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AUTOMATIC GENERATION CONTROL USING FUZZY LOGIC

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***Abstract**: The reliable operation of a large interconnected power system necessarily requires an Automatic Generation Control (AGC). The objective of AGC is to regulate the power output of Generators within a specified area in response to change in the system frequency, tie line power or relation of the two to each other, so as to maintain the scheduled system frequency and power interchange in the other are within the prescribed limits. In this paper, the AGC system investigated consists of two equal area reheat thermal systems. A model of the same with conventional integrator controller is developed in MATLAB and responses of area control error, tie line power and change in frequency are observed. The later part of the study involves replacing the integral controller with 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*

1. Introduction

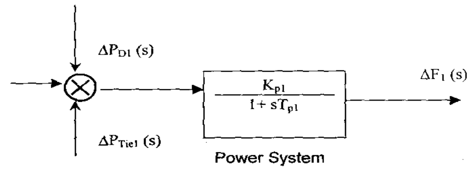
1.1 Introduction of AGC

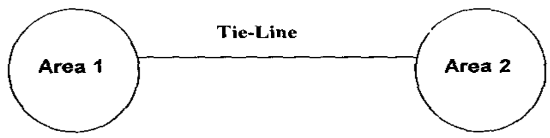
Power system operators have the end responsibility to ensure that adequate power is delivered to the load reliably and economically. In order to ensure this electrical energy system must be maintained at desired operating state represented by nominal frequency, voltage profile and load flow configuration. This is made possible by having a close control of real and reactive power generations of the system. The real and reactive power demands on the power system are never steady, but continuously vary with the rising or falling trend. The real and reactive power generations must change accordingly to match the load perturbations. The control of an electrical energy system, In order to have an exact matching of the generation to load at nominal state, is quite a challenging problem. It is so because in a dynamic system the load continuously changes and system generation, responding to control impulses, chases the load with the transient unbalance of load and generation reflected in speed hence frequency variations. The variations should be with in the tolerance levels. For small perturbations, the active power is dependant on internal machine angle δ and is independent of bus voltage, while bus voltage is dependant on machine excitation and is independent of machine angle δ. Change in angle δ is caused by momentary change in generator speed. Therefore, load frequency and excitation voltage control problems are non interactive for small perturbations hence treated as two independent 'decoupled control problems for all practical purposes. In any power system, it is a desirable feature to achieve a better frequency consistency than is obtained by a speed governing system alone. In the large interconnected power system, it is also desirable to maintain the tie-line power flow at a given level irrespective of load changes in any area. To accomplish this, it becomes necessary to automatically regulate the operations of main steam valves or hydro gates in accordance with a suitable control strategy, which in turn controls the real power output of electric generators. The problem of controlling the output of electric generators in this way is termed as Automatic Generation Control (AGC).The AGC problem of a large interconnected power system is studied by dividing the entire power system into a number of control areas. A "control area" is defined as a power system, a part of the system or a combination of the system to which a common generation control scheme is applied and the frequency is assumed to be the same through out, in static as well as dynamic conditions. All the generators in the control area swing in unison and form a coherent group. Automatic Generation Control (AGC) of an interconnected system is defined as "The regulation of power output of generators within a prescribed area, in response to changes in system frequency, tie-line power, or the relation of these to each other, so as to maintain scheduled system frequency and/or the established power interchanges with other areas within the prescribed limits". The main objectives of AGC would be as follows: i) each control area should take care of its own load demand. ii) The tie-line flows should be scheduled as per the system economics. iii) The system frequency should be maintained as far as possible isochronously iv) in emergency, neighboring areas should help each other based on system economics. The present study considers the following qualitative specifications for design purpose according to Elgerd and Fosha. 1. The steady state frequency error following a step load change in an area should be zero. 2. The steady state change in tie-line power following a step load change in an area should be zero. 3. The area control error should be zero.4. The transient frequency and tie line power errors should be small. The problem of Automatic Generation Control can be sub divided into fast (primary) and slow (secondary) control modes. The loop dynamics following immediately upon the onset of the load disturbance is decided by fast primary mode of AGC. This fast primary mode of AGC is also known as "Uncontrolled mode" since the speed changer position is unchanged. The secondary control acting through speed changer and initiated by suitable controller constitutes the slow secondary or the "Controlled modes" of AGC. The overall performance of AGC in any power system depends on the proper design of both primary and secondary control loops. Literature survey shows that a lot of work pertaining to secondary control aspect of AGC has been reported. Secondary controllers are designed to regulate the area control errors to zero effectively. Many investigations in the area of AGC of interconnected power systems have been reported over the past six decades. The amount of literature in the area of Automatic Generation Control (AGC) is very vast. Some of the works have been reviewed here. Most of the research work in AGC deals with "net interchange tie line bias control" strategy making use of Area Control Errors (ACE), which reflects mismatch of generation and load in a control area. Area supplementary control would change generation in such a manner as to keep the ACE to a minimum. It would not be desirable even if it were possible, to maintain ACE at zero because this would require unnecessary rapid maneuverings of generator unit. Elgerd and Fosha have optimized the gain setting of integral controllers using integral of squared error (ISE) technique considering several values of frequency bias B for a two equal area non reheat thermal system. Their investigations reveal that the best dynamic performance is obtained for $B=0.5\beta$. However, Cohn, Ross and others have focused in their technical publications that B less than β is not acceptable. The investigation of Concordia and Kirchmayer on simulation studies of AGC of two equal area thermal systems shows that for minimum interaction between control areas, frequency bias must be set equal to area frequency response β. They have also analyzed the effect of governor dead band on system dynamic responses. Nanda and Kaul have extensively studied the AGC problem of two equal area reheat thermal system using both parameter plane for optimization of integral gain setting and for investigation of the degree o f stability of the system. They have analyzed the effect of Generator Rate Constraint (CRC), speed regulation parameter R in the optimum controller setting and system dynamic performance. M.L.Kothari, Nanda and Das were the first to introduce a new control strategy capable of regulating simultaneously area control errors, time errors and inadvertent interchange. Such a control strategy makes each area to meet its load and energy demand on a continuous basis. The controller proposed by them is based on New Area Control Error (ACEN). The ACEN is the weighted sum of ACE and Integration of ACE. G.A.Chown and R.C.Hartman proposed the design, implementation and operational performance of a fuzzy controller as part of the AGC system. The fuzzy controller was integrated into the existing of the shelf AGC system with only a few modifications. The operational performance showed an overall improvement of over fifty percent in the reduction of control compared to the original AGC controller.

