World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:5, No:10, 2011

Hybrid Neuro Fuzzy Approach for Automatic Generation Control of Two -Area Interconnected Power System

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Open Science Index, Electrical and Computer Engineering Vol:5, No:10, 2011 publications.waset.org/6556/pdf

***Abstract*—**The main objective of Automatic Generation Control (AGC) is to balance the total system generation against system load losses so that the desired frequency and power interchange with neighboring systems is maintained. Any mismatch between generation and demand causes the system frequency to deviate from its nominal value. Thus high frequency deviation may lead to system collapse. This necessitates a very fast and accurate controller to maintain the nominal system frequency. This paper deals with a novel approach of artificial intelligence (AI) technique called Hybrid Neuro-Fuzzy (HNF) approach for an (AGC). The advantage of this controller is that it can handle the non-linearities at the same time it is faster than other conventional controllers. The effectiveness of the proposed controller in increasing the damping of local and inter area modes of oscillation is demonstrated in a two area interconnected power system. The result shows that intelligent controller is having improved dynamic response and at the same time faster than conventional controller.

***Keywords*—**Automatic Generation Control (AGC), Dynamic Model, Two-area Power System, Fuzzy Logic Controller, Neural Network, Hybrid Neuro-Fuzzy(HNF).

I. Introduction

THE analysis and design of Automatic Generation Control (AGC) system of individual generator eventually controlling large interconnections between different control areas plays a vital role in automation of power system. The purpose of AGC is to maintain system frequency very close to a specified nominal value to maintain generation of individual units at the most economical value, to keep the correct value of the line power between different control areas. Many investigations in the area of Load Frequency Control (LFC) problem of interconnected power systems have been reported over the past six decades [1-5].

A number of control strategies have been employed in the design of load frequency controllers in order to achieve better dynamic performance. Among the various types of load frequency controllers, the most widely employed is the conventional proportional integral (PI) controller [6-10]. Conventional controller is simple for implementation but takes more time and gives large frequency deviation. A number of state feedback controllers based on linear optimal control theory have been proposed to achieve better performance [11,12]. Fixed gain controllers are designed at nominal operating conditions and fail to provide best control performance over a wide range of operating conditions. So, to keep system performance near its optimum, it is desirable to track the operating conditions and use updated parameters to compute the control. Adaptive controllers with self-adjusting gain settings have been proposed for LFC [13,14].

In this paper, an attempt has been made to apply hybrid neuro-fuzzy (HNF) controller for the automatic load frequency control for the two area interconnected system. With the help of MATLAB we have proposed a class of adaptive networks that are functionally equivalent to fuzzy inference systems. The proposed architecture referred to as ANFIS [17-19]. The performance of the hybrid neuro-fuzzy (HNF) controller is compared with the conventional PI controller to show its superiority.

II. System Model

An inter-connected power system is considered in the present study to design the HNF controller. The system comprises of two-area thermal system provided with supplementary controllers. A step load perturbation of 1% of nominal loading has been considered in area-1. Small perturbation transfer function block diagram of a two-area non-reheat thermal system is shown in Fig. 1 [7]. Here, the tie-line power deviations can be assumed as an additional power disturbance to any area *k*. For the load frequency control, the proportional integral controller is implemented.

A. Automatic Controller

The task of load frequency controller is to generate a control signal U_i that maintains system frequency and tie-line interchange power at predetermined values.

