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Simulation study for automatic generation control of a multi-area power system by ANFIS approach

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ABSTRACT

This paper deals with the application of artificial neural network (ANN) based ANFIS approach to automatic generation control (AGC) of a three unequal area hydrothermal system. The proposed ANFIS controller combines the advantages of fuzzy controller as well as quick response and adaptability nature of ANN. Appropriate generation rate constraints (GRC) have been considered for the thermal and hydro plants. The hydro area is considered with an electric governor and thermal area is considered with reheat turbine. The design objective is to improve the frequency and tie-line power deviations of the interconnected system. 1% step load perturbation has been considered occurring either in any individual area or occurring simultaneously in all the areas. It is a maiden application of ANFIS approach to a three unequal area hydrothermal system with GRC considering perturbation in a single area as well as in all areas. The performance of the ANFIS controller is compared with the results of integral squared error (ISE) criterion based integral controller published previously. Simulation results are presented to show the improved performance of ANFIS controller in comparison with the conventional integral controller. The results indicate that the controllers exhibit better performance. In fact, ANFIS approach satisfies the load frequency control requirements with a reasonable dynamic response.

1. Introduction

With the enlargement of power system size and capacity together with the strengthening of interconnections, abnormal phenomena have been frequently observed such as excessively large tie-line power deviations and/or sustained power oscillations under sudden system load changes. This fact suggests the necessity of more advanced control strategies to be incorporated for better control. With the recent technological innovations, intelligent controllers have been replacing conventional controllers in order to have fast and good dynamic response for load frequency control problem. Many intelligent techniques such as fuzzy logic, artificial neural network (ANN), genetic algorithm, bacteria foraging, etc. are being used extensively in isolated as well as interconnected power systems. An interconnected power system is made up of several areas. In each area, an automatic generation controller (AGC) monitors the system frequency and tie-line flows, computes the net change in the generation required (generally referred to as area control error-ACE) and changes the set position of the generators within the area so as to keep the time average of the ACE at a low value. For stable operation of power systems, both constant frequency and constant tie-line power exchange should be provided [1]. Therefore ACE, which is defined as a linear combination of power net-interchange and frequency deviations, is generally taken as the controlled output of AGC. As the ACE is driven to zero by the AGC, both frequency and tie-line power errors will be forced to zeros [2]. AGC function can be viewed as a supervisory control function which attempts to match the generation trend within an area to the trend of the randomly changing load of the area, so as to keep the system frequency and the tie-line power flow close to scheduled value. The growth in size and complexity of electric power systems along with increase in power demand has necessitated the use of intelligent systems that combine knowledge, techniques and methodologies from various sources for the real-time control of power systems.

Literature survey shows that very little attention has been given to the study of AGC of multi-area systems. And, in these studies of multi-area systems, the focus has been to optimize the supplementary controller gains using artificial neural network (ANN), hybrid genetic algorithm-simulated annealing (GA-SA) or fuzzy logic based techniques. Various heuristic search approaches such as genetic algorithm (GA), optimal, and particle swarm for optimizing the controllers is available in the literature [3–5]. Also, Nanda et al. [6] have demonstrated that bacterial foraging, a more recent and powerful evolutionary computational technique, based integral controller provides better performance as compared to that with integral controller based on classical and GA techniques in three

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Nomenclature

f	nominal system frequency
i	subscript referring to area ($i = 1, 2, 3$)
P_{ri}	rated power of ith area
H_i	inertia constant of ith area
D_i	$\Delta P_{Di}/\Delta f_i$
T_{ij}	synchronizing coefficient
R_i	governor speed regulation parameter for ith area
T_{ri}	steam turbine reheat time constant for ith area
T_{ti}	steam turbine time constant for ith area
T_{gi}	speed governor time constant of ith area
T_{pi}	power system time constant of ith area ($2H_i/fD_i$)
K_{pi}	power system gain for ith area ($1/D_i$)
K_{ri}	steam turbine reheat coefficient for ith area
ACE_i	area control error of ith area
B_i	frequency bias for ith area
K_D, K_p, K_i	electric governor derivative, proportional and integral gains, respectively
T_w	water starting time
$\beta_i = (D_i + 1/R_i)$	area frequency response characteristics for ith area
a_{ij}	$-P_{ri}/P_{rj}$