2. AGC of a two equal area system

2.1 Concept of control area and tie-line power

Automatic Generation Control problem of a large interconnected power system is studied by dividing the whole system into number of control areas. A "Control Area" is defined as a power system, a part of the power system or a combination of systems to which a common generation control scheme is applied and the frequency is assumed to be the same through out in static as well as dynamic conditions. All the generators in the control area swing in unison and form a coherent group. The electrical interconnections with each control area are very strong as compared with the ties to the neighboring areas. In normal steady state operation each control area of a power system should strive to compensate for changes in power demand in it. Each control area of a power system should help to maintain the frequency and the voltage profile of the overall system. A multiple area-interconnected system is one that consists of a number of control areas, each of which is expected to absorb its own load changes. The tie-line power flows between areas are maintained as per the schedule. The control objective now is to regulate the frequency of each area and to simultaneously regulate the tie line power as per inter area power contracts. The Proportional plus Integral controller installed brings the study state errors in frequency and the tie line power to zero. Two-area system has been considered for the investigations due to the following reasons: 1. it is the simplest of multi area systems. 2. The technical papers, which have been published on multiple - area control, have limited their analysis to two - area systems. This enables us o compare the results. 3. Before we attempt to study the large systems, it is of great importance that we command the two-area case. Each control area is represented by an equivalent speed governor, Tandem compound single Reheat Turbine awl a generator. The following block diagram represents the Control Area I





Now the tie-line power transported in or out of an area 1 is given by

$$P_{tie1} = \frac{|V_1|\,|V_2|\,\mathrm{Sin}\,(\delta_1^0 - \delta_2^0)}{X_{12}}$$

Where δ_1^0 , $\delta_2^0$are power angles of equivalent generators of the two areas V1, V2 are terminal bus voltages of lines 1 and 2 respectively. X12 is a reactance of the tie line. For incremental changes in δ_1 and δ_2, the incremental tie line power can be expressed as $P_{tie}(pu) = T_{12}(\delta_1 - \delta_2,)$;

Where $T_{12} = |V_1 \,||V_2| = Cos(\delta_1^0 - \delta_2^0)$

P_{r1} X_{12} = Synchronizing coefficient or electrical stiffness of the tie line. But, phase angle changes arc related to the area frequency changes by following equations.