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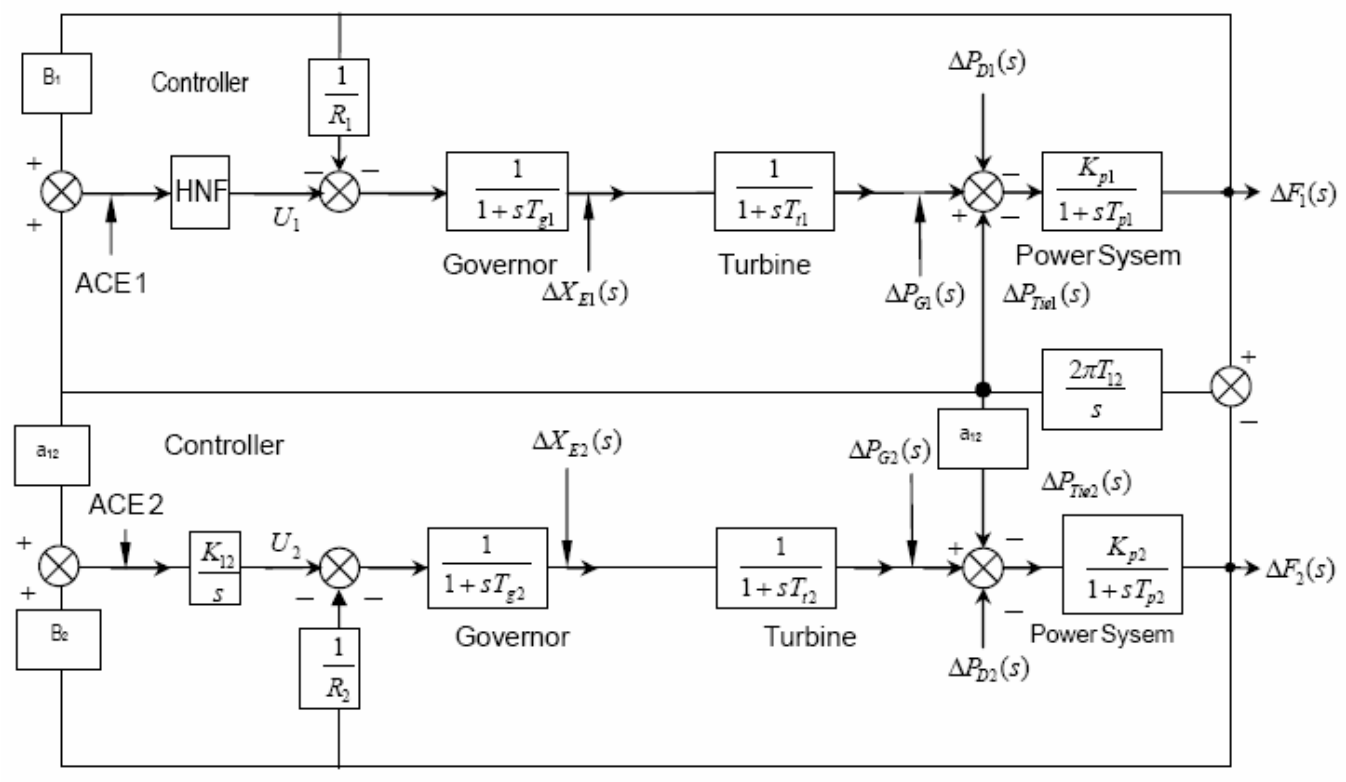


Fig. 1 Transfer function model of two-area nonreheat thermal system

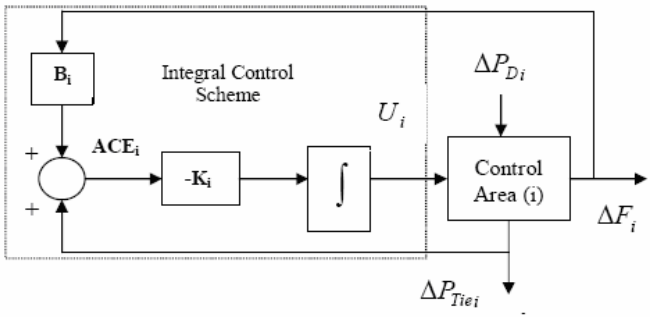


Fig. 2 Conventional PI Controller Installed on i^{th} Area

The block diagram of the PI controller is shown in Fig. 2. The control input U_i is constructed as follows:

$$U_i = -K_i \int_0^T (ACE_i)dt = -K_i \int_0^T (\Delta P_{Tiei} + B_i \Delta F_i)dt \quad (1)$$

Taking the derivative of equation (1) yields

$$\dot{U}_i = -K_i (ACE_i) = -K_i (\Delta P_{Tiei} + B_i \Delta F_i) \quad (2)$$

III. Hybrid Neuro Fuzzy (HNF) Model

In recent years, Hybrid Neuro-Fuzzy (HNF) approach has considerable attention for their useful applications in the fields like control, pattern recognition, image processing, etc [17, 18]. In all these applications there are different neuro-fuzzy applications proposed for different purposes and fields. HNF results are obtained from fusion of neural network and fuzzy logic.

