International Journal Of Scientific & Engineering Research, Volume 4, Issue 8, August 2013
ISSN 2229-5518

Performance Analysis of Conventional and Intelligent Controllers In Power Systems With AGC

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Abstract— large scale power systems are normally composed of control areas or regions representing coherent groups of generators. Area load changes and abnormal conditions lead to mismatches in frequency and scheduled power interchanges between areas. These mismatches have to be corrected by Automatic Generation Control (AGC), which is defined as the regulation of the power output of generators within a prescribed area. In this paper, the system investigated consists of two area thermal systems. A model of the same with conventional PI and PID controller is developed in MATLAB/SIMULINK and responses of change in frequency, tie line power and change in mechanical power are observed. Tuning of PI and PID controllers are done using Ziegler-Nichols tuning method. The later part of the study involves replacing the conventional controller with Fuzzy Logic Controller (FLC). After comparing the dynamic responses with the one obtained from the conventional controllers, Fuzzy logic controller is found to be a best controller than the conventional controllers.

Index Terms— Automatic Generation Control, Fuzzy logic controller, PI controller, PID controller, Thermal system, Two Area System, Ziegler-Nichols method

1. INTRODUCTION

Automatic Generation Control (AGC) is very important issue in power system operation and control to ensure the supply of sufficient and reliable electric power with good quality. When load in the system increases turbine speed drops before the governor can adjust the input. As the change in the value of speed decreases the error signal becomes smaller and the positions of governor valve get close to the required position, to maintain constant speed. However the constant speed will not be the set point and there will be an offset, to overcome this problem an integrator is added, which will automatically adjust the generation to restore the frequency to its nominal value. This scheme is called automatic generation control [9]. The role of AGC is to divide the loads among the system, station and generator to achieve maximum economy and accurate control of the scheduled interchanges of tie-line power while maintaining a reasonability uniform frequency [8]. Modern power system network consists of a number 1of utilities interconnected together and power is exchanged between utilities over tie lines by which they are connected. Automatic generation control (AGC) plays a very important role in power system as its main role is to maintain the system frequency and tie line flow at their scheduled values during normal period. A control signal made up of tie line flow deviation added to frequency deviation weighted by a bias factor would accomplish the desired objective. This control signal is known as area control error (ACE).ACE serves to indicate when total generation must be raised or lowered in a control area. In an interconnection, there are many control areas, each of which performs its AGC with the objective of maintaining the magnitude of ACE (area Control Error) "sufficiently close to 0" using various criteria. In order to maintain the frequency sufficiently close to its synchronous value over the entire interconnection, the coordination of the control areas' actions is required. As each control area shares in the responsibility for load frequency control, effective means are needed for monitoring and assessing each area's performance of its appropriate share in load frequency control [10].

The pioneering work by a number of control engineers, namely Bode, Nyquist, and Black, has established links between the frequency response of a control system and its closed-loop transient performance in the time domain. The investigations carried out using classical control approaches reveal that it will result in relatively large overshoots and transient frequency deviation. Moreover, the settling time of the system frequency deviation is comparatively long and is of the order of 10–20 s. The AGC regulator design techniques using modern optimal control theory enable the power engineers to design an optimal control system with respect to given performance criterion. Fosha and Elgerd were the first to present their pioneering work on optimal AGC regulator design using this concept.

Automatic generation control of a multi-area power system with conventional integral controllers carried out by J. Nanda, Fellow IEEE; M. Parida, A. Kalam deals with automatic generation control (AGC) of a multi-area hydrothermal system [6]. In 'Frequency stabilization using fuzzy logic based controller for multi-area power system' by H.D. Mathur and H.V. Manjunath proposed a fuzzy logic controller for load frequency control problem of electrical power system. Drawbacks of conventional controllers are slow response, the effect of nonlinearities like governor dead band, boiler dynamics etc. are not considered in conventional controllers. These drawbacks are rectified to a great extent by intelligent controllers.