$$\delta_1=2\prod\int\Delta f_1 dt;\ \Delta\delta_2=2\prod\int\Delta f_2 dt$$

Where Δ f1 and Δ f2 are incremental frequency changes in area 1 and 2 respectively. Similarly the incremental tie line power out of area 2 is given by

$$\Delta Ptie2=2\prod T_{21}\int(\Delta f1-\Delta f2)dt;T_{21}= |V_1 \,||V_2| = Cos(\delta_1^0 - \delta_2^0)$$ ****check

Upon Laplace transformation, we get the above equations as below: $\Delta Ptie1=2\prod T_{12}\frac{1}{s}\{(\Delta F1(s)-\Delta F2(s))\}dt$ and $\Delta Ptie2=2\prod T_{21}\frac{1}{s}\{(\Delta F2(s)-\Delta F1(s))\}dt$

2.2 Uncontrolled system

Before we discuss as how to control the two area system, it is useful to have a glance at the responses of the uncontrolled system. The block diagram of the two-equal area reheat thermal system is shown in the fig 2.1

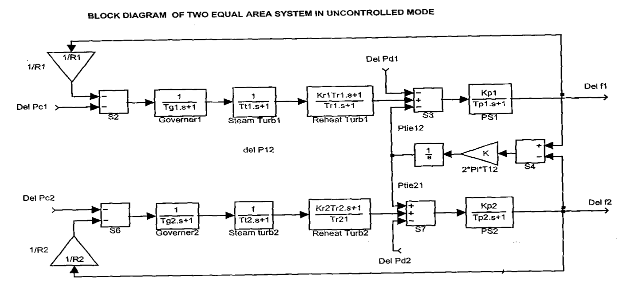


Fig. 2.1.

There are no control inputs fed to the speed governor, as it is evident from the block diagram. i.e. we set Pc1=Pc2=0. The model is created in MATLAB with the nominal parameters included. The model is shown in fig 2.2.

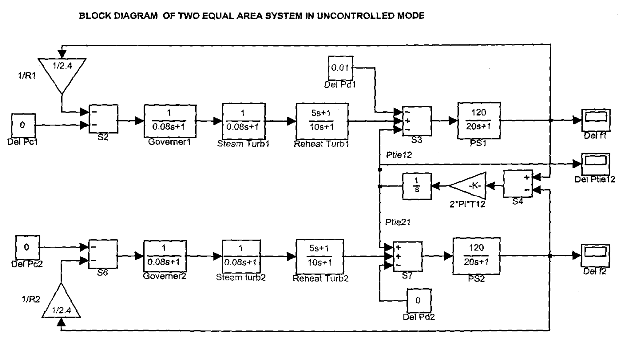


Fig.2.2

2.3 Dynamic responses

Dynamic responses are observed after simulation. Step loads are applied to area 1 and the subsequent variations of Δf1, Δf1 and are studied. The following features are observed: 1. All the three variables (Δf1, Δ f2 and ΔP_{tie}) have non-zero static errors. 2. The two frequency errors will be equal after steady state is reached.3. The system is stable but oscillatory. The responses are shown in fig 2.3 and 2.4.

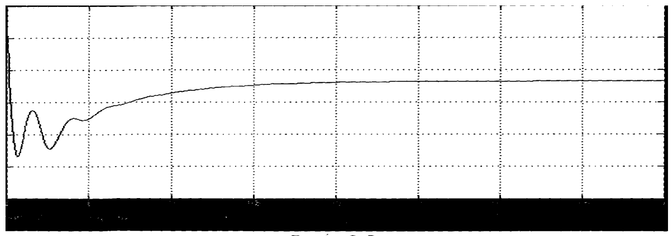


Fig No. 2.3

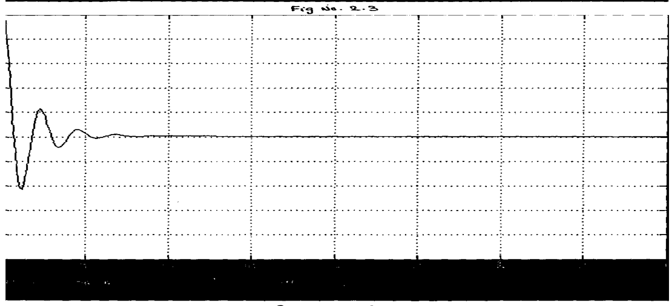


Fig No. 2.4

After studying the responses it is concluded that the response of the uncontrolled system is unacceptable in several aspects.

