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Fuzzy controller for Load Frequency Control

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Abstract : *In an interconnected area system for Automatic Generation Control (AGC) of power system various control aspects concerning the problems. The load on the power system is always varying with respect to time which results in the variation of frequency, thus leading to load frequency control problem (LFC).The variation in the frequency is highly undesirable and maximum acceptable variation in the frequency is ± 0.5Hz.The conventional controller such as PI, PID are slow and do not allow the controller designer to take into account possible changes in operating conditions and nonlinearities in the generator unit. In order to overcome these drawbacks a new intelligent controller such as fuzzy controller is presented in this paper to quench the deviations in the frequency and the tie line power due to different load disturbances. The effectiveness of the proposed controller is confirmed using MATLAB/SIMULINK software. The results shows that fuzzy controller provides fast response, very less undershoot and negligible peak overshoots with having small state transfer time to reach the final steady state.*

Keywords: *Load Frequency Control (LFC), PID controller, Fuzzy Logic Controller (FLC), Inter-connected Two Area system, Tie-line power Deviation.*

I. Introduction

Classical control techniques of power systems are based on mathematical models. These techniques have difficulties in achieving the control objectives in the presence of uncertainties, changing of operating points under which the mathematical model is derived, and worn out of system components. In order to overcome these limitations, applications of intelligent technologies such as fuzzy systems, artificial neural networks, and genetic algorithms have been investigated. In the last two decades, applications of such intelligent techniques to various aspects of power systems, such as operation, planning, control, and management have witnessed increasing attention [1]. The load frequency control (LFC) of a multi-area power system is the mechanism that balances between power generation and the demand regardless of the load fluctuations to maintain the frequency deviations within acceptable limits. The basic means of controlling prime-mover power to match variations in system load is through control of the load reference set points of selected generating units [2].A survey of different control schemes of LFC and strategies of automatic generation control (AGC) can be found in [3],[4]. A unified PID LFC controller tuning using internal model control is presented in [4].A new systematic tuning method with a new structure to design a robust PID load frequency controller for multi machine power systems based on maximum peak resonance specification is presented in [5].Based on the active disturbance rejection control concept, a robust decentralized LFC scheme is proposed in [6] for an interconnected three-area power system. The approximation capabilities of the fuzzy logic systems [7] are exploited in the present work to design an adaptive fuzzy logic LFC.

II. Two area load frequency control

An extended power system can be divided into a number of load frequency control areas inter-connected by means of tie lines. Let us consider a two-area case connected by a single tie-line. The control objective is now to regulate the frequency of each area and to simultaneously regulate the tie-line power as per inter-area power contracts.