unequal areas thermal system. There has also been considerable research work attempting to propose better AGC systems based on modern control theory [7,8], neural network [9–13], fuzzy system theory [13–19] and reinforcement learning [20]. Recent studies show that ANFIS approach has also been applied to hydrothermal system [21–23]. All research in the past in the area of AGC pertains to interconnected two equal area thermal system and little attention has been paid to AGC of unequal multi area systems. Most of past works have been centered around the design of governor secondary controllers, and design of governor primary control loop (i.e., selection of suitable governor droop or speed regulation parameter 'R'). Apparently no literature has discussed AGC performance subject to simultaneous small step load perturbations in all area or the application of ANFIS technique to a multi-area power system. It is a maiden application of ANFIS approach to a three unequal area hydrothermal system considering small step load perturbation occurring in a single area as well as simultaneously in all the areas. All the cases are considered with generation rate constraints (GRC).

The prominent feature of fuzzy and neural network based schemes is that they provide a model-free description of control systems and do not require model identification. In this article a control scheme based on ANFIS, which is trained by the results of off-line studies, obtained using genetic algorithm has been proposed. The simulations are carried out in presence of the GRC's because ignoring GRC leads to nonrealistic results. In view of this, the main objectives of the present paper are the following:

1. To consider a three unequal area hydrothermal system under perturbation in a single area and simultaneously in all areas, and then obtain system dynamic responses with ANFIS controller at different perturbation location.
2. To present a systematic and comprehensive approach for designing ANFIS based controller.
3. To compare the ANFIS controller results with already published result of Nanda et al. [24]. And, then analyze the dynamic performance obtained with the above control strategy, i.e., ANFIS based controller.

For the design purpose, MATLAB/Simulink model of the power system with ANFIS controller is developed and the results obtained are compared with the optimized conventional integral controller results [24]. A detailed comparative result is also included in Tables 1 and 2 considering maximum overshoot and settling time.

2. System investigated

The AGC system investigated consists of three generating areas of equal sizes. Areas 1 and 2 are reheat thermal systems and area 3 is a hydro system. The characteristics of hydro turbine differ from steam turbine in many respects. The typical value of permissible rate of generation for hydro plant is relatively much higher (a typical value of generation rate constraints (GRC) being 270%/min for raising generation and 360%/min for lowering generation), as compared to that for reheat type thermal units having GRC of the order of 3%/min [25–27]. Fig. 1 [24] shows the AGC model of a three area hydrothermal system. The thermal plant has a single stage reheat steam turbine and the hydro plant is equipped with an electric governor. A bias setting of $B_i = \beta_i$ is considered in both hydro and thermal areas. MATLAB version 7.7 has been used, to obtain dynamic responses for frequency and tie-line power deviations for 1% step load perturbation in either area or simultaneously in all areas. The system parameters are given in Appendix A [28,29].

In a power system having steam plants, power generation can change only at a specified maximum rate. A typical value of the

Table 1
Comparison of maximum overshoot (in Hz) obtained by integral squared error (ISE) criterion and ANFIS approach.

Case	Integral squared error (ISE) criterion	ANFIS approach
Frequency deviation in area 1 due to disturbance in area 1	3.5	1.65
Frequency deviation in area 2 due to disturbance in area 1	3.266	1.377
Frequency deviation in area 3 due to disturbance in area 1	3.225	2.107
Tie-line power deviation in area 1 due to disturbance in area 1	0.018	0
Tie-line power deviation in area 2 due to disturbance in area 1	0.715	0.669
Tie-line power deviation in area 3 due to disturbance in area 1	0.625	1.105
Frequency deviation in area 1 due to disturbance in area 3	3.0	0
Frequency deviation in area 2 due to disturbance in area 3	3.05	0
Frequency deviation in area 3 due to disturbance in area 3	3.3	0
Tie-line power deviation in area 1 due to disturbance in area 3	0.665	0.563
Tie-line power deviation in area 2 due to disturbance in area 3	0.651	0.568
Tie-line power deviation in area 3 due to disturbance in area 3	0.028	0.593
Frequency deviation in area 1 due to disturbances in all areas	1.05	0.65
Frequency deviation in area 2 due to disturbances in all areas	1.0	0.71
Frequency deviation in area 1 due to disturbances in all areas	0.61	0
Tie-line power deviation in area 1 due to disturbance in all areas	0.173	0.164
Tie-line power deviation in area 2 due to disturbance in all areas	0.168	0.147
Tie-line power deviation in area 3 due to disturbance in all areas	2.8	2.35