.



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Hence the control objectoves are:

1. Each control area should supply its own load demand as far as possible and power transfer through the tie line should be on mutual agreement.
2. Both control areas should be controllable through frequency control.

2.2 Modelling of two area system in SIMULINK with PI controller

The system taken into consideration here is a two area thermal-thermal sytem connected through tie-line. Each area is represented by it own governor, turbine and generator-load model. A PI controller unit has been introduced in each area. The turbines considered here are non-reheat type. The PI controller basically consists of an integrator block and a proportional gain block and values of the constants can be varied as required. The input to the integrator is the frequency error of the system and this error is generally referred to as Area Control Error (ACE). The SIMULINK model incorporating the PI controller is shown below.

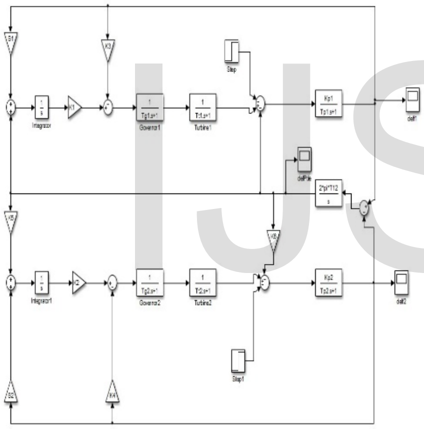


Fig.1 Two Area LFC with PI controller

By varying the values of K1 and K2 can be varied and best response giving minimum steady state error is selected. But as these responses are not satisfactory, we move on towards desingning the Fuzzy Logic Controller (FLC).

2.3 Fuzzy Logic Controller (FLC)

Fuzzy logic is a logical system which is a form of multivalued logic. It is related with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. Due to the dynamic behaviour of power system, conventional controllers (i.e. PI controller) cannot provide desired results. Therefore these controllers can be replaced with intelligent controllers like FLC to get fast and better response in LFC problems.In the next part, we try to design a FLC which will give us considerably less fluctuations in system output.

There are three main elements in a fuzzy controller

1. Fuzzification module (Fuzzifier)
2. Rule base and inference engine
3. Defuzzification module

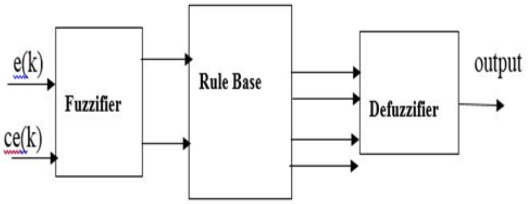


Fig.2 Schematic diagram of FLC

The Fuzzifier converts real life data input into suitable linguistic values. During fuzzification, an FLC receives input value, also known as the fuzzy variable, and analyses it according to user-defined charts called **Membership Functions.** Here the input values are always crisp numerical values. First the inputs are taken and it is determined to which degree they belong to each of the appropriate fuzzy sets with the help of their MFs. The output of fuzzification process is degree of membership corresponding to its numerical value defined by the qualifying linguistic set.

In this paper, we have considered two inputs to the controller, **area control error e(k)** and **change in area control error ce(k)**. The output is **delPc, the change in speed changer setting**. These two input signals to the fuzzy controller are converted to fuzzy members first in the fuzzifier using five membership functions: Negative Big(NB), Negative Small(NS), Zero(ZZ), Positive Small(PS), Positive Big(PB). The input variables range from -0.25 to +0.25. Triangular membership functions are used here because it is easier to intercept membership degrees from a triangle. Membership functions for output variable delPc are: Small(S), Medium(M), Big(B), Very Big(VB) and Very Very Big(VVB). The output variable ranged from 0 to 0.02.

