LOAD FREQUENCY CONTROL OF FOUR AREA POWER SYSTEM USING ARTIFICIAL INTELLIGENCE

[1]Radharani Panigrahi , [2]Suchismita Swain

[1,2]Asst professor, EEE, Kalam Institute of Technology (India)

ABSTRACT

This paper presents the use of one of the methods of artificial intelligence to study the automatic generation control of interconnected power systems. In this paper, the AGC system investigated consists of four equal area reheat thermal systems. The load frequency is controlled by using Fuzzy Logic Controller (FLC). The design of FLC in MATLAB involves the allocation of areas inputs and outputs, mapping of rules between inputs and outputs and defuzzification of outputs into a real value. After comparing the dynamic responses with the one obtained from the conventional controller, Fuzzy logic controller is found to be a best controller than the conventional Integral controller.

***Keywords*: Area Control Error (ACE), Fuzzy logic Controller Interconnected Power System, Frequency Control, Integral Controller, MATLAB / SIMULINK, Tie-line**

I INTRODUCTION

Power systems are used to convert natural energy into electric power. They transport electricity to factories and houses to satisfy all kinds of power needs. To optimize the performance of electrical equipment, it is important to ensure the quality of the electric power. It is well known that three-phase alternating current (AC) is generally used to transport the electricity. During the transportation, both the active power balance and the reactive power balance must be maintained between generating and utilizing the AC power. Those two balances correspond to two equilibrium points: frequency and voltage. When either of the two balances is broken and reset at a new level, the equilibrium points will float. A good quality of the electric power system requires both the frequency and voltage to remain at standard values during operation. For India, the standard values for the frequency and voltage are *50 Hertz* and *230 Volts* respectively. However, the users of the electric power change the loads randomly and momentarily. It will be impossible to maintain the balances of both the active and reactive powers without control. As a result of the imbalance, the frequency and voltage levels will be varying with the change of the loads. Thus a control system is essential to cancel the effects of the random load changes and to keep the frequency and voltage at the standard values.

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. An interconnected power system can be considered as being divided into control areas, all generators are assumed to form a coherent group (George et al, 2001). One of the objectives of LFC is to maintain the system frequency at nominal value (50 Hz). In the steady state operation of power system, the load demand is increased or decreased in the form of Kinetic Energy stored in generator prime mover set, which results the variation of speed and frequency accordingly. Therefore, the control of load frequency is essential to have safe operation of the power system (Kothari et al. 2003; Kundur, 1994; Wadhawa, 2007). Also Load Frequency control is defined as, the regulation of power output of controllable generators within a prescribed area in response to change in system frequency, tie-line loading, or a relation of these to each other, so as to maintain the schedules system (Elgerd, 1971). Therefore, a control strategy is needed that not only maintains constancy of frequency and desired tie-power flow but also achieves zero steady state error and inadvertent interchange. Among the various types of load frequency controllers, the most widely employed is the conventional proportional integral (PI) controller. The PI controller is very simple for implementation and gives better dynamic response, but their performances deteriorate when the complexity in the system increases due to disturbances like load variation boiler dynamics (Talaq et al. 1999; Arvindan et al. 2009). Therefore, there is need of a controller which can overcome this problem.

In this work an attempt is made to compare the performance of the Fuzzy Logic Controller with conventional Integral Controller. In this project four area interconnected thermal reheat system is used.

II MODELING INCLUDING GRC

In power systems having thermal plants, power generation can be changed only at a specified maximum rate. The generation rate for reheat turbines is very low. If these constrains are not considered, the system is likely to chase large momentary disturbances. This results in undue wear and tear of the controller. It is, therefore, extremely important to understand the influence of Generation Rate Constraint (GRC) in the AGC problem. The GRCs result in larger deviations in ACEs as the rate at which generation can change in the area is constrained by the limits imposed. Therefore, the duration for which power needs to be imported increases considerably as compared to the case where generation rate is not constrained.