A. Hybrid Neuro Fuzzy modelling

The general algorithm for a fuzzy system designer can be synthesized as follows:

Fuzzyfication:

1. Normalize of the universes of discourses for the fuzzy input and output vectors.
2. Choose heuristically the number and shape of the membership functions for the fuzzy input and output vectors.
3. Calculate of the membership grades for every crisp value of the fuzzy inputs.

Fuzzy Inference:

1. Complete the rule base by heuristics from the conventional control results.
2. Identify the valid (active) rules stored in the rule base.
3. Calculate the membership grades contributed by each rule and the final membership grade of the inference, according to the chosen fuzzification method.

Defuzzyfication:

1. Calculate the fuzzy output vector, using an adequate defuzzification method.
2. Simulation results are obtained.

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From the beginning, a fuzzy-style inference must be accepted and the most popular are:

- *Mamdani-style inferenc*e, based on Lotfi Zadeh's 1973 paper on fuzzy algorithms for complex systems and decision processes that expects all output membership functions to be fuzzy sets. It is intuitive, has widespread acceptance, is better suited to human input, but it's main limitation is that the computation for the defuzzification process lasts longer;
- *Sugeno-style inferenc*e, based on Takagi-Sugeno-Kang method of fuzzy inference, in their common effort to formalize a systematic approach in generating fuzzy rules from an input-output data set, that expects all membership functions to be a singleton. It has computational efficiency, works well with linear techniques (e.g. PID control, etc.), works well with optimization and adaptive techniques, guaranties continuity of the output surface, is better suited to mathematical analysis. The results are very much similar to Mamdani - style inference. A simple fuzzy inference system has limited learning (or adaptation) possibilities. If learning capabilities are required, it is convenient to put the fuzzy model into the framework of supervised neural networks that can compute gradient vectors systematically. Sugeno–style inference is preferred and the typical fuzzy rule is:

If x is A and y is B then z=f(x,y)

where A and B are fuzzy sets in the antecedent and $z = f(x, y)$ is a crisp function in the consequent. Usually, function z is a first-order or a zero-order.

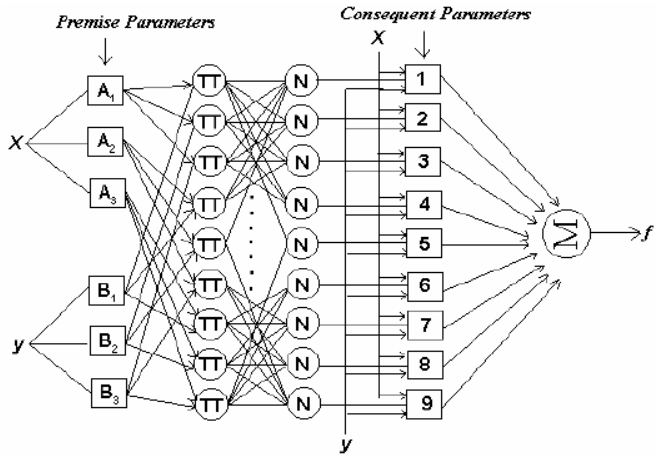


Fig. 3 Architecture of a Two-Input Sugeno Fuzzy Model with Nine Rules

Fig. 3 shows a Sugeno Fuzzy model of five layers. Each layer of the model represents a specific part as:

Layer 1:

Each adaptive node in this layer generates the membership grades the input vectors i (A_i = 1,2,3). For instance, the node function of the *i-th* node may be a generalized bell membership function:

$$O_1^1 = \mu_{A_i}(x) = 1 \Big/ \left[1 + \left| \frac{x - c_i}{a_i} \right|^{2bi} \right] \tag{3}$$

Where

A_i are the input vectors associated with the *i-th* node and $\{a_i, b_i, c_i\}$ are their parameter set that changes the shapes of the membership function; x is the input to the node i, . Parameters in this layer are referred to as the *premise parameter*s.

Layer 2:

Each fixed node in this layer calculates the firing strength of a rule via multiplication. Each node output represents the firing strength of a rule:

$$O_i^2 = \mu_{A_i}(x).\mu_{B_i}(y), i = 1,2 \tag{4}$$

Layer 3:

Fixed node i in this layer calculate the ratio of the i-th rule's firing strength to the total of all firing strength:

$$O_i^3 = \overline{w_i} = \frac{w_i}{w_1 + w_2}, i = 1,2 \tag{5}$$

For convenience, outputs of this layer will be called *normalized firing strengt*h.