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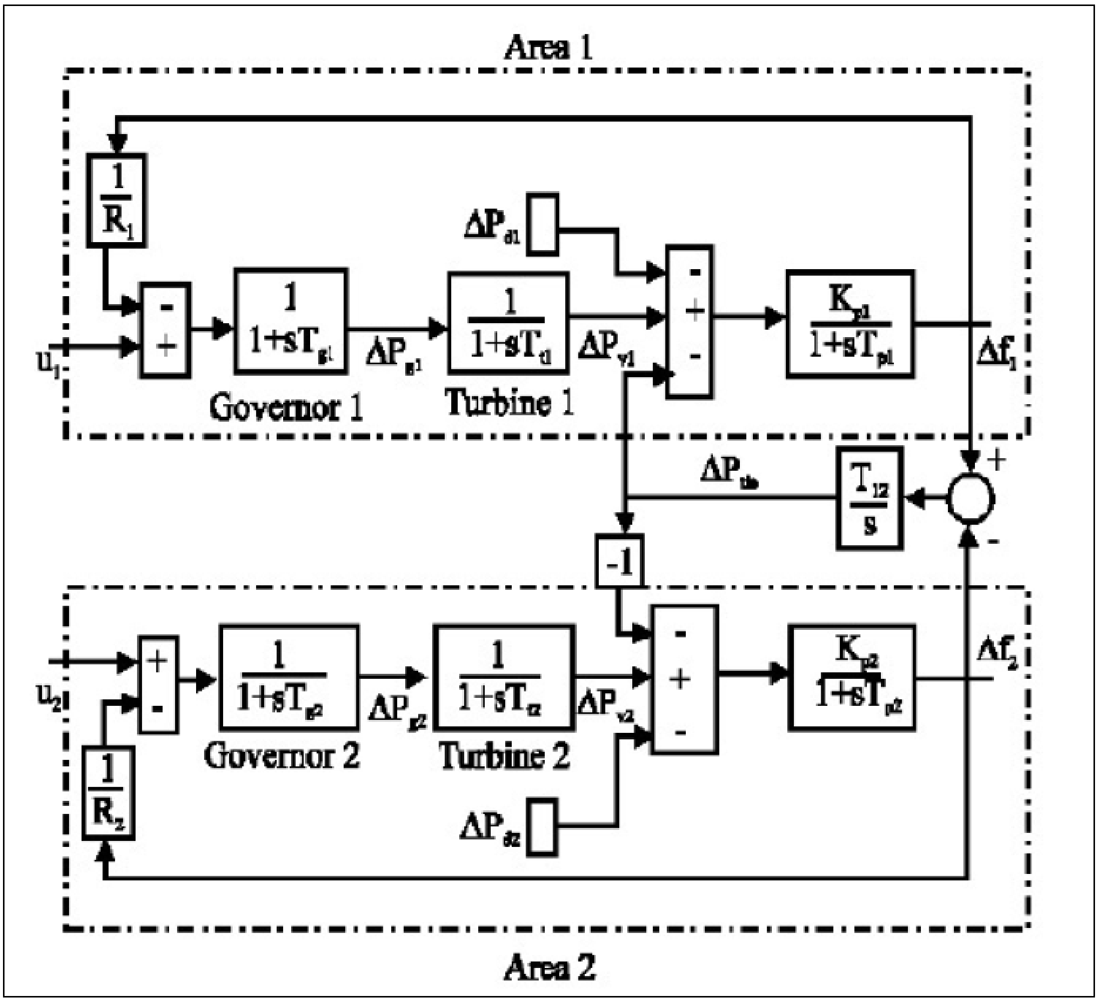

Fig.1 Complete block diagram of Two Area LFC

Each control area can be represented by an equivalent turbine, generator and governor system. Symbols with suffix 1 refer to area 1 and those with suffix 2 refer to area 2. In an isolated control area case the incremental power (ΔP_G-ΔP_D) was accounted for by the rate of increase of stored kinetic energy and increase in area load caused by increase in frequency. Since a tie-line transports power in or out of an area, this must be accounted for in the incremental power balance equation of each area.

Let's design two area power systems mathematically as below:

Power transported out of area 1 is given by

$P_{tie}=|V_1||V_2| / X_{12} * \sin(\delta_1 - \delta_2)$……………………………………………………………………3.1

[7] Where δ_1 and δ_2 are power angles of equivalent machines of two areas .For incremental changes in δ_1 and δ_2, the incremental tie line power can be expressed as

ΔP_{tie} (pu) $=T_{12}(\Delta\delta_1 - \Delta\delta_2)$……………………………………………………………………..3.2

Where

$T_{12}=V_1V_2/P_{r1}X_{12} * \sin(\delta_1 - \delta_2)$……………………………………………………………………3.3

is a synchronizing coefficient.

$\Delta P_{tie1}=2\pi T_{12}(\int \Delta f_1\, dt - \int \Delta f_2\, dt)$……………………………………………………………………..3.4

Similarly, the incremental tie-line power out of area 2 is given by

$\Delta P_{tie2}=2\pi T_{21}(\int \Delta f_2\, dt - \int \Delta f_1\, dt)$

…………………………………………………………………………3.5

Where

$T_{21}= (P_{r1}/P_{r2})\ T_{12}=a_{12}T_{12}$……………………………………………………………………………………………3.6

The power balance equation for area 1 is given by,

$\Delta P_{G1}-\Delta P_{G2}=2H_1/f_0\ d/dt\ (\Delta f_1)+B\Delta f+\Delta P_{tie1}$ …… ……………………………………………………………..3.7