Intelligent control techniques are of great help in implementation of AGC in power systems. Today's power systems are more complex and require operation in uncertain and less structured environment. Some of these techniques are rule based logic programming; model based reasoning, computational approaches like fuzzy sets, artificial neural networks, evolutionary programming and genetic algorithms. The comprehensive and critical review of the published literature in the area of AGC has been presented. Literature on recent developments, such as AGC schemes based on the concepts of artificial intelligence, including the neural networks has also been reviewed. Various AGC strategies reported in the literature that highlights their salient features have also been reviewed and discussed.

2. AGC IN A SINGLE AREA SYSTEM

In an isolated power system, maintenance of interchange power is not an issue. Therefore, the function of AGC is to restore frequency to the specified nominal value. This is accomplished by adding a reset or integral control which acts on the load reference settings of the governors of units on AGC. The integral control action ensures zero frequency error in the steady state [12]. The supplementary generation control action is much slower than the primary speed control action. As such it takes effect after the primary speed control (which acts on all units on regulation) has stabilized the system frequency. Thus, AGC adjusts load reference settings of selected units, and hence their output power, to override the effects of composite frequency regulation characteristics of power system [13]. In doing so, it restores the generation of all other units not on AGC to scheduled values.

With the primary LFC loop, a change in the system load will result in a steady state frequency deviation, depending on the governor speed regulation. In order to reduce the frequency deviation to zero, a reset action should be provided. The reset action is achieved by introducing an integral controller to act on the load reference setting to change the speed set point.

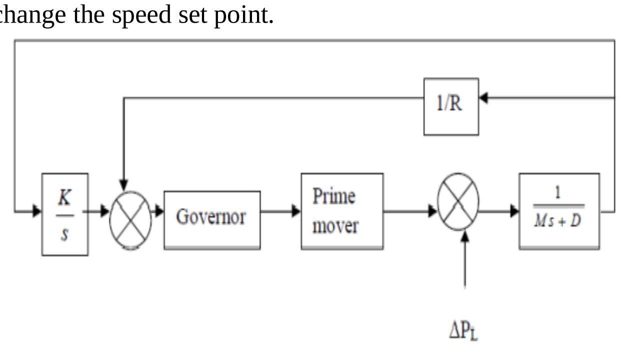

Fig.1 Single area system with AGC

3. AGC FOR A TWO AREA SYSTEM

In an interconnected (multi area) system, there will be one ALFC (Automatic Load Frequency Control) loop for each control area. They are combined as shown in Figure 2 for the interconnected system operation. With a governor controller alone, we cannot bring steady state error to zero. However, we can bring steady state error to zero by using a supplementary control which set the value of Δ P_{ref}. This supplementary control is known as automatic generation control. Value of Δ P_{ref} is changed based on frequency deviation. In a two area power system, when an additional load is added in area 1, the frequency of entire system decreases [13]. Hence, generation in both area increases because of governor action. However, without AGC steady state frequency deviation will not be zero. Since generation in area 2 has increased, there will be tie line flow from area 2 to area 1 to share the additional load in area 1.

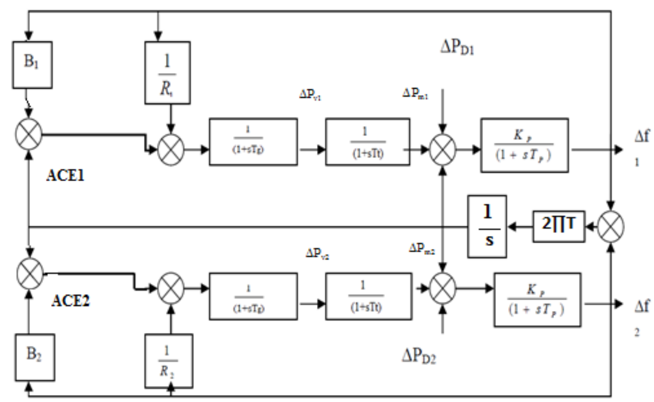

Fig. 2 Two area system with AGC

4.AGC CONTROL SCHEMES

4.1 PI Controller

The proportional plus integral controller produces an output signal consisting of two terms one proportional to error signal and other proportional to integral of error signal [18].