III FUZZY LOGIC CONTROLLER

The increasing prominence of the computers has led to a new way of looking at the world. Artificial Neural Networks and the Fuzzy logic (systems) that are considered as the so called soft computing methods are now a day's becoming predominant tools in the area of Artificial Intelligence linked application oriented methods

Fuzzy Systems or logic's as introduced by Zadeh in 1965 has basically introduced to solve inexact and vague concepts by relating those using multi-valued fuzziness in a logical way. Earlier research in this field was based on mathematical understanding of set theory and probability. Further as a part of developing it as mathematics the applications of these theories were considered in different areas. The application of fuzzy systems were mainly in the field of modal interface, speech recognition, functional reasoning hybrid application along with Neural nets, information, traction control, business other than in almost all the areas of the power systems.

3.1 Fuzzy Logic and Fuzzy Systems

Fuzzy set theory derives from the fact that almost all-natural classes and concepts are fuzzy rather than crisp in nature. Fuzzy systems are model free systems in which all things are matters of degree. These systems use an inferential approach oriented towards system analysis and decision support. Fuzziness describes event ambiguity. It matters the degree, to which an event occurs, not whether it occurs or occurs in random to what degree it occurs is fuzzy. Whether an ambiguous event occurs - as when we say, "there is 20 percent chance of light rain tomorrow" - involves compound uncertainties, the possibility of fuzzy event emerges. Fuzzy systems store benefits of fuzzy associates or common sense "rules". Fuzzy programming admits degrees. They systems "reason" with parallel associate's interference. When asked a question or given an input, fuzzy systems fire each fuzzy rule in parallel, but to a different degree, to infer a conclusion or output. Thus fuzzy systems reason with sets, "fuzzy" or multi valued sets, instead of bivalent propositions. They estimate sampled functions from input to output. They may use linguistic or numeric samples for example they may use HEAVY, LONGER or number (relative) for the degree of fuzziveness. Fuzzy interpretations of data are a natural and intuitively plausible way to formulate and solve various problems in pattern recognition.

Fuzzy logic is a thinking process or problem-solving logical system for formalization of approximate reasoning, and in a wider sense, used anonymously with Fuzzy set theory. It is an extension of multi valued logic. Fuzzy logic systems provide an excellent framework to more completely and effectively model uncertainty and imprecision in human reasoning with the use of linguistic variables with membership functions. Fuzzification offers superior expressive power, greater generality, and an improved capability to model complex problems at a low solution cost. Unlike fuzziness the probability dissipates with increasing information.

3.2 Fuzzy Sets and Rules

In fuzzy set theory ' normal 'sets are called crisp sets, in order to distinguish them from fuzzy sets. Let C be a crisp set defined on the universe U, then for any element of u of U, either u (C) or U (C) occurs. In fuzzy set theory this property is generalized, therefore in a fuzzy set F, It is not necessary that either $u \in F$ or u (F) exist. In the fuzzy sets theory the generalization of the membership properties are as follows. For any crisp set C it is possible to define a characteristic function $\mu C: U \rightarrow [0,1]$ instead from the two-element set {0,1}. The set that is defined on the basis of such an extended membership function is called as fuzzy set. Fuzzy rules are elementary or composed proposals. They result from a conjunction between elementary fuzzy proposals. A fuzzy rule is composed of a premise and a conclusion.

The classical structure of a rule is "If < premise> then <conclusion>"

When the premise is an elementary fuzzy proposal, the rule is described as follows. If <x is A> then < conclusion>. The x is a variable; generally real, defined on a referential called the universe of discourse, given as a capital letter here X. A is a linguistic term, taken in a set of terms noted as TX. Basic concept of fuzzy logic's is fuzzy " If then Rule " or Fuzzy Rule.