Taking the Laplace form of the above equation and arranging them we get, Let

$\Delta F = [\Delta P_{G1}(s)-\Delta P_{G2}(s)-\Delta P_{tie}(s)]*K_{ps1}/1+T_{ps1}$…………………………………………………………….3.8

Let,

Kps, 1 =1/B1 and Tps, 1 =2H1/B1 f

$\Delta Ptie1=2\pi T12/s * [\Delta F_1\ (s) - \Delta F_2(s)]$……………………………………………………………………….3.9

$\Delta Ptie2=-2\pi a12\ T12/s * [\Delta F_2\ (s) - \Delta F1(s)]$……………………………………………………………...3.10

For control area 1,

$ACE_1=\Delta P_{tie1}+b_1\Delta f_1$………………………………. ……………………………………………………………………………3.11

$$\Delta P_{tie1(s)}=\frac{2\pi T12}{s}\,[\Delta F_{1}(s)-\Delta F_2(s)]\ \ldots\ldots\ldots\ldots\ldots\ldots 4.9$$

Taking the Laplace transform of the above equation, we get

$ACE_1(s)=\Delta P_{tie1}+b_1\Delta f_1(s)$……………………………………………………………………………………………….....3.12

Similarly for control area 2,

$ACE_2(s)=\Delta P_{tie1}+b_2\Delta f_2(s)$………………………………………………………………………………………………… 3.13

III. Fuzzy logic controller

Fuzzy logic control is a range-to-point or range-to-range control. The output of a fuzzy controller is derived from fuzzifications of both inputs and outputs using the associated membership functions. A crisp input will be converted to the different members of the associated membership functions based on its value. From this point of view, the output of a fuzzy logic controller is based on its memberships of the different membership functions, which can be considered as a range of inputs. To implement fuzzy logic technique to a real application requires the following three steps:

1) Fuzzification: Convert classical data or crisp data into fuzzy data or Membership Functions (MFs).
2) Fuzzy Inference Process: Combine membership functions with the control rules to derive the fuzzy output.
3) Defuzzification: Use different methods to calculate each associated output and put them into a table: the lookup table. Pick up the output from the lookup table based on the current input during an application.

1.1 Fuzzy sets

The fuzzy set is actually a fundamentally broader set compared with the classical or crisp set. The fuzzy set uses a universe of discourse as its base and it considers an infinite number of degrees of membership in a set.

1.1.1 Fuzzy sets and operation

A fuzzy set contains elements which have varying degrees of membership in the set, and this is contrasted with the classical or crisp sets because members of a classical set cannot be members unless their membership is full or complete in that set. A fuzzy set allows a member to have a partial degree of membership and this partial degree membership can be mapped into a function or a universe of membership values. Assume that we have a fuzzy set A, and if an element x is a member of this fuzzy set A, this mapping can be denoted as

$$\mu_A(x) \in [0, 1] \qquad (A = (x, \mu_A(x))\ |x \in X)\ \ldots\ldots\ldots\ldots 3.14$$

A fuzzy subset A with an element x has a membership function of $\mu_A(x)$.

1.2 Fuzzification and membership functions

Fuzzification is the first step to apply a fuzzy inference system. It needs to convert those crisp variables (both input and output) to fuzzy variables, and then apply fuzzy inference to process those data to obtain the desired output. Finally, in most cases, those fuzzy outputs need to be converted back to crisp variables to complete the desired control objectives. Generally, fuzzification involves two processes: derive the membership functions for input and output variables and represent them with linguistic variables.

3.3 Fuzzy control rules

In a fuzzy logic controller (FLC), the dynamic behavior of a fuzzy system is characterized by a set of linguistic description rules based on expert knowledge. The expert knowledge is usually of the form: IF (a set of conditions are satisfied) THEN (a set of consequences can be inferred). Since the antecedents and the consequents of these IF-THEN rules are associated with fuzzy concepts (linguistic terms), they are often called fuzzy conditional statements. Basically, fuzzy control rules provide a convenient way for expressing control policy and domain knowledge.

3.4 Defuzzification

To make the conclusion or fuzzy output available to real applications, a defuzzification process is needed. The defuzzification process is meant to convert the fuzzy output back to the crisp or classical output to the control objective. Three defuzzification techniques are commonly used, which are: Mean of Maximum method, Center of Gravity method and the Height method.