3. AGC with integral controller

3.1 Control strategy

As explained in the previous chapter, the responses obtained in the uncontrolled mode of the two equal area thermal systems are not acceptable. To improve the responses, the North American Power Systems Interconnection Committee (NAPSIC) has suggested the following specifications: 1. the static frequency error following a step load change must be zero. 2. The static change in tie line power flow following a step load change in either area must be zero. 3. The transient frequencies should not exceed ± 0.02 Hz under normal conditions. 4. The individual generators within each area should divide their loads for optimum economy. In order to meet the above specifications some form of reset integral control must be added to the two-area system. The persistent static errors in frequency and tie line power flow are intolerable as they violate the basic guiding principle in ‘Pool operation’. A basic guiding principle in pool operation must be that each area in normal study state absorbs its own load. For multi area systems various methods of reset integral control have been tried over the years. In one of the methods area 1 would be responsible for the frequency reset and area 2 would take care of tie line power. In such a case area control errors would be as given: ACE1 $\approx \Delta f1$; ACE2 $\approx \Delta f2$

These ACE's would be fed via slow integrators on to the respective speed changes. This arrangement would work but not too well. In another method of pool operation one area was designated to reset the system frequency and the others would be responsible for zeroing their own 'net interchanges'. The problem with this arrangement was that the central frequency station tended to regulate everybody trying to absorb everybody else's errors and offsets.

As a result it would swing widely between its generation limits. The control standard developed by Cohn has been adopted by most operating systems. The control strategy is termed as "Tie Line Bias Control" and is based on the principle that all operating pool members must contribute their share to frequency control in addition to taking care of their own net interchange. This controller is very popular with the industries because of its inherent simplicity, easy realization, low cost and decentralized nature of control strategy.

3.2 TIE - Line bias control

When reset control method is applied to the two-area system, the block diagram looks as shown in fig 3.1

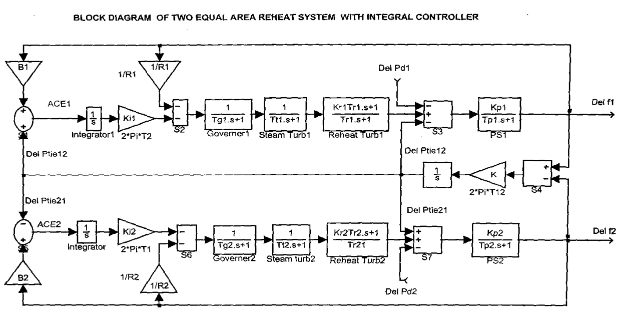


Fig. 3.1

The control error for each area consists of linear combination of frequency and tie line errors as shown below:

ACE1=ΔPtie1+ B1Δf1 and ACE2 =- ΔPtie2+ B2Δf2. The speed - changer commands will thus be of the form:

$\Delta Pc1=-K_{i1}\int(\Delta Ptie1+B1\Delta f1)dot;$

$\Delta Pc2=-K_{i2}\int(\Delta Ptie2+B2\Delta f2)dt$

The constants K_{i1}, and K_{i2} are integral gains, and the constants B1 and B2 are the frequency bias parameters. Since the control signals are of integral form, the name integral control is being used. The minus sign must be included since each should increase its generation if either its frequency error or its tie line power increment is negative. The above strategy will now eliminate the steady state frequency and tie line errors for the following reasons. Following a step load change in either area, a new static equilibrium, if exists, can be achieved only after the speed changer commands have reached constant values. But this evidently requires that both integrands be zero.

i.e. (ΔPtie1+B1Δf1) =0;

and (ΔPtie2+B2Δf2) =0

Above conditions can be met only if ΔPtie1=ΔPtie2=Δf1=Δf2=0. Hence this confirms that the steady state errors in tie line power and frequency are completely eliminated after incorporating the integral controller.

3.3 System under study

The two equal area reheat thermal system with integral controller in each area is shown in fig 3.2 after including the nominal parameters.

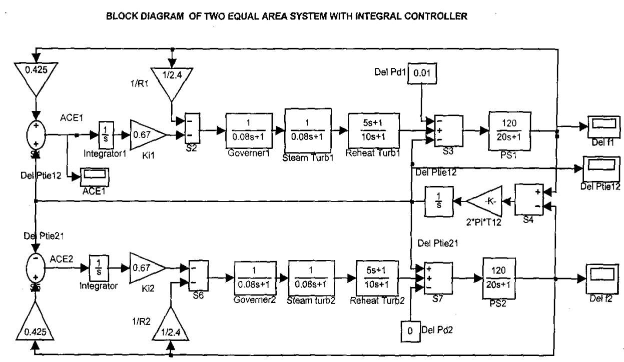


Fig. 3.2

The mathematical model is created in MA'ILAB using the Simulink tool.