IV FUZZY LOGIC CONTROLLER FOR LOAD FREQUENCY CONTROL OF THERMAL REHEAT INTERCONNECTED SYSTEM

As we studied that Fuzzy logic is a thinking process or problem-solving control methodology incorporated in control system engineering, to control systems when inputs are either imprecise or the mathematical models are not present at all. Fuzzy logic can process a reasonable number of inputs but the system complexity increases with the increase in the number of inputs and outputs, therefore distributed processors would probably be easier to implement. Fuzzification is process of making a crisp quantity into the fuzzy (Ross, 1985). They carry considerable uncertainty. If the form of uncertainty happens to arise because of imprecision, ambiguity, or vagueness, then the variable is probably fuzzy and can be represented by a membership function.[5]

Defuzzification is the conversion of a fuzzy quantity to a crisp quantity, just as fuzzification is the conversion of a precise quantity to a fuzzy quantity. The output of a fuzzy process can be the logical union of two or more fuzzy membership functions defined on the universe of discourse of the output variables. There are many methods of defuzzification, out of which smallest of maximum method is applied in making fuzzy inference system (Ross, 1985).[5]

4.1 SOM (Smallest of Maximum) Method

This is also called first (or last of maximum) and this method uses the overall output or union of all individual output fuzzy sets Ck to determine the smallest value of the domain with maximum z membership degree in Ck (Ross, 1985). The equation for *Z* is as follows:

$Z=\inf_{e\in z}\{e\in z\ \mu c, (z)=hgt(C_k)\}$……………………….…………………….......……..(1)

The Fuzzy logic control consists of three main stages, namely the fuzzification interface, the inference rules engine and the defuzzification interface [8]. For Load Frequency Control the process operator is assumed to respond to respond to variables error (*e*) and change of error (*ce*). The fuzzy logic controller with error and change in error is shown in figure 21.