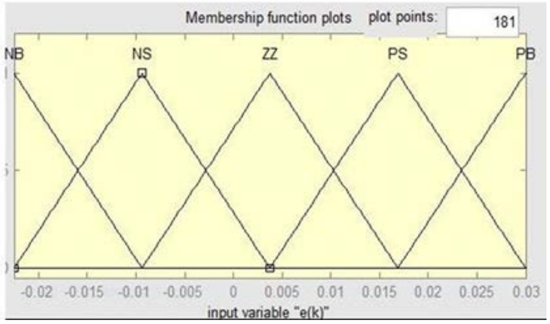
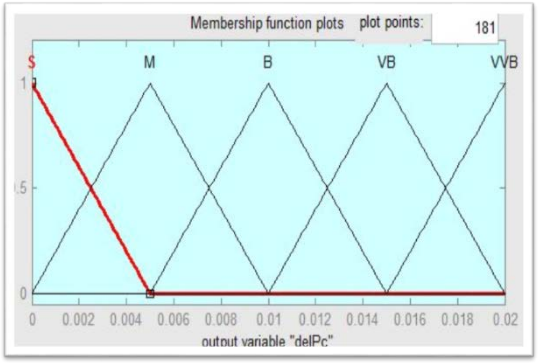


Fig.3 Membership function for input variables e(k), ce(k)



ce(k)

e(k)		NB	NS	ZZ	PS	PB
	NB	S	S	M	M	B
	NS	S	M	M	B	VB
	ZZ	M	M	B	VB	VB
	PS	M	B	VB	VB	VVB
	PB	B	VB	VB	VVB	VVB

Fig.4 Membership function for output variable delPc

The second element in an FLC is the rulebase and inference engine. Rule base gives a decision making logic. For various combinations of the input membership functions we get the output values in terms of membership functions. Here we have e(k) and ce(k) as the linguistic input and delPc as the linguistic output. The controller has upto 25 rules with 5 membership functions. The table below shows the rules. For the area control error e(k) and change in error ce(k) the rules are interpreted as if e(k) is NB and ce(k) is NS then delPc is S. Triangular membership functions are used for both input and output.

Fig.5 Fuzzy rule base table

The third element is the defuzzifier. The final output of the defuzzifier is in the form of crisp quantity.The method used for defuzzification here is the **centre of gravity (COG)** method.

2.4 Incorporating the fuzzy controller (FLC) in the two area system along with the PI controller

The designed fuzzy controller is now incorporated in the two area system alongwith the PI controller. The FLC has two input; one is the ACE and the othe one is the change in ACE. The output of the FLC is fed as input to the PI controller. The SIMULINK model for 'fuzzy plus PI control' is given below.

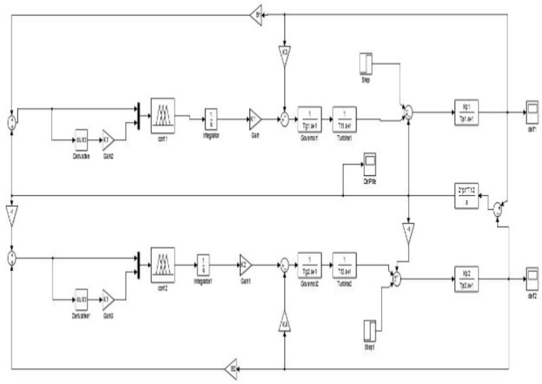


Fig.6 Two Area LFC with Fuzzy plus PI controller

3 RESULTS OF SIMULATION

We obtain responses of frequency deviations in each area and the change in tie-line power for 3%, 5% and 8% load variations with both **PI** and **Fuzzy plus PI** controllers.

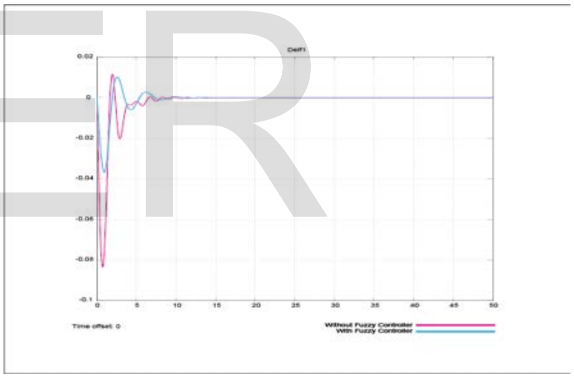


Fig7: **Delf1 vs Time** curve for 3% load variation (frequency deviation of area1 with respect to time with and without fuzzy controller)