3.4 Dynamic responses

Simulation is carried out for 40 sec. with 1% step load perturbations in area I. The responses of change in frequency, tie line power and area control error are shown in fig. 3.3, 3.4, and 3.5 respectively.

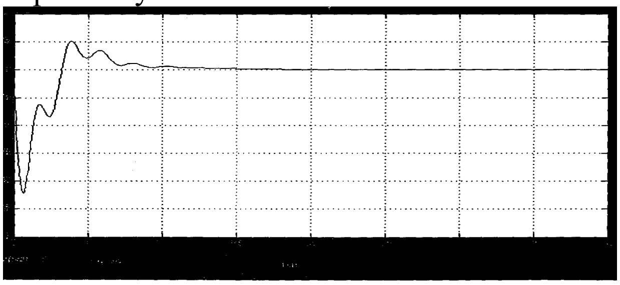


Fig No. 3.3

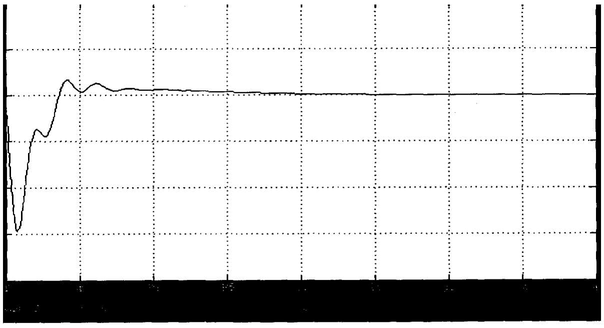


Fig No. 3.4

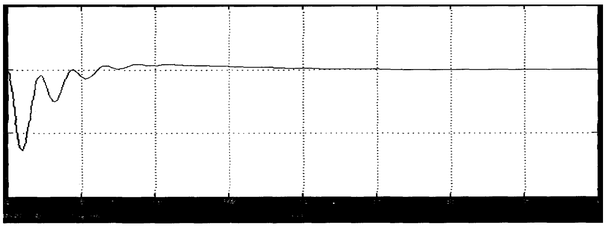


Fig No. 3.5

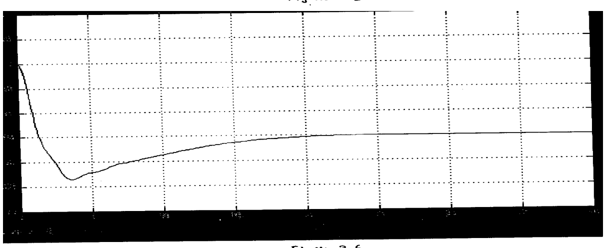


Fig No. 3.6

The response of integration of ACE is also shown in fig 3.6 as it is used for the design of fuzzy controller.

3.5 Analysis

It is observed from the responses that the settling time is about 25 seconds in all the three cases. The maximum peak deviation in frequency is about -0.02 towards the negative side and +0.005 towards the positive side.

3.6 AGC with generation rate constraint (GRC)

The AGC problem discussed so far does not consider the effect of the restrictions on the rate of change of power generation. 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.

3.7 System under study with GRC

The mathematical model of the two equal area reheat thermal systems with GRC is shown in fig. 3.7.

BLOCK DIAGRAM OF TWO EQUAL AREA SYSTEM WITH GENERATOR RATE CONSTRAINT

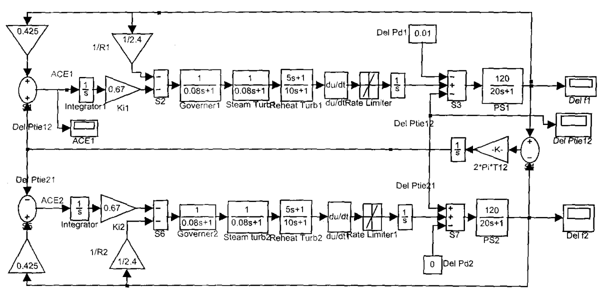


Fig. 3.7

For the simulation of GRC, the output from the reheat turbine is differentiated by a function d/dt and further a saturation limiter is made use of which decides the upper and lower limit of the rate. For the system under the study GRC of 3% per minute is used. The function of the limiter is to limit the rate, if rate is more than 3% per minute it arrests it at 3% per minute and below it passes unregulated. Further the signal is integrated by function I/s to get back the original signal.