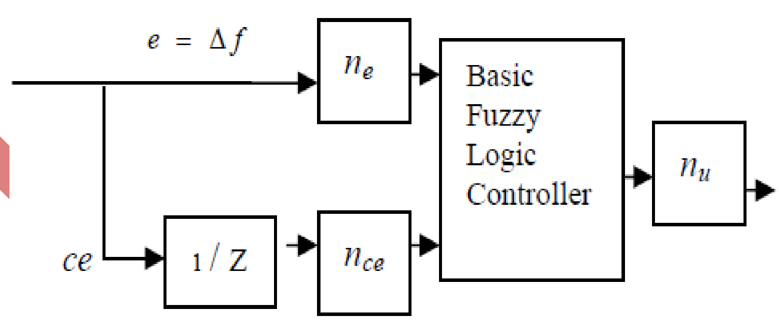

Fig 1: Block diagram of a Fuzzy Logic controller

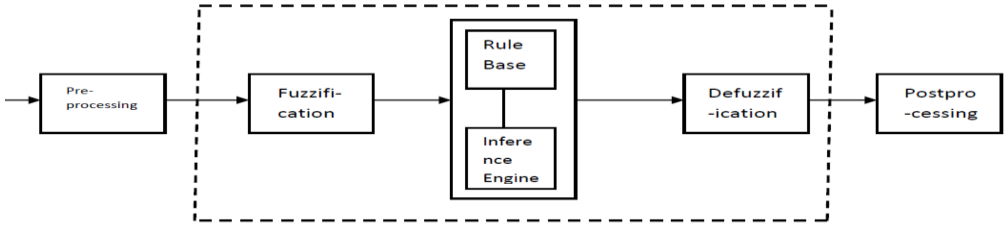

Fig 2: Block diagram of 3 processes of a Fuzzy Logic controller

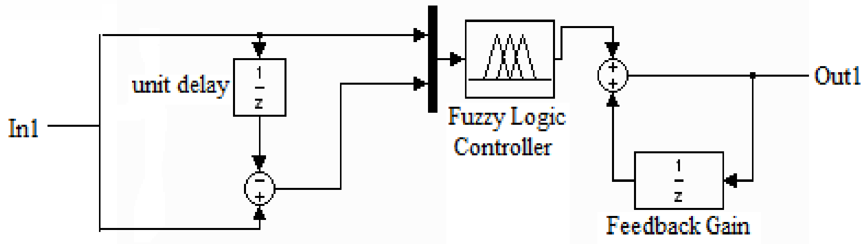

Fig 3: Simulink Representation of a fuzzy Logic Controller

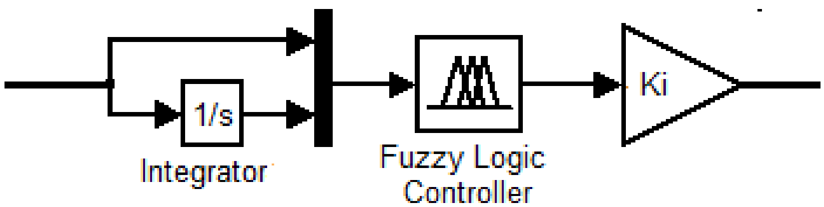

Fig 4: Simulink Representation of a fuzzy Logic & I Controller

The variable error is equal to the real power system frequency deviation (ΔF). The frequency deviation ΔF is the difference between the nominal or scheduled power system frequency (F_N) and the real power system frequency (F). Taking the scaling gains into account, the global function of the FLC output signal can be written as.

ΔP_C= F [n_c e(k), n_{ce} ce(k)] ……………..……………………………..……….……….(2)

Where n_e and n_{ce} are the error and the change of error scaling gains, respectively, and F is a fuzzy nonlinear function. FLC is dependant to its inputs scaling gains . The block diagram of FLC is shown in Fig 5.3,. n_u is output control gain (Talaq et al. 1999) [6]. A label set corresponding to linguistic variables of the input control signals, *e(k) and* ce(k), with a sampling time of 0.01 sec is as follows:

For two area system A label set corresponding to linguistic variables of the input control signals, *e(k) and* ce(k), with a sampling time of 0.01 sec is as follows:

L(*e*, *ce*) = { NB, NM, NS, ZO, PS, PM, PB},

Where, NB = Negative Big,

NM = Negative Medium, PS = Positive Small,

NS = Negative Small, PM = Positive Medium,

ZO = Zero, PB = Positive Big

Fuzzy logic controller has been used in three two area hydro-thermal interconnected areas with seven number of triangular membership function (MFs) which provides better dynamic response with the range on input (error in frequency deviation and change in frequency deviation) i.e universe of discourse is -0.25 to 0.25 and -0.01 to 0.01. The numbers of rules are 49.

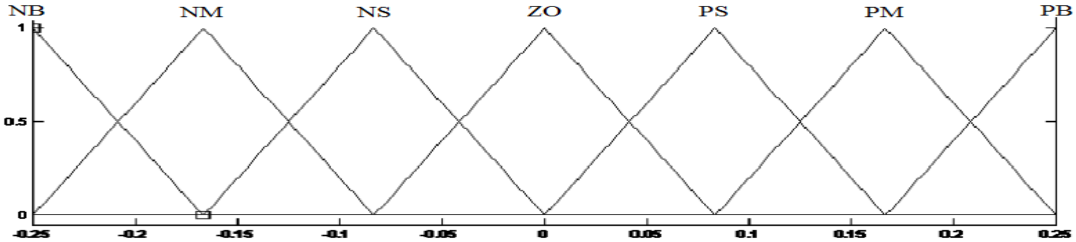

Fig 5: Membership Function for the control input variables for three area system

Table 1: Fuzzy inference rule for Fuzzy Logic Control for three area system

Input		*e(k)*						
		NB	NM	NS	ZO	PS	PM	PB
ce(k)	NB	PB	PB	PB	PB	PM	PM	PS
	NM	PB	PM	PM	PM	PS	PS	PS
	NS	PM	PM	PS	PS	PS	PS	ZO
	ZO	NS	NS	NS	ZO	PS	PS	PS
	PS	ZO	NS	NS	NS	NS	NM	NM
	PM	NS	NS	NM	NM	NM	NB	NB
	PB	NS	NM	NB	NB	NB	NB	NB

V SYSTEM DATA

Table 2: System data for four area interconnected system using both conventional I- Controller and Fuzzy logic controller with GRC

	Using I- controller with GRC	Using Fuzzy logic controller with GRC
R_1, R_2, R_3 R_4	2.4 Hz/ per unit MW	2.4 Hz/ per unit MW
K_g	1	1
T_g	0.08 sec	0.08 sec
K_t	1	1
T_t	0.3 sec	0.3 sec
K_{ps}	120	120
T_{ps}	20 sec	20 sec
K_r	0.5	0.5
T_r	10 sec	10 sec