Control signal, $u(t) = K_p e(t) + \frac{K_p}{Ti} \int e(t)\,\mathrm{dt}$ (1)

Where,

K_p Proportional gain
T_i Integral time

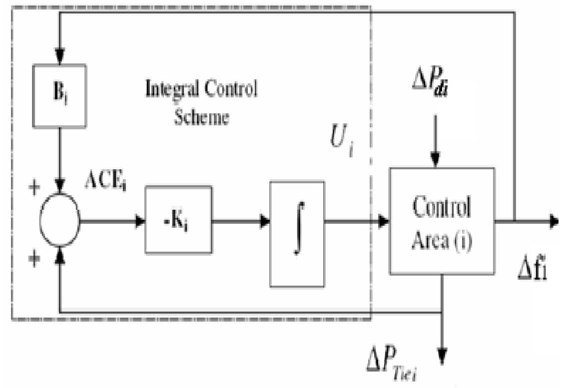

Fig. 3 Conventional PI controller

4.2 PID Controller

A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism widely used in industrial control systems – a PID is the most commonly used feedback controller. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. In the absence of knowledge of the underlying process, PID controllers are the best controllers. However, for best performance, the PID parameters used in the calculation must be tuned according to the nature of the system – while the design is generic, the parameters depend on the specific system.

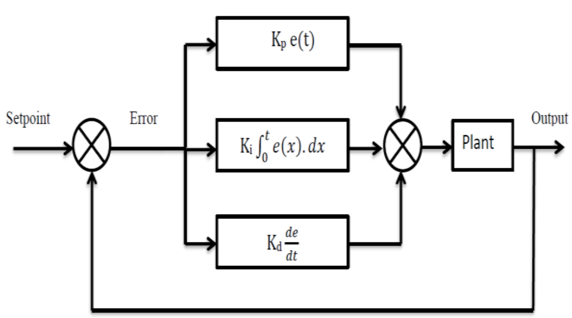

Fig. 4 Basic block diagram of a conventional PID controller

The PID controller is probably the most-used feedback control design. PID is an acronym for Proportional-Integral-Derivative, referring to the three terms operating on the error signal to produce a control signal. If u(t) is the control signal sent to the system, y(t) is the measured output and r(t) is the desired output, and tracking error e(t) = r(t) − y(t), a PID controller has the general form

$$u(t) = \mathrm{Kpe(t)} + \mathrm{Ki}\int \mathrm{e(t)dt} + \mathrm{Kd}\frac{\mathrm{d}}{\mathrm{dx}}\mathrm{e(t)} \qquad (2)$$

4.3 Ziegler-Nichols Reaction Curve Method

Another heuristic tuning method is formally known as the Ziegler–Nichols method, introduced by John G. Ziegler and Nathaniel B. Nichols.

- Process Reaction Curve

The closed-loop system will respond in a desirable way only if its controller is properly tuned. This means that its proportional, integral and derivative (PID) settings are properly made. A popular procedure for tuning a controller is the Ziegler-Nichols Reaction Curve Tuning Method. This procedure requires a step change of the controllers output alters the controlled variable. The method used to make the step change and measure the controlled variable is called the Process Identification Procedure. This controller setting puts the system into an open-loop condition. Based on the shape and magnitude of the controlled variable's reaction curve in reference to the step change, value are obtained and used in mathematical formulas. These values are then used to determine the PID settings.