3.8 Dynamic responses

The Dynamic responses for 1% step load perturbations in area 1, with GRC included are obtained after simulation. The responses are shown in fig. 3.8, 3.9 and 3.10

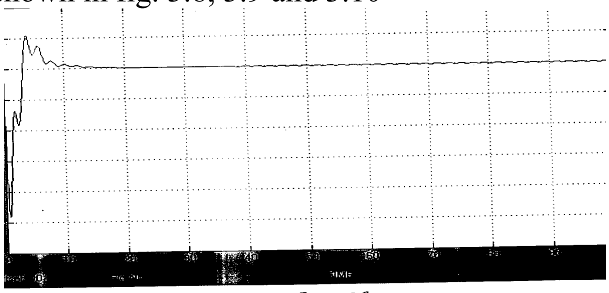
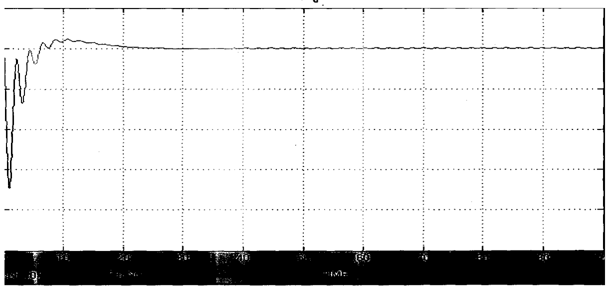


Fig No. 3.8



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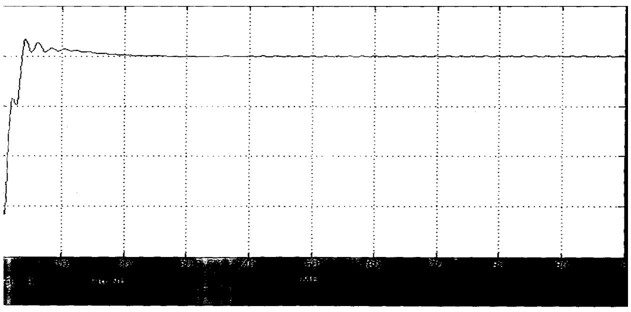


Fig No. 3.10

3.9 Analysis

With Generation Rate Constraint included in the AGC model, the dynamic responses are found to be deteriorating. The maximum peak deviation in frequency, tie line power and area control error are observed to be more than the ones obtained in unconstrained mode of AGC.

4. AGC of a two equal area reheat system using fuzzy logic controller

4.1 Introduction

Artificial intelligence methodologies have been acknowledged to have a significant role in improving controller performance. However, the use of classical Al expert systems for control purpose is generally viewed to be impractical, except for very simple applications, because it requires an unrealizable large number of "IF Then" rules. On the contrary, by applying fuzzy logic theory an object-oriented expert system can be derived and the number of rules typically reduced by a large order of magnitude. Fuzzy logic in this regard is considered as a generalization of conventional rule-based expert systems. There are, however, a number of difficulties associated with Fuzzy Logic Control (FLC) design. A common bottleneck is that the derivation of fuzzy control rules is often time consuming and often difficult, and relies to a great extent on process expertise. There also exists no formal frame work for the choice of parameters of fuzzy systems and hence the means of tuning them and learning models in general has become an important subject of fuzzy control. The most common criticism is that fuzzy design heuristic methodology for which no analytical tools exist to verify controller performance and stability. It is, however, generally acknowledged that FLC is most suitable for problems for which a control strategy can be defined in analytical or quantitative tents. Fuzzy control systems are appropriate if sufficient expert knowledge about the process is available.

4.2 Fuzzy logic

Lotif Zadeb, a professor at University of California at berkely, conceived the concept of fuzzy logic.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. Fuzzy logic provides an effective means of capturing the approximate, in exact nature of the real world. In conventional set theory based on Boolean logic, a particular object or variable is either a member (logical I) of a given set or it is not (logic 0). 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.