K_i	**0.67**	**0.67**
$P_{tie,max}$	**200 MW**	**200 MW**
H_1 H_2 H_3 H_4	**5 sec**	**5 sec**
P_{r1} P_{r2} P_{r3} P_{r4}	**2000MW**	**2000MW**
D_1 D_2 D_3 D_4	**8.33 * 10-3 p.u MW/Hz**	**8.33 * 10-3 p.u MW/Hz**
a_I a_2 a_3 a_4	**0.545(a=2*pi*T12=2*pi*T23=2*pi*T31=0.545)**	**0.545(a=2*pi*T12=2*pi*T23=2*pi*T31=0.545)**
$delPd_1$ $delPd_2$ $delPd_3$ $delPd_4$	**0.01**	**0.01**

VI SIMULATION (USING I-CONTROLLER)

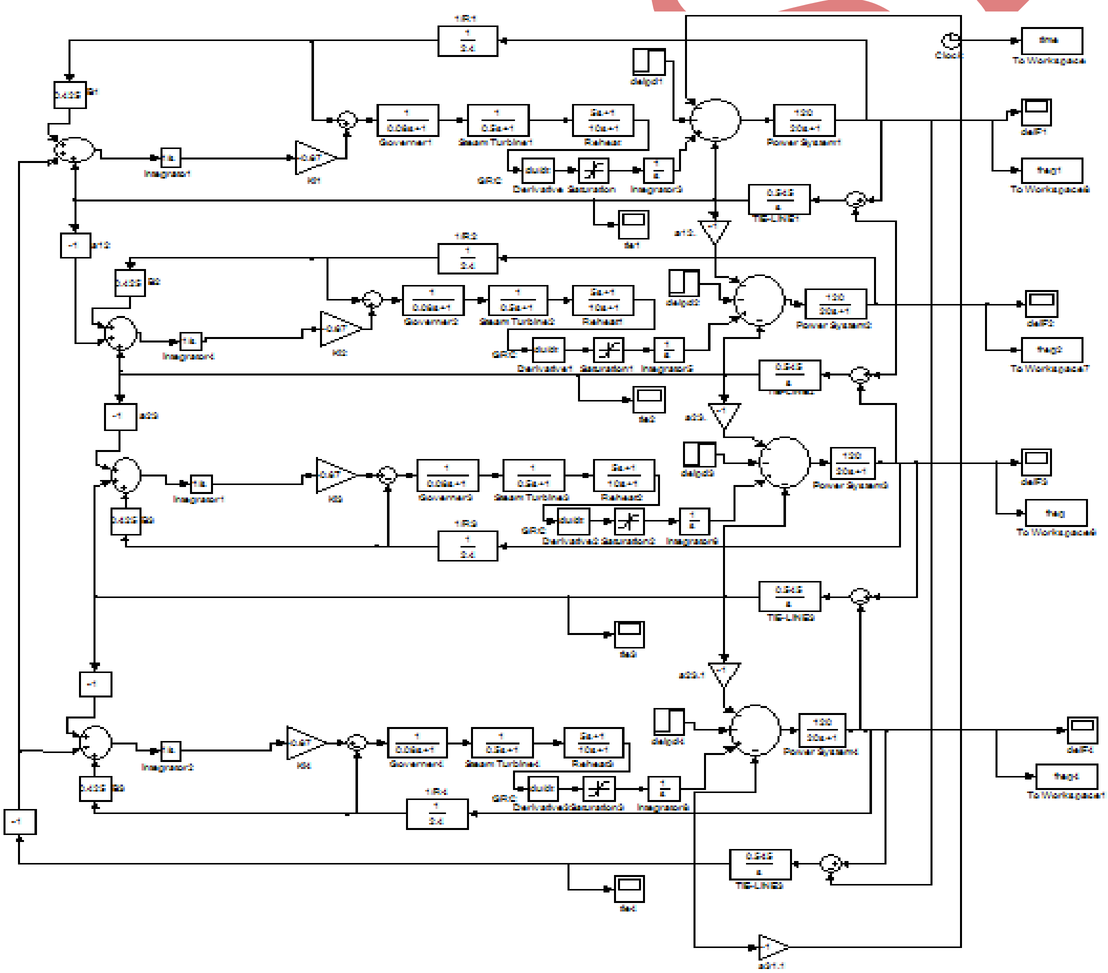

Fig 6 : Simulink Model of Four-Area Interconnected System with I-Controller Including GRC