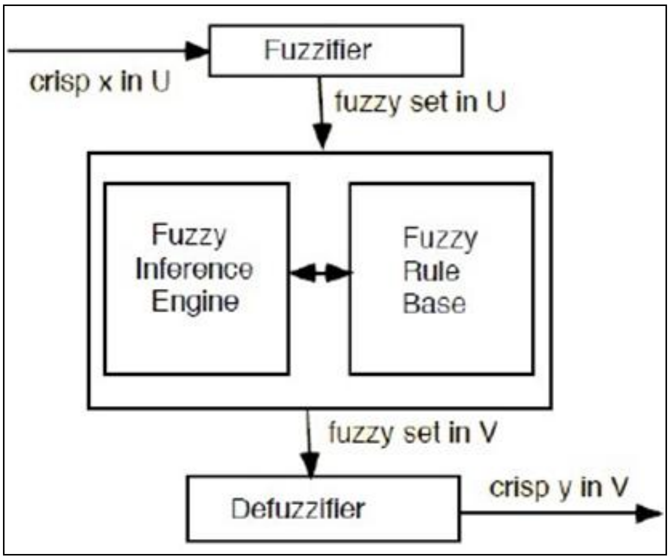

Fig.2 Fuzzy Logic Controller

Now we design Fuzzy inference system for FLC as below:

- Let the error e and change in error e: are inputs of FLC.
- Two inputs signals are converted to fuzzy numbers first in fuzzifier using five memberships functions as Positive Big (PB), Positive Small (PS), Zero (ZZ), Negative Small (NS), Negative Big (NB), Small (S), Medium (M), Big (B), very Big (VB), Very Very Big (VVB).
- Finally resultant fuzzy subsets representing the controller output are converted to the crisp values using the center of area (COA)/center of Gravity (COG) defuzzifier scheme.

The rules for this fuzzy controller are developed as:

ACE	*ACE·*				
	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

Table 1.IF-THEN rules for Fuzzy Logic Controller

IV. Simulation Results Of Two Area LFC

The two-area LFC is also implemented using MATLAB/SIMULINK FUZZY controller. The following are the specifications of simulation:

For Control Area 1

- Gain of speed governor Ksg = 1
- Gain of turbine Kt = 1
- Gain of generator load Kps = 120
- Time-constant of governer Tsg = 0.08
- Time-constant of turbine Tt = 0.28
- Time-constant of generator load Tps = 18

For Control Area 2

- Gain of speed governor Ksg = 1
- Gain of turbine Kt = 1
- Gain of generator load Kps = 100
- Time-constant of governor Tsg = 0.1
- Time-constant of turbine Tt = 0.28

Time-constant of generator load Tps = 20

Finally the results of Fuzzy controller are compared with that of the PID controller and without controller [8] and [9].

The simulation results are as follows: The simulation results of two area system area are shown below. In this three cases are considered based on the values used for LFC parameters.

Case 1: In this case we consider the parameters of deviation of area 1 shown in Fig.3.
Case 2: In this case we consider the parameters of deviation of area 2 shown in Fig.4.
Case 3: In this case we consider the parameters of deviation of area for tie-line shown in Fig.5