Layer 4:

Adaptive node i in this layer compute the contribution of *i-th* rule toward the overall output, with the following node function:

$$O_i^4 = \overline{w_i} f_i = \overline{w_i}(p_i x + q_i y + r_i) \tag{6}$$

where $\overline{w_i}$ is the output of layer 3, and $\{p_i, q_i, r_i\}$ is the parameter set. Parameters in this layer are referred to as the *consequent parameters*.

Layer 5:

The single fixed node in this layer computes the overall output as the summation of contribution from each rule:

$$O_i^5 = \sum_i \overline{w_i} f_i \frac{\sum_i w_i f_i}{\sum_i f_i} \tag{7}$$

The basic learning rule is the back propagation gradient descendent, which calculates error signals (the derivative of the squared error with respect to each node's output) recursively from the output layer backward to the input nodes. This learning rule is exactly the same as the back propagation learning rule used in the common feed forward neural

networks.

The overall output f can be expressed as a linear combinations of the consequent parameters:

$$f = \overline{w_i} f_1 + \overline{w_2} f_2 = (\overline{w_1} x) p_1 + (\overline{w_1} y) q_1 (\overline{w_1}) r_1 + (\overline{w_2} x) p_2 + (\overline{w_2} y) q_2 + (\overline{w_2}) r_2 \quad (8)$$

Based on equation (8), the hybrid learning algorithm combines the gradient descendent and the least-squares method for an optimal parameter search.

B. Sugeno type Neuro-Fuzzy Controller

Adaptive Neuro Fuzzy Inference System (ANFIS) is more complex than Fuzzy Inference System (FIS), but users have some limitations: only zero-order or first-order Sugeno fuzzy models, And Method: prod, Or Method : max, Implication Method : prod, Aggregation Method : max, Defuzzification Method : *wtaver* (weighted average). On the other hand, users can provide to ANFIS their own number of MFs (*numMFs*) both for inputs and outputs of the fuzzy controller, the number of training and checking data sets (*numPts*), the MF's type (*mfType*), the optimization criterion for reducing the error measure (usually defined by the sum of the squared difference between actual and linearized N curve).

Membership function type (mfType):

Gbell MFs are preferred by ANFIS in most cases. For other types of MFs preferred by the user for a certain application (*pimf, gaussmf, trimf, trapmf, gauss2mf dsigmf* and *psigmf*) there is no rule in choosing them. The general rule is to obtain the best smallest error measure with minimum training parameters. MFs type such as *sigmf* and *zmf* are not accepted.

Number of Membership function (numMFs):

The great advantage of neuro-fuzzy design method comparing with fuzzy design method consists in the small number of input and output MFs (usually 2...4 !), which implies the same maximum number of rules. Thus, the rule base and the occupied memory become very small

Number of Epochs (numEpochs):

The number of epochs is determined according to the above parameters and to the accepted error measure, fixed by the user. In the present study 10 epochs have been taken.

Based on the training data set, (Derived from PI controller results) ANFIS automatically generates a first-order Sugeno fuzzy type, using only 3 gbell MFs and 9 rules. ANFIS automatically trains its fuzzy model 10 epochs. For better results, users can supplementary introduce more epochs.

IV. Results and Discussions

A hybrid neuro-fuzzy automatic generation controller is designed following the procedure presented above. The proposed scheme utilizes sugeno-type fuzzy inference system controller, with the parameters inside the fuzzy inference system decided by the neural-network back propagation method. The ANFIS is designed by taking ACE and rate of change of ACE as inputs. This network consists of five layers with, each layer representing a specific part in ANFIS controller.

Fig. 4-6 shows system dynamic response of a two area non-reheat power system of HNF controller with 1% step load perturbation in area-1. In all Figs. the performance of the proposed HNF controller is compared with a conventional PI controller. It is clear from Figs. 4 -6 that the designed HNF controller is robust in its operation and gives a superb damping performance both for frequency and tie line power deviation compare to conventional PI controller. Besides the simple architecture of the controller it has the potentiality of implementation in real time environment.

