Automatic Generation Control of Multi Area Power System Using Fuzzy Logic and ANN Controller

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Abstract

An electric supply with reliable and good quality is very important in power system operation and control. To achieve reliability and quality in interconnected power system Automatic Generation Control (AGC) is used. The components of AGC are change in frequency deviation (ΔF) and tie-line power flow (ΔPtie). For any load change, there is an existence of (ΔF) and (ΔPtie) which are used as a feedback signal to the controllers of AGC. This paper presents an application of Fuzzy Logic Controller (FLC), Artificial Neural Network Controller (ANN) and combination of Fuzzy logic with ANN controller to AGC of a multi-area interconnected power system. The state space model is designed for multi-area power system and the model is tested with step input, ramp rate and disturbance due to fault. The results prove that the performance of Fuzzy Logic with ANN controller (FLANN) is performed better than other controllers.

Key Words: Automatic Generation Control (AGC), Frequency Deviation (ΔF), Tie-Line Power Flow (ΔPtie), Fuzzy Logic Controller (FLC), Artificial Neural Network Controller (ANN)

1. INTRODUCTION

In a large inter-connected system, large and small generating stations are synchronously connected and hence all have the same frequency. For any sudden load perturbation results in frequency deviation (ΔF) and change in tie-line power (ΔPtie) in any area of power system. The ΔF and ΔPtie are used as an input to controller. Any deviation in the system frequency is the sensitive indicator of real power imbalance. Fixed gain controllers based on classical control theories are presently used. These are insufficient because of changes in operating points during a daily cycle and may no longer be suitable in all operating conditions. Therefore, variable structure controller [1-3] is proposed and many adaptive control techniques have been introduced for AGC. For designing these controller the perfect model is required which has to track the state variables and satisfy system constraints. So it is difficult to apply these adaptive control techniques to AGC in practical implementations.

In [4-6], the method of constructing membership function using stored data and formation of rule base from training examples are explained. ANN Controller application to AGC is explained in [7-8]. The power system considered here includes four different areas connected through tie lines. First three areas consist of steam turbines, which include re-heater. For comparing the performance, the model considered is controlled by conventional integral controller, FLC, ANNC and FLANNNC. The results are obtained against change in load, disturbance at any area and it shows that the performance of FLANNNC is better than other controllers.

2. MODELING OF THE POWER SYSTEM FOR AGC WITH FOUR AREAS

The transfer function model of the multi area power system is given in Fig. 1 and system parameters are given in nomenclature. Each area supplies to its user pool and tie lines allow electric power to flow between areas. Therefore, each area affects others, i.e., a load disturbance in any one of the areas affects the output frequency of other areas as well as power flows in tie lines. The control system of each area needs information about the transient situation in all areas to bring the local frequency to its steady state value. The information about each area during perturbation is found in its frequency and the information about the other area in the perturbation is found in its tie-line power flow. In conventional system, turbine reference power of each area is tried to be set to its nominal value by an integral controller and the input of the integral controller of each area is \( B_i \Delta f_i + \Delta P_{tie i} \) (i=1, 4) called Area Control Error (ACE) of the same area. Parameters Bi is found from \( 1/K_{pi} + 1/R_i \).

\[
ACE_i = B_i \Delta f_i + \Delta P_{tie i}
\]

where (i=1,...,4).

**Fig. 1 Four Area power system**

Each of three areas including steam turbines contains governor, re-heater stage of steam turbine and generation rate constraints. All of the governors have dead-band effects that are important for speed control under small disturbances but the effects of dead-band are ignored because of simplicity. The re-heater effect of the steam turbines is considered in the model by state space...
equations. Moreover, fourth area includes hydro turbine which contains generating rate constraint. Dead band effect of governor in hydro turbine is ignored for simplicity.