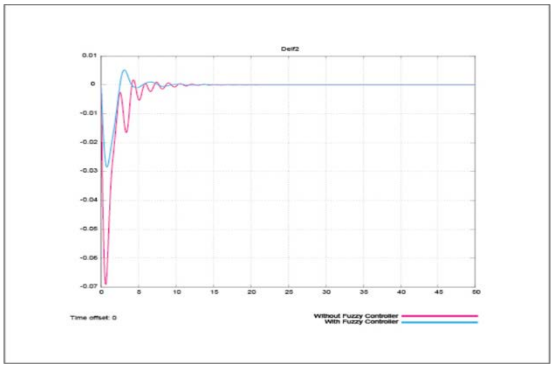


Fig8: **Delf2 vs Time** curve for 3% load variation (frequency deviation of area2 with respect to time with and without fuzzy controller)

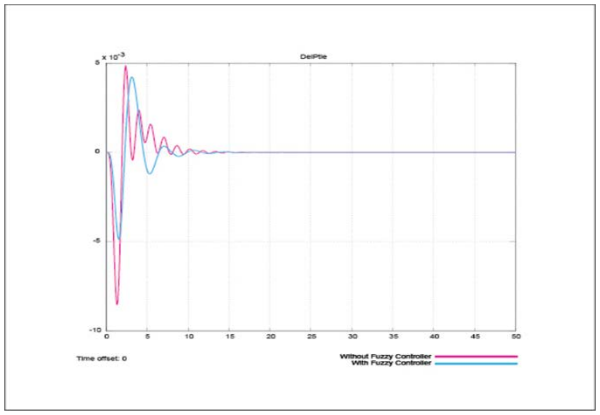


Fig9: **DelPtie vs Time** curve for 3% load variation (tie-line power deviation between area1 and area2 with respect to time with and without fuzzy controller)

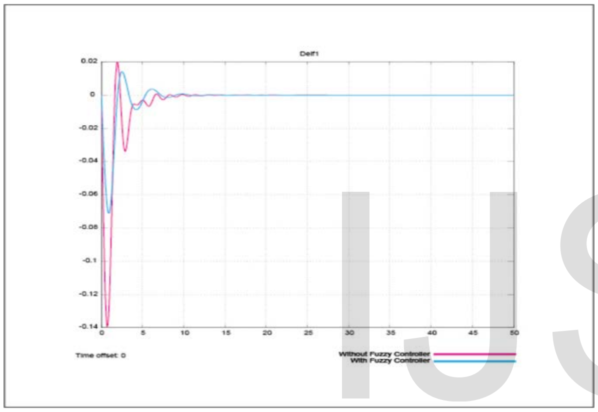


Fig10: **Delf1 vs Time** curve for 5% load variation (frequency deviation of area1 with respect to time with and without fuzzy controller)

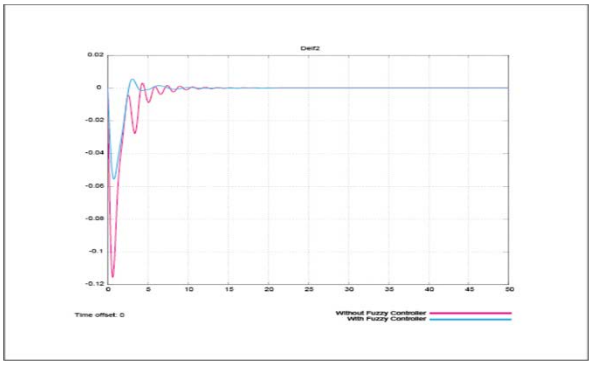


Fig11: **Delf2 vs Time** curve for 5% load variation (frequency deviation of area2 with respect to time with and without fuzzy controller)