6.1 Simulation Results (Using I –Controller)

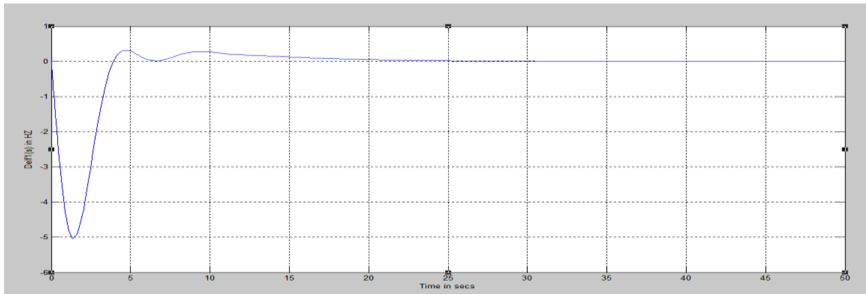

Fig 7 : Simulation Results (delf1(s) vs time) of Four-Area Interconnected System with I –Controller Including GRC

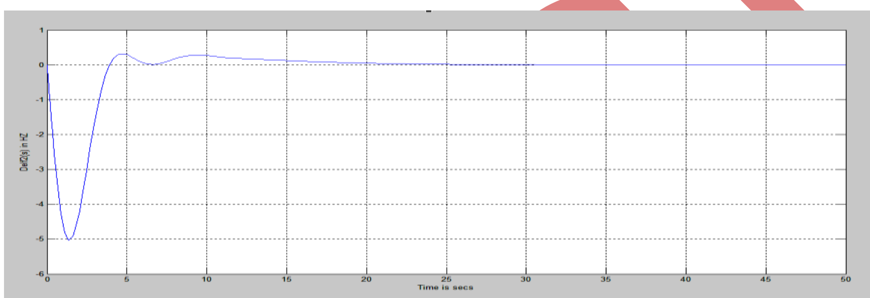

Fig 8 : Simulation Results (delf2(s) vs time) of Four-Area Interconnected System with I –Controller Including GRC

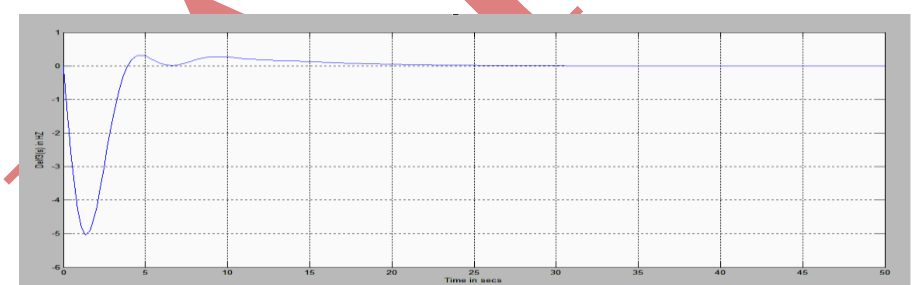

Fig 9: Simulation Results (delf3(s) vs time) of Four-Area Interconnected System with I-Controller Including GRC