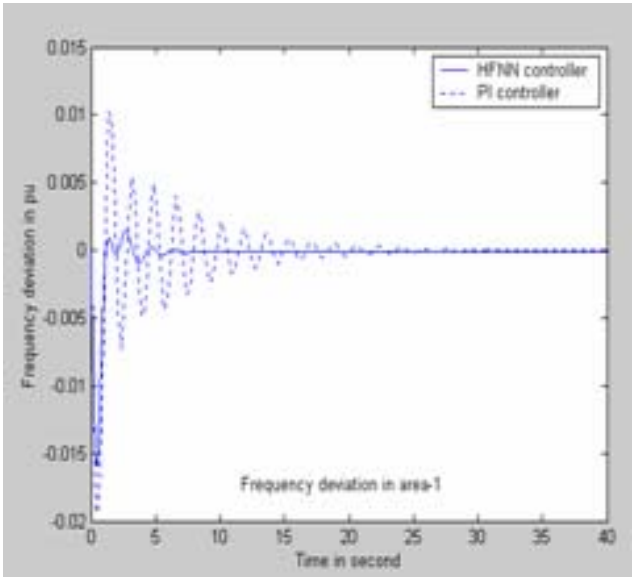


Fig. 4 Frequency deviation of area-1

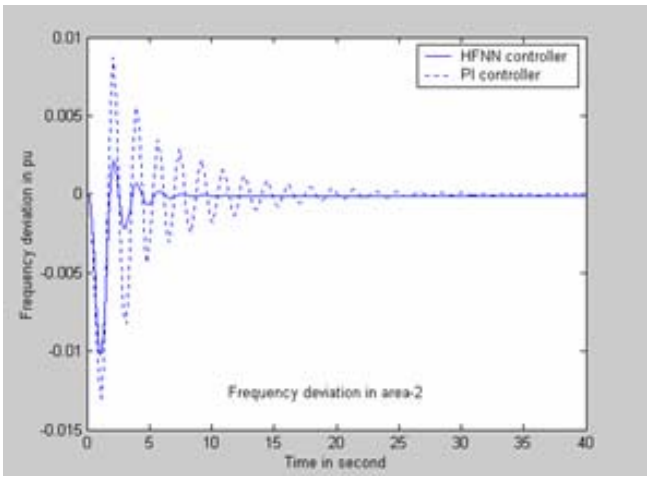


Fig. 5 Frequency deviation of area-2

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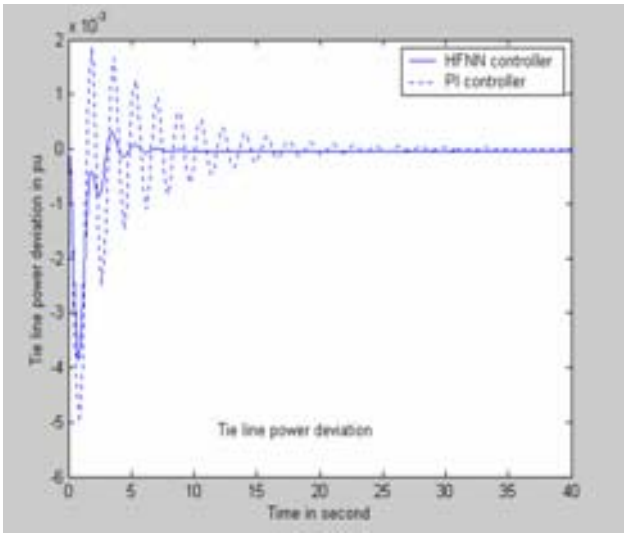


Fig. 6 Tie-line power deviation

VI. Conclusion

In this study, Hybrid Neuro-Fuzzy (HNF) approach is employed for an Automatic Generation Control (AGC) system. The proposed controller can handle the non-linearities and at the same time faster than other conventional controllers. The effectiveness of the proposed controller in increasing the damping of local and inter area modes of oscillation is demonstrated in a two area interconnected power system. Also the simulation results are compared with a conventional PI controller. The result shows that the proposed intelligent controller is having improved dynamic response and at the same time faster than conventional PI controller.

Appendix

The nominal system parameters are: $f = 60$ Hz, $R_k = 2.4$ Hz / Unit, $T_g = 0.08$ Sec, $T_r = 10.0$ Sec, $H_k = 5$ .0 Sec, $K_r = 0.5$, $T_f = 0.3$ Sec, $2\pi T_{ki} = 0.05$ Mw, $D_k = 0.00833$ pu Mw/Hz

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