![Diagram of power system](image)

Fig. 2 The transfer function model of the multi area power system

3. DESIGN OF FUZZY LOGIC CONTROLLER

Fuzzy logic provides not only with the meaning and powerful representations for uncertainties in the power system, but also represents vague concepts in meaningfully using natural language. The fuzzy controller is developed based on the optimal control theory. This is capable of obtaining a near optimal fuzzy controller that is characterized by its systematic nature in design. The design steps required for developing the fuzzy controller is as follows:

A. Choice of process state and control output

A first step is to choose the correct input signals to the FLC. For this controller the choice of process state variables representing the contents of the rule-antecedent (If-part of a rule) is selected as generator speed deviation (ω) and change in speed deviation (ώ) signal. The control output signals (process input) variable represents the contents of the rule-consequent (then-part of the rule) and denoted by (u).

B. Normalization

Normalization performs a scale transformation and it also called input normalization. It maps the physical values of the current process state variables into a normalized universe of discourse. It also maps the normalized value of control output variables into its physical domain (output de-normalization). For this controller, normalization is obtained by dividing each crisp input on the upper boundary value for the associated universe.

C. Fuzzification

Fuzzification is the process of making crisp quantity to fuzzy. In many of the quantities that considered being crisp and deterministic are actually not deterministic at all. Fuzzification is related to the vagueness and imprecision in a natural language. It is a subjective valuation, which transforms a measurement into a valuation of a subjective value. Hence, it could be defined as a mapping from an observed input space to fuzzy sets in certain input universes of discourse. Fuzzification plays an important role in dealing with uncertain information, which might be objective or subjective in nature.

D. Determination of membership function

The ranges of input and output variables are assigned with linguistic variables. These variables transform the numerical values of the input of the fuzzy controller to fuzzy quantities. These linguistic variables specify the quality of the control. As the number of the linguistic variables increases, the computational time and required memory space are increased. Among all membership functions, triangular membership function and gauss membership function gives good results and easy to implement. In this paper, gauss membership function is used for simulating the model.

The generator speed deviation (ω), change in speed deviation (ώ) and control output (u) are classified into Negative maximum (ω-vemax); Negative medium (ω-vemed); Zero (ω-zero); Positive medium (ω+vemed); Positive maximum (ω+vemax)

E. Knowledge base

The knowledge base of an FLC is comprised of two components, a database and fuzzy control base. The concepts associated with a database are used to characterize fuzzy control rules and a fuzzy data manipulation in an FLC. It should be noted that the correct choice of the membership function of a term set plays an essential role in the success of an application. A lookup table based on discrete universes defines the output of a controller for all possible combinations of the input signals. A fuzzy system is characterized by a set of linguistic statements. It is in the form of “IF-THEN” rules; these rules are easily implemented in fuzzy conditional statements. For example

“If ω is ω-vemed, ώ is Zero then u is –vemed”

For the proposed work, the rule is presented in Table .1.

![Table 1. Rule base](image)

F. Defuzzification

This process is used to convert a fuzzy value back to the actual crisp output value for the final decision-making.
The simplest method of defuzzification is centroid method as given in (2). The crisp control output \( u \) is obtained by

\[
 u = \frac{\sum_{i=1}^{N} f_i \mu_i}{\sum_{i=1}^{N} \mu_i}
\]  

(2)

4. DESIGN OF ARTIFICIAL NEURAL NETWORK (ANN) CONTROLLER

In three-area power system, frequency perturbation in each area has to be brought back to their steady state values. The ANN controller can be used to provide control input, which succeeds in this deed. ANN controller is indeed an adaptive nonlinear controller with control strategy defined by the learning rule used in changing the weights of the synaptic connections [7-8]. In this work, a Multi-Layer Perceptron network is trained between inputs speed deviation, change in speed deviation \( \Delta \omega \) and control output \( u \). The training is performed using MATLAB 6.0 Neural Network Toolbox. Wherein the learning rate and momentum are adjusted internally to minimize the mean square error within the prescribed epochs. After the network is trained, an ANN control block is created using the command “gensim”.