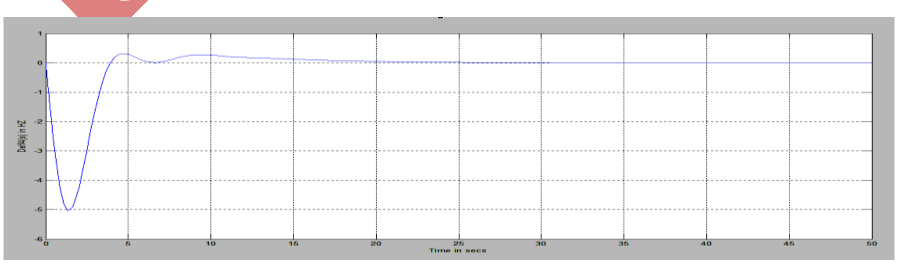

Fig 10: Simulation Results (delf4(s) vs time) of Four-Area Interconnected System with I-Controller Including GRC

VII SIMULATION (USING FUZZY –CONTROLLER)

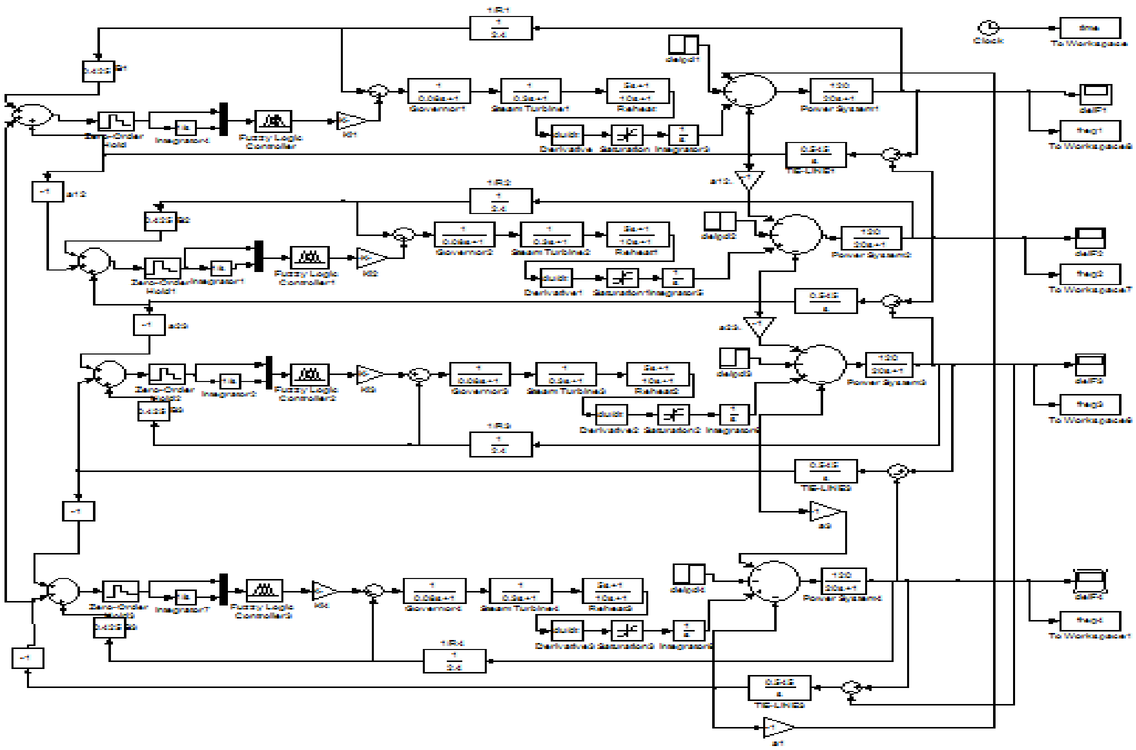

Fig 11: Simulink Model of Three-Area Interconnected System with fuzzy-Controller Including GRC

7.1 Simulation Results (Using Fuzzy –Controller)

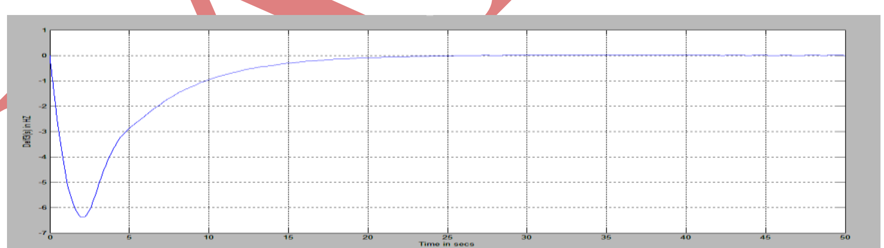

Fig 12: Simulation Results (delf1(s) vs time) of Four-Area Interconnected System with Fuzzy -Controller

