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Simulation based neuro-fuzzy hybrid intelligent PI control approach in four-area load frequency control of interconnected power system

Surya Prakash [a,*], S.K. Sinha [b]

[a] Electrical & Electronics Engg. Dept., SHIATS-Deemed University, Allahabad, India
[b] Electrical Engg. Dept., K.N.I.T. Sultanpur, India

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ABSTRACT

This paper presents a novel control approach of hybrid neuro-fuzzy (HNF) for load frequency control (LFC) of four-area power system. The advantage of this controller is that it can handle the non-linearities, and at the same time it is faster than other existing controllers. The effectiveness of proposed controller in increasing the damping of local and inter area modes of oscillation is demonstrated in four area interconnected power system. Area-1 and area-2 consist of thermal reheat power plant whereas area-3 and area-4 consist of hydro power plant. Performance evaluation is carried out by using fuzzy, ANN, ANFIS and conventional PI and PID control approaches. The performances of the controllers are simulated using MATLAB/Simulink package. The result shows that intelligent HNF controller is having improved dynamic response and at the same time faster than ANN, fuzzy and conventional PI and PID controllers.

1. Introduction

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 system is maintained. Any mismatch between generation and demand causes the system frequency to deviate from the nominal value. This high frequency deviation may lead to system partial or complete collapse. AGC comprises a load frequency control (LFC) loop and an automatic voltage regulator (AVR) loop interconnected power systems regulate power flows and frequency by means of an AGC. LFC system provides generator load control via frequency zero steady-state errors of frequency deviations and optimal transient behavior are objectives of the LFC in a multi-area interconnected power system [1]. Load frequency control (LFC) is being used for several years as part of the automatic generation control (AGC) scheme in electric power systems [2–5]. 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 and PID controllers are 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 [6,7]. Therefore, there is need of a controller which can overcome this problem. The artificial intelligent controllers like fuzzy and neural control approaches are more suitable in this respect. Fuzzy system has been applied to the load frequency control problems with rather promising results by Nanda [8]. The literature survey says that by the application of conventional controllers such as PI and PID, though the steady state error is minimized to zero but it fails when the system complexity increases due to many interconnections and non-linearity. The performance of fuzzy controllers is much better than the conventional controllers [9–13]. The salient feature of these techniques is that they provide a model-free description of control systems and do not require model identification. The controllers based on ANN technique further improve the performance once it is trained by taking a suitable number of neural network and plant identifications [12,13]. The state of art provided by the authors mentioned in [14–16] reveals that conventional and intelligent controllers designed for AGC; however a better track on the frequency deviation can be provided by the intelligent control approaches. The variable structure control also reduces some of the oscillations in frequency and tie-line power changes.

In this paper an attempt has been made to apply hybrid neuro-fuzzy (HNF) controller for automatic load frequency control for the four-area interconnected power system. With the help of MATLAB

* Corresponding author. Tel.: +09956722055.
E-mail addresses: sprakashgiri0571@yahoo.com (S. Prakash), Sinhask98@engineers.com (S.K. Sinha).

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Nomenclature

i	subscript referring to area (i = 1, 2, 3, 4)
f	nominal system frequency
H_i	inertia constant
ΔP_{Di}	incremental load change
ΔP_{gi}	incremental generation change $D_i = \frac{\Delta P_{Di}}{\Delta f_i}$
T_g	steam governor time constant
K_r	reheat constant
T_r	reheat time constant
T_t	steam turbine time constant
R_i	governor speed regulation parameter
B_i	frequency bias constant
T_{pi}	$2H_i/f \times D_i$
K_{pi}	$1/D_i$
K_t	feedback gain of FLC
T_w	water starting time
ACE	area control error
P	power
E	generated voltage
V	terminal voltage
δ	angle of the voltage (V)
$\Delta\delta$	change in angle
ΔP	change in power
Δf	change in supply frequency
ΔP_c	speed changer position
R	speed regulation of the governor
K_H	gain of speed governor
T_H	time constant of speed governor
K_p	$1/B$ = power system gain
T_p	$2H/Bf_0$ = power system time constant

a class of adoptive network that are functionally equivalent to fuzzy inference system have been proposed. The proposed architecture referred to as ANFIS. The performance of the hybrid neuro-fuzzy controller is compared with the Fuzzy, ANN and conventional PI and PID controller to show its superiority.