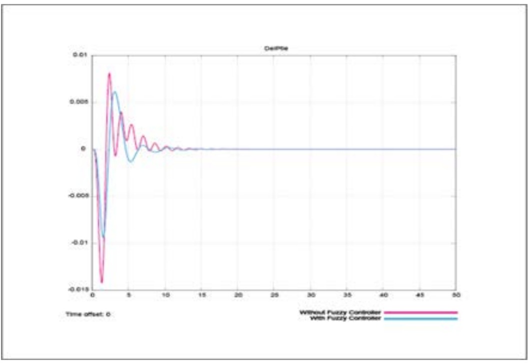


Fig12: **DelPtie vs Time** curve for 5% load variation (tie-line power deviation between area1 and area2 with respect to time with and without fuzzy controller)

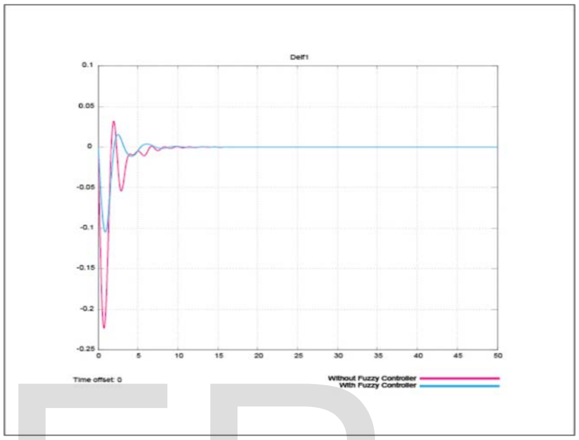


Fig13: **Delf1 vs Time** curve for 8% load variation (frequency deviation of area1 with respect to time with and without fuzzy controller)

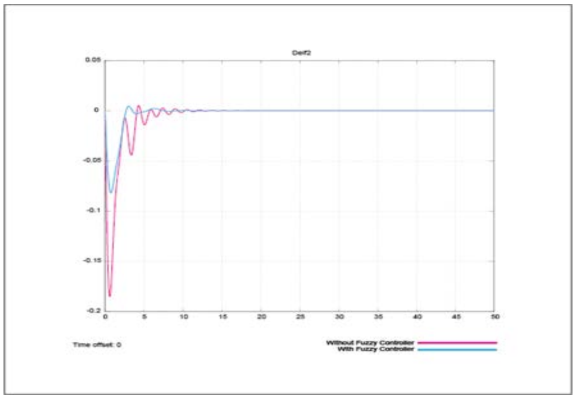


Fig14: **Delf2 vs Time** curve for 8% load variation (frequency deviation of area2 with respect to time with and without fuzzy controller)

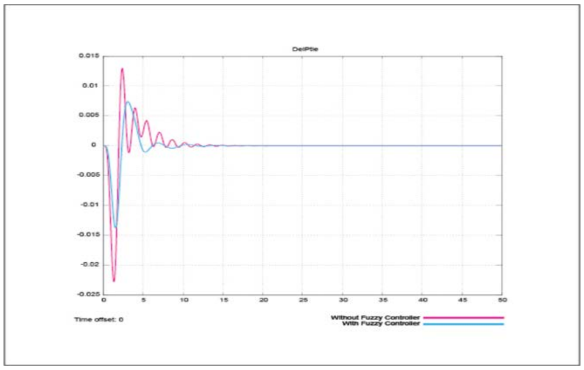


Fig15: **DelPtie vs Time** curve for 8% load variation (tie-line power deviation between area1 and area2 with respect to time with and without fuzzy controller)

4 COMPARISON OF RESULTS

After obtaining the responses for the two area system under consideration with both **PI** and **Fuzzy plus PI** controllers, we compare the results in terms of **peak overshoot**, **peak undershoot** and **settling time** for 3%, 5% and 8% load variations respectively.