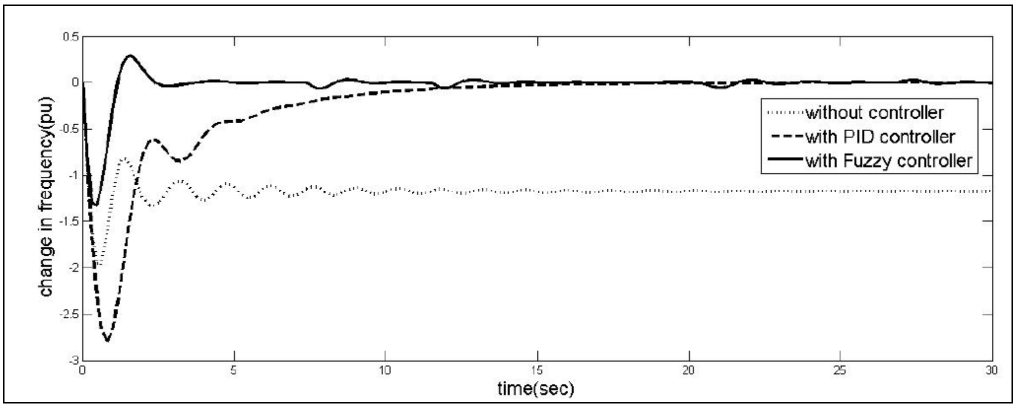

Fig.3 Dynamic responses for frequency deviation of area 1

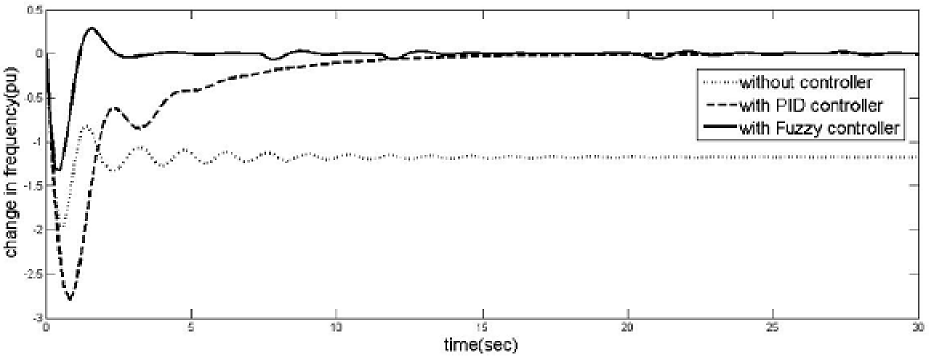

Fig.4 Dynamic responses for frequency deviation of area 2

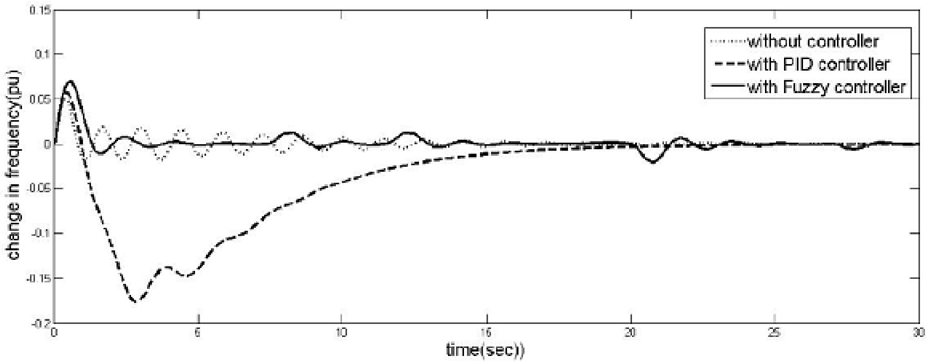

Fig.5 Dynamic responses for frequency deviation of tie-line between area1 and area2

The following chart shows the comparison between the results obtained with Fuzzy and PID controllers:

Area	Parameter	No controller	PID	Fuzzy
1	Peak overshoot(Hz)	0.5	0	0.2
	Settling time(sec)	Never settles	15	4
	Steady state error	1.2	0	0
2	Peak overshoot(Hz)	0.4	0	0.3
	Settling time(sec)	Never settles	17	6
	Steady state error	1.3	0	0

Table2. Comparison between PID and Fuzzy controllers

This shows that the steady state error in the response of two-area LFC with Fuzzy controller is almost zero when compared with the response obtained without controller and with PID controller. From Fig 3,4 and 5 it is observed that by using Fuzzy controller, the steady state error, settling time and peak overshoot are reduced which is preferred.

V. Conclusion

In this paper a fuzzy logic controller is designed for load frequency controller of two area inter-connected power system. It can be implemented in four area power system and controlled by using advanced controller systems. The system performance is observed on the basis of dynamic parameters i.e. settling time, overshoot, undershoot and steady state error. The system performance characteristics reveal that the performance of fuzzy logic controller is better than other controllers. As a further study the proposed method can be applied to multi area power system load frequency control (ALFC) and also optimum values can be obtained by Genetic Algorithm and Neural networks.

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