Table 1 Ziegler Nichols tuning rule table

CONTROLLER	K_P	K_I	K_D
P	$\frac{T}{L}$	0	0
PI	$0.9\frac{T}{L}$	$0.27\frac{T}{L^2}$	0
PID	$1.2\frac{T}{L}$	$0.6\frac{T}{L^2}$	0.6T

5. FUZZY LOGIC BASED CONTROL

Lotfi Zadeh, a professor at University of California, conceived the concept of fuzzy logic [7]. Fuzzy logic is basically a multi valued logic that, unlike Boolean or crisp logic, deals with problems having vagueness; uncertainty and uses membership functions with values varying between 0 and 1.Fuzzy logic tends to mimic human thinking that is often fuzzy in nature. On the contrary, a fuzzy set theory is based on fuzzy logic; a particular object has a degree of membership in a given set, which is in the range of 0 to 1. Fuzzy logic controller is used for automatic generation control in a two area system.

5.1 Fuzzy Logic Controller

The main building units of an FLC are a fuzzification unit, a fuzzy logic reasoning unit, a knowledge base, and a defuzzification unit. Defuzzification is the process of converting inferred fuzzy control actions into a crisp control action [8].

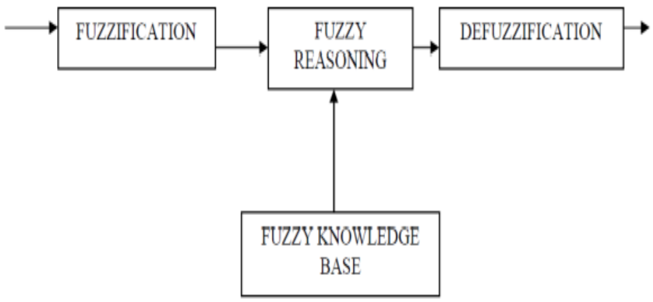

Fig.5 Basic structure of fuzzy logic controller

5.1.1 Algorithm for Fuzzy Logic Application to AGC Problem

The calculation of the control action in the fuzzy algorithm consists of following four steps.

- Calculate area control error (ACE) and change of area control error.
- Convert the error and change of frequency into fuzzy variables i.e. linguistic variables such as Positive Big (PB), Positive Medium (PM) etc., as given below.
    - Evaluate the decision rules shown in rule base given below using the compositional rule of inference.
    - Calculate the deterministic input required to regulate the process.

5.1.2 Selection of Membership Function

The number of linguistic variables describing the fuzzy subsets of a variable varies according to the application. Usually an odd number is used [4], [5]. A reasonable number is five. Each linguistic variable has its fuzzy membership function. The membership function maps the crisp values into fuzzy variables. The triangular membership functions are used to define the degree of membership. It is important to note that the degree of membership plays an important role in designing a fuzzy controller. Each of the input and output fuzzy variables is assigned five linguistic fuzzy subsets varying from negative big (NB) to positive big (PB). Each subset is associated with a triangular membership function to form a set of five membership functions for each fuzzy variable.

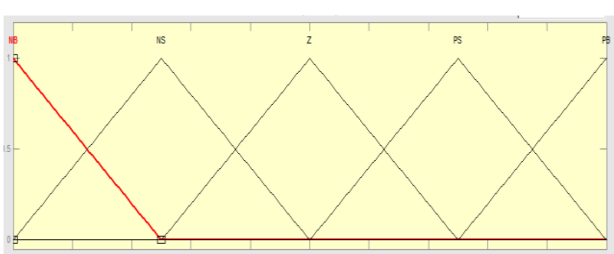

Fig. 6 Membership function for error

5.1.3 Fuzzy Rule Base

A set of rules which define the relation between the input and output of fuzzy controller can be found using the available knowledge in the area of designing the system [14]. These rules are defined using the linguistic variables. The two inputs, error and rate of change in error, result in 25 rules. All the 25 rules governing the mechanism for each output are explained in table 2 where all the symbols are defined in the basic fuzzy logic terminology.

Table 2 Fuzzy Rule Decision Table

		ė				
		NB	NS	ZZ	PS	PB
e	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

Each output is obtained by applying a particular rule expressed in the form of membership functions. Finally the output membership function of the rule is calculated. This procedure is carried out for all of the rules and with every rule an output is obtained. Using min-max inference, the activation of the ith rule consequent is a scalar value which equals the minimum of the two antecedent conjuncts' values. If the system dynamics are not known or are highly nonlinear, trial-and-error procedures and experience play an important role in defining the rules [14].