Table1: Comparison of **peak overshoot** (in Hz) for 3% load variation

Controller	Delf1(Hz)	Delf2(Hz)	DelPtie(pu)
PI	0.012	0.002	0.0049
Fuzzy plus PI	0.010	0.005	0.0040

Table2: Comparison of **peak undershoot** (in Hz) for 3% load variation

Controller	Delf1(Hz)	Delf2(Hz)	DelPtie(pu)
PI	0.090	0.068	0.0085
Fuzzy plus PI	0.035	0.028	0.0049

Table3: Comparison of **settling time** (in seconds) for 3% load variation

Controller	Delf1(Hz)	Delf2(Hz)	DelPtie(pu)
PI	14	16	17
Fuzzy plus PI	13	13	15

Table4: Comparison of **peak overshoot** (in Hz) for 5% load variation

Controller	Delf1(Hz)	Delf2(Hz)	DelPtie(pu)
PI	0.020	0.004	0.0085
Fuzzy plus PI	0.013	0.005	0.0055

Table5: Comparison of **peak undershoot** (in Hz) for 5% load variation

Controller	Delf1(Hz)	Delf2(Hz)	DelPtie(pu)
PI	0.140	0.115	0.0145
Fuzzy plus PI	0.070	0.055	0.0080

Table6: Comparison of **settling time** (in seconds) for 5% load variation

Controller	Delf1(Hz)	Delf2(Hz)	DelPtie(pu)
PI	15	18	17
Fuzzy plus PI	13	15	15

Table7: Comparison of **peak overshoot** (in Hz) for 8% load variation

Controller	Delf1(Hz)	Delf2(Hz)	DelPtie(pu)
PI	0.035	0.008	0.013
Fuzzy plus PI	0.020	0.010	0.007

Table8: Comparison of **peak undershoot** (in Hz) for 8% load variation

Controller	Delf1(Hz)	Delf2(Hz)	DelPtie(pu)
PI	0.225	0.185	0.023
Fuzzy plus PI	0.110	0.060	0.014

Table9: Comparison of **settling time** (in seconds) for 8% load variation

Controller	Delf1(Hz)	Delf2(Hz)	DelPtie(pu)
PI	14	16	18
Fuzzy plus PI	11	13	15

5 CONCLUSION

This work finally gives a comparative analysis between the conventional PI controller and the fuzzy logic controller for a two area thermal-thermal system for some load disturbance. It aims to observe how the load frequency control scheme will work with these two types of controllers and which will give better performance. From the responses of delf1, delf2 and delPtie for the two area system, we observe that in each case, the frequency or the change in tie-line power first deviates to a maximum value and then settles down within a finite duration of time known as settling time. From the comparison tables, it is clear that for a step load change of 3%, 5% and 8% respectively, while keeping the other system parameters constant, the system with PI and fuzzy controller provides better dynamic performance and reduces oscillation of the frequency deviation and tie-line power flow in each area. However it is observed that with the increase of load variation system disturbances tend to increase to some extent, yet the controller tries to suppress it to tolerable limits. Therefore artificial intelligence approach using fuzzy controller is more accurate and faster than the conventional PI controllers.

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Appendix

The different parameters of the two area system are defined as:

Tgi=Governor time constant of ith area [sec]
Tti=Turbine time constant of ith area [sec]
Kpi=Gain of power system (Generator+Load) of ith area
Tpi=Time constant of power system (Generator+Load) of ith area [sec]
Ri = Governor Speed Regulation of ith area [Hz/puMw]
B1=B2=Constants which specify the frequency bias for the line load bias control
a12=-1; constant which accounts for the fact that power is being imported by area2 from area1
T12= Synchronizing coefficient
K3=1/R1
K4=1/R2

The default values used for the different parameters are as given below:

Tg1=Tg2=0.08s
Tt1=Tt2=0.3s
Kp1=Kp2=120Hz/puMw
Tp1=Tp2=20s
R1=1/K3=2.5Hz/puMw
R2=1/K4=1.5/puMw
a12=K5=K6= -1
K1=K2= -0.671
B1=B2=0.425
T12=0.110
Delfi=Incremental frequency deviation of ith area [Hz]
DelPtie=Change in tie line power [p.u.]