4.3 Fuzzy Logic Controller (FLC)

The Fuzzy Logic Controller is based on fuzzy logic and provides an algorithm, which can convert the linguistic control strategy based on expert knowledge in to an automatic control strategy. The methodology of FLC is found to be very useful when the processes are too complex for analysis by conventional quantitative techniques or when the available sources of information are interpreted qualitatively inexactly or uncertainly. The basic configuration of an FLC is as shown in fig.4. 1. It consists of four principal components .1. A Fuzzification Interface, 2. A knowledge bone, 3. A decision making logic, 4. A De fuzzification Interface. The Fuzzification interface has the following functions: a) It measures the values of input variables. b) It performs a scale mapping that transfers the range of input variables into corresponding universe of discourse. c) It performs the function of Fuzzification that converts input data into suitable linguistic values, which may be viewed as labels of fuzzy set. 2. The knowledge base comprises knowledge of application domain and the attendant control goals. It consists of a database and a 'linguistic control rule base'. a) The database provides necessary definitions that are used to define linguistic control rules and fuzzy data manipulation in an FLC. b) The rule base characterizes the control goals and control policy of the domain experts by means of a set of linguistic control rules. 3. The decision-making logic is the kernel of an FLC. It has the capability of simulating human decision-making based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of interference in fuzzy logic. 4. The defuzzification interface performs the following functions: a) A scale mapping, which converts the range of values of output variables into corresponding universes of discourse. b) Defuzzification, which yields a non-fuzzy control action from an inferred fuzzy control action.

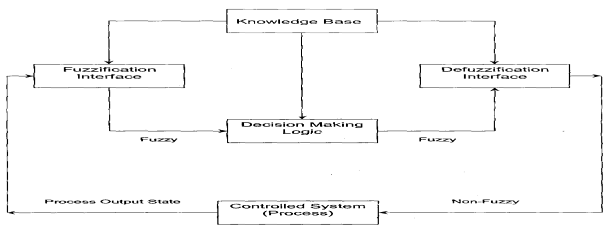
4.4 Design of Fuzzy Logic Controller

The design of Fuzzy Logic Controller can be divided into three areas namely, the allocation of the areas of inputs, the determination of the rules associated with the inputs and outputs and the defuzzification of the output into a real value.

Allocation of Areas of Inputs and Outputs

The inputs to FLC are taken as ACE and ∫ACE the the previous chapters, with the conventional integral controller the responses for ACE and ∫ACE are plotted as shown in fig.3.5 and 3.6 .By examining these responses, the overall maximum and minimum values are noted. It can be seen from figure that the overall maximum is + 0.003 and overall minimum is — 0.022. However, for Fuzzification tolerance is kept for maximum and minimum values. Hence the logical control range is considered as -0.05 and +0.05. This range has been divided into control areas by membership functions that are triangular or trapezoidal. The input output ranges are as shown

Input range for ACE and INTACE with 3 MF's: N [-0.09 -0.055 -0.044 -0.01]; Z [-0.025 0 025]P [0.01 0.04 0.05 0.1]Output range for ACE OUT (-0.02 to 0.02) with 3 MF's: N [-0.03 -002 -0.0180 -0.006]Z [-0.013 0 0.009]P[4-0.005 0.018 0.02 003] Fig 4.2, 4.3 and 4.4 show the Membership Functions with ranges for input and output variables.



Basic Configuration of Fuzzy Logic Controller (FLC)

Fig. 4. 1

4.5 Fuzzy rules

The rules are developed heuristically for a particular task and are implemented as a set of fuzzy conditional statements. The rules used are obtained by examining the output response to corresponding inputs to the fuzzy controller. The rules used for the design of fuzzy logic controller are described in the fuzzy rule table shown below:

ACE OUT, ACE

The interpretation of rules is done as follows:

If ACE is N and INTACE is N then ACEOUT is N. If ACE is N and INTACE is Z then ACEOUT is N
And so on.

4.6 System under study with FLC

FLC is designed for the system using the "Fuzzy Logic Tool Box" in MATLAB. The fuzzy logic tools for building, editing and observing fuzzy inference systems: Fuzzy Inference System (FIS) Editor, Membership Function (MF) Editor, Rule Editor, Rule Viewer and Surface Viewer. In the FIS editor, the input variables are named as ACE and INTACE and the output variable as ACEOUT and their ranges are specified. In the MF editor the type of MF associated with each variable is defined. In the rule editor rules are framed which define the behavior of the system. The FLC designed is shown in fig. 4.5.The FLC is designed for the system under study and it replaces the conventional integral controller in both areas. The model of the two area reheat thermal system with Fuzzy Logic Controller is shown in the fig 4.6 with the nominal] parameters included. Before simulating the model in MATLAB, the FLC (is. 515 file) is saved in the workspace with some name that is further used in the AGC model.4.7 DYNAMIC Responses. The dynamic responses of two equal area reheat thermal system without GRC, following a 1% step load perturbations in area I are shown in fig.4.7 ,4.8 and 4.9.