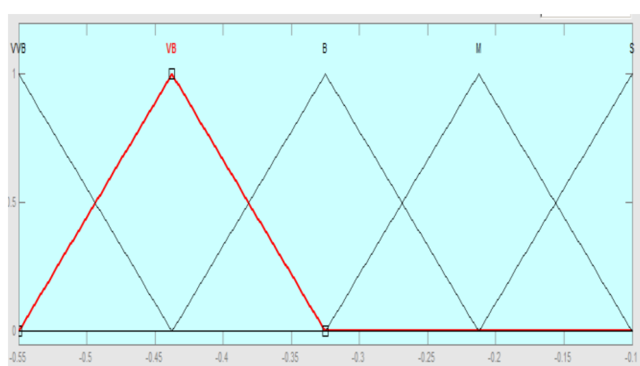

Fig.7 Membership function for gain

6. RESULTS AND DISCUSSIONS

In this presented work, Thermal-thermal interconnected power system has been developed with PI, PID and Fuzzy Logic Controllers to illustrate the performance of AGC using MATLAB/SIMULINK package. The parameters used for simulation are given in appendix. Three types of Simulink models are developed with PI, PID and Fuzzy controller to obtain better dynamic behavior. Simulations were obtained by MATLAB 7.0 SIMULINK software. Dynamic responses using different controllers are shown. Simulation is carried out with 2% step load perturbations in area I. The responses of change in frequency, tie line power and mechanical power are shown in figure respectively. Parameters are fixed as per appendix.

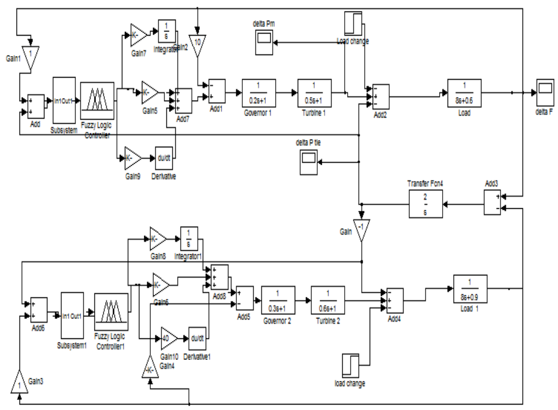

Fig.8 MATLAB model of test system with fuzzy logic controller

6.1 AGC with PI Controller

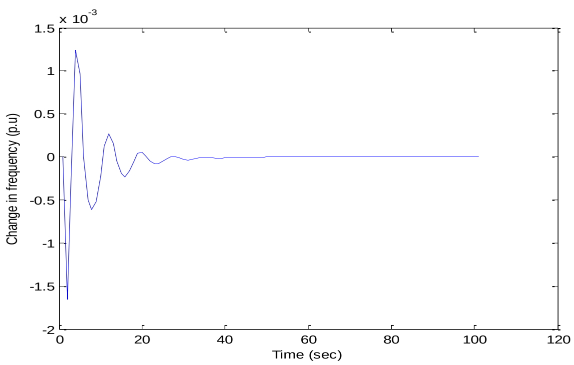

Fig. 9 Frequency response of two area system with PI controller

6.2 AGC with PID Controller

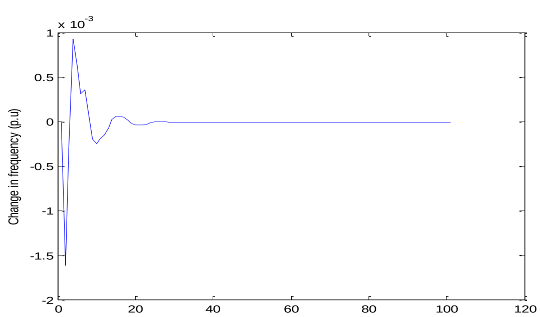

Fig. 10 Frequency response of two area system with PID controller

Responses of two area system considered with PID controller are observed. This shows that the steady state error in frequency response settles to zero. This signifies the importance of PID controller in AGC. Tuning of PI and PID controller is done with Ziegler Nichols method. Proportional, integral and derivative gains are as shown in appendix.