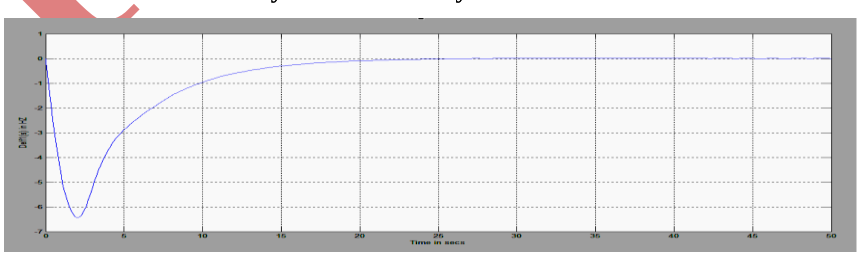

Fig 13: Simulation Results (delf2(s) vs time) of Four-Area Interconnected System with Fuzzy –Controller Including GRC

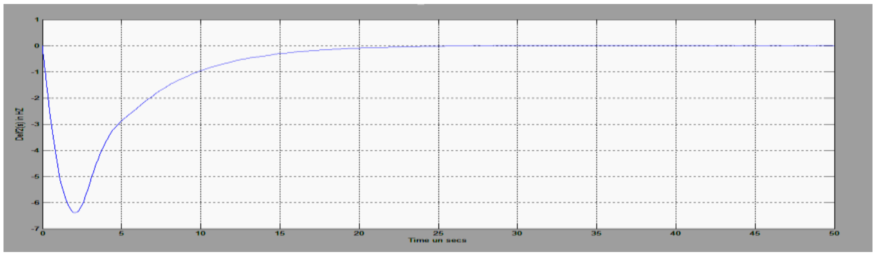

Fig 14: Simulation Results (delf3(s) vs time) of Four-Area Interconnected System with Fuzzy –Controller Including GRC

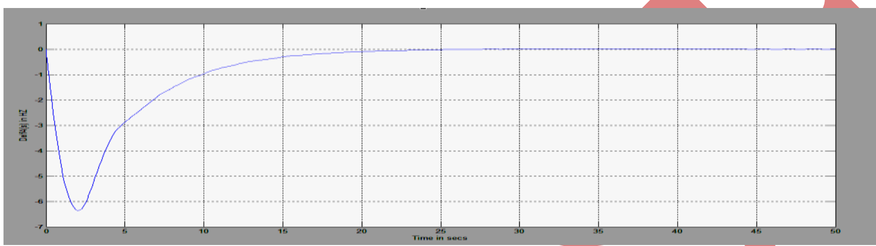

Fig 15: Simulation Results (delf4(s) vs time) of Four-Area Interconnected System with Fuzzy –Controller Including GRC

The dynamic responses are found to be deteriorating. In the next part of the work, the conventional integral controller is replaced by the fuzzy logic controller (FLC) and the dynamic responses are observed after simulation. The FLC(Fuzzy Logic Controller) is designed with ACE and ∫ ACE as the inputs. It is observed from the responses that with the FLC the oscillations in the positive side are totally eliminated in case of area control error and they are almost eliminated in case of frequency. The settling time in all cases are also observed to be less than that used with conventional I-controller with GRC. It is observed that the Fuzzy Logic Controller with GRC provides the oscillations of smaller magnitude compared to the conventional ones. Hence Fuzzy Logic Controller is proved to be effective in Automatic Generation Control of interconnected reheat thermal system.

VIII CONCLUSION

From the responses obtained, it is clear that use of Fuzzy Logic controller improves dynamic performance and reduces the overshoots with respect to frequency deviation in each of the areas .Therefore, the intelligent control approach using fuzzy logic concept is more accurate and faster. And also it gives better results even when GRC are considered.

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