5. RESPONSE OF FLC, ANN C AND CONVENTIONAL CONTROLLER

Fuzzy logic has been successfully used to capture heuristic control of laws obtained from human experience or engineering practice in automated algorithm. In this work, the FLC, ANNC and FLANNC has been developed, analyzed and validated by using MATLAB simulink toolbox. The important points to be noticed in controller performance are transient recovery time and magnitude of overshoot. The model is tested for various conditions and results are compared as follows:

A. Sudden increase in load

The conventional, FLC, ANN Controller and Fuzzy Logic with ANN Controller are designed and tested under various conditions such as sudden increase in load, sudden decrease in load, disturbance due to fault and change in inertia. The performance of ANN controller is compared with FLC and conventional controller for four areas. The curves are identical in the three areas. Only Area1 is shown in Fig. 3.

The under shoot of \( \Delta F \) is -0.053 for FLC and -0.005 for ANN controller in thermal plant. The under shoot in \( \Delta F \) in case of hydro plant is -0.065 for FLC and -0.04 for ANN controller. The settling time for FLC is 100 sec and ANN controller is 70 sec in thermal plants. The settling time for FLC is 100 sec and ANN controller is 100 sec in hydro plants. For different plant make up, the performance of ANN controller is better, but oscillations are more at the beginning.

B. Sudden decrease in load

For sudden decrease in load \( \Delta F \) raises positively and the performance is shown in Fig.4. From the result it is observed that the positive overshoot of \( \Delta F \) is 0.008 for ANN controller and 0.015 for FLC. The transient recovery time is 30 sec for ANN controller and 15 sec for FLC. FLC is settles finally at 0.001 and ANN controller settles near zero. If initial oscillation is considered FLC is better than ANN controller.

C. Response to disturbance

Figure 5 indicates ANN controller and FLC output of Area1 for a disturbance created in Area 2. From the Fig 5, undershoot of \( \Delta F \) is -0.04 due to disturbance and settling time is 150 sec for FLC. For the same disturbance, \( \Delta F \) is -0.001 and settling time is 50 sec for ANN controller.

Fig. 3 Performance of controllers in Area 1 for increase in load

Fig. 4 Performance of controllers in Area 1 for decrease in load

Fig. 5 Performance of controllers in Area 1 for disturbance occur in Area 2
D. Ramp rates

In this model, for getting different ramp rates the values of Tp1 and Tp3 are chosen as 50. The same model is tested with ANN controller and FLC. The performance of FLC is given in Fig. 6. It shows that FLC settles at 80 sec but the ANN controller oscillates even though the time period reaches 100 sec. It indicates the value of $\Delta F$ at 100 sec is -0.005 for ANN controller and -0.003 for FLC. It is observed from the Fig. 6, FLC produced oscillations due to inertia after 80 sec and there are no such oscillations in ANN controller.

![Fig. 6 Response to Slower ramp rates](image)

E. Different plant makeup

The different plant make up is achieved by changing the values of Kp and Tp. In the proposed model Area 2 and Area 4 is considered as hydro plant having the transfer function $80/(13s+1)$. The performance of ANN controller and FLC is given in Fig. 7 for thermal plant.

![Fig. 7 Response of controllers (thermal units) for different plant make up](image)

**6. CONCLUSION**

This work is intended to demonstrate the successful application of computational intelligence techniques based controller to AGC for Multi Area power system. The multi area power system considered here consists of three thermal units and one hydro unit. By using Multi-Layer Perceptron, an ANN is trained for AGC. The controllers are tested for various perturbations such as increase in load, decrease in load, response due to disturbance and ramp rates. The results are compared with each other and conventional controller. From the performances of FLC, it is observed that the oscillations in the conventional integral controller are eliminated in FLC. The ANN controller performance is better than four FLC and conventional controller for all the cases, but there is an initial oscillation.

**REFERENCES**