6.3 AGC with Fuzzy Controller

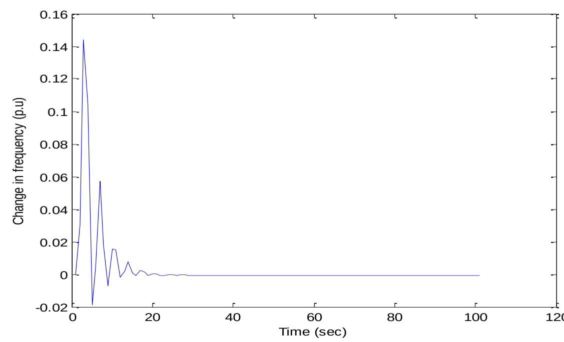

Fig. 11 Frequency response of two area system with fuzzy logic controller

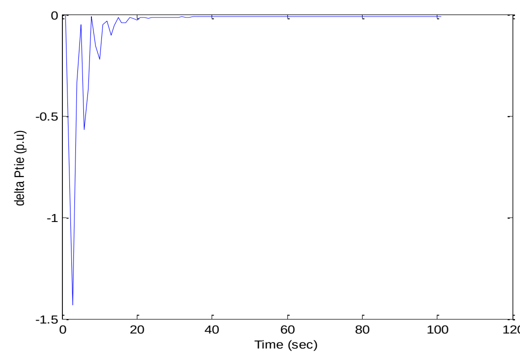

Fig. 12 Tie line power deviation of two area system with fuzzy logic controller

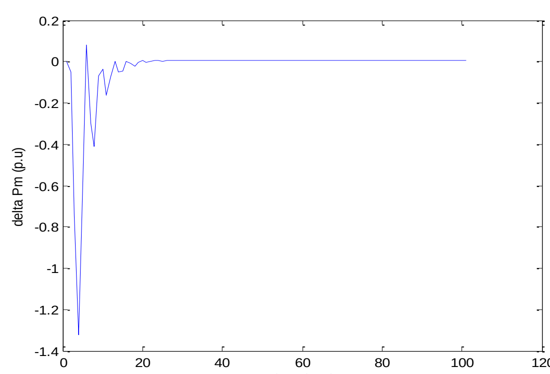

Fig. 13 Mechanical power deviation of two area system with fuzzy logic controller

Table 3 Change in frequency for 2 % load variation

Controller	Settling time(sec)
PI Controller	40
PID Controller	32
Fuzzy Logic Controller	20

Comparison of simulation results shows the performance comparison of different controllers such as PI, PID and Fuzzy Logic Controller in a two area interconnected system are shown in table 3

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7. CONCLUSION

In this paper, a fuzzy logic controller is designed for the automatic generation control of two-area interconnected power systems. The performance of three controllers is evaluated on the basis of the settling time and peak overshoots of frequency deviations. The simulation results show the effectiveness of fuzzy controller in the load frequency control. Settling time for the disturbances is comparatively low for fuzzy controller. Fuzzy controller proves to be a better controller in settling time aspect of error signal.

APPENDIX

System parameters used are shown below

PARAMETERS	AREA 1	AREA 2
Governor time constant, Tg	0.2 sec	0.3 sec
Turbine time constant, Tt	0.5 sec	0.6 sec
Frequency dependent load coefficient, D	0.6	0.9
Speed regulation, R	0.0625 p.u	0.05 p.u
Inertia constant, H	4	4
Load change	0.02	0

Tuning Parameters

PI Controller	
Proportional Gain (Kp)	0.3
Integral Gain (Ki)	-0.4
PID Controller	
Proportional Gain (Kp)	-0.1
Integral Gain (Ki)	-0.3
Derivative Gain (Kd)	0.1

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