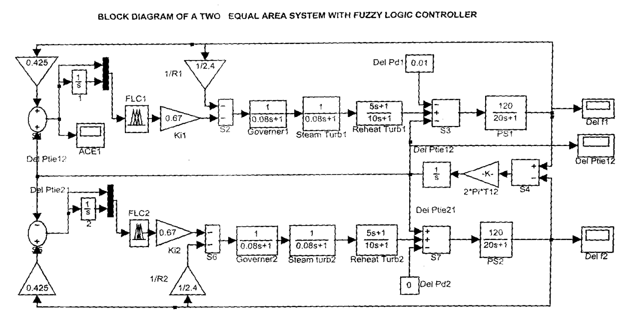


Fig. 4.6

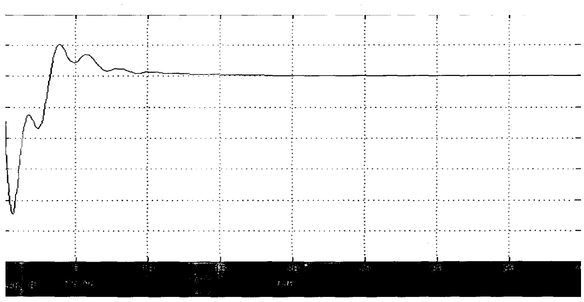


Fig No. 4.7

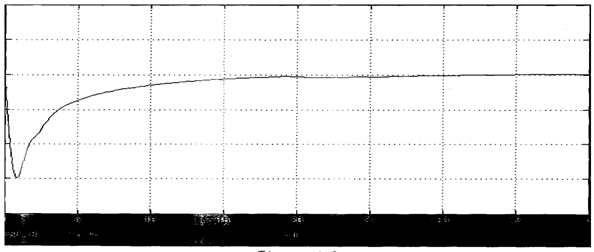


Fig No. 4.8

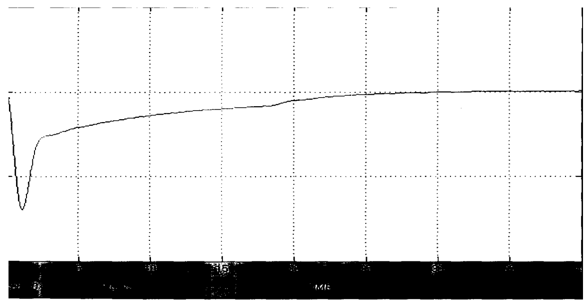


Fig No. 4.9

The responses are compared with those obtained from conventional integral controller.

4.8 Analysis

The Fuzzy Logic Controller with 3 Membership functions gives fewer oscillations. All responses settle down at the same time at 25 sec. The oscillations on the positive side are almost eliminated in all the responses.

5.Conclusion

Automatic Generation control problem of a large interconnected power system has been studied by dividing the whole system into a number of control areas. The standard control strategy used in the industry to meet the requirement of Zero steady state error in frequency and tie line power is of Linear Integral form. In the present work, a two equal area reheat thermal system has been studied for automatic generation control (AGC). The system dynamic responses have been found by simulating the models in MATLAB.The following table gives a comparison of various modes of operation of two equal area systems. The uncontrolled mode of operation of the two equal area systems is discussed first. It is observed that the responses have a steady state error, which violates the control strategy. Hence, the necessity of having a controller for AGC is emphasized. The two equal area reheat thermal system with Integral controller is modeled and the dynamic responses are observed. The integral controller eliminates the steady state errors in frequency and tie line power. The maximum peak deviations in frequency, tie line power and area control error are found to be -0.022, -0.006, -0.015 respectively. All the responses have settled at around 20 sec. The controlled mode of AGC with Generation Rate Constraint (GRC) is also discussed in this work. 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 is designed with ACE and ∫ ACE as the inputs. Three membership functions are considered for input and output variables. 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 tie- line power and they are almost eliminated in case of frequency. The maximum peak deviations in the responses remained unaffected. The settling time is also observed to be the same i.e. around 20 sec. It is observed that the Fuzzy Logic Controller 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 two equal area reheat thermal system.

In this work an attempt is made to compare the performance of the Fuzzy Logic Controller with Integral Controller. Further work can be done in designing the Fuzzy controller with 5 and 7 membership functions. But as the membership functions increase, the number of rules increases and the design becomes complex. Fuzzy controller can be designed to improve the dynamic performance of the two-area system with GRC included. Variable structure controller, which is a combination of conventional and fuzzy control, can also be designed to study the problem of AGC with and without GRC.

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