2. Power system investigated

Interconnected power system consists of many control areas connected by tie-lines. Power system has had complex and multi-variable structures. Also they consist of many different control blocks. Most of them are non-linear time variant and/or non-minimum phase systems. All the generators are supposed to constitute a coherent group in each control area. From the experiment on power system, it can be seen that each area needs its system frequency and tie line power flow to be controlled. Frequency control is accomplished by two different control actions in interconnected four-area power system: primary speed control and supplementary or secondary control actions. The primary speed control makes the initial coarse readjustment of the frequency. By its action, the various generators in the control area track a load variation and share it in proportion to their capacities. The speed of the response is limited only by the natural time lags of the turbine and the system itself. The secondary loops takes over the fine adjustment of frequency by resetting the frequency error to zero through integral action. The relationship between speed and load can be adjusted by changing a load reference set point input. In practice, the adjustment of load reference set point is accomplished by operating the speed changer motor. The output of each unit at a given system frequency can be varied only by changing its load reference, which, in effect, moves the speed droop characteristics up and down. This control is considerably slower and goes into action only when the primary control has done its job. For power and load sharing among generators connected to the system, speed regulation or droop characteristic must be provided [2]. The speed droop or regulation characteristic may be obtained by intelligent controllers. The four-area hydro-thermal power system interconnected with tie-lines is shown in Fig. 1.

In this paper, the performance evaluation based on ANN, Fuzzy and ANFIS control technique for four areas interconnected thermal-hydro power plant is proposed. The sliding concept arises due to variable structure concept. The objective of VSC has been greatly extended from stabilization to other control functions. The most distinguished feature of VSC is its ability to result in very robust control systems and external disturbances [17–19]. The aim of control areas is as:

(i) Each control area as for as possible should supply its own load demand and power transfer through tie line should be on mutual agreement.
(ii) Each control areas should controllable to the frequency control [18].

In an isolated control area case the incremental power ($\Delta P_G - \Delta P_D$) was accounted for by the rate of increase of stored kinetic energy and increase in area load caused by increase in frequency. The MATLAB model of four-area hydro-thermal reheat power system simulated is shown in Fig. 1.

The stat variable for each of areas are ΔP_i (i = 1, . . ., 4) and state space equation related to the variables are different for each areas.

$$\Delta P_1(k) = \Delta P_{12}(k) + a_{41}\Delta P_{41}(k) \quad (1)$$

$$\Delta P_2(k) = \Delta P_{23}(k) + a_{12}\Delta P_{12}(k) \quad (2)$$

$$\Delta P_3(k) = \Delta P_{34}(k) + a_{23}\Delta P_{23}(k) \quad (3)$$

$$\Delta P_4(k) = \Delta P_{41}(k) + a_{34}\Delta P_{34}(k) \quad (4)$$

Tie-line bias control is used to eliminate steady state error in frequency in tie-line power flow. This states that the each control area must contribute their share to frequency control in addition for taking care of their own net interchange.

Let

ACE_1 = area control error of area 1
ACE_2 = area control error of area 2
ACE_3 = area control error of area 3
ACE_4 = area control error of area 4

In this control, ACE_1, ACE_2 and ACE_3 are made linear combination of frequency and tie line power error [2].

$$ACE_1 = \Delta P_{12} + b_1\Delta f_1 \quad (5)$$

$$ACE_2 = \Delta P_{23} + b_2\Delta f_2 \quad (6)$$

$$ACE_3 = \Delta P_{34} + b_3\Delta f_3 \quad (7)$$

$$ACE_4 = \Delta P_{41} + b_4\Delta f_4 \quad (8)$$

where the constant b_1, b_2, b_3 and b_4 are called area frequency bias of area 1, area 2, area 3 and area 4 respectively. Now ΔPR_1, ΔPR_2, ΔPR_3 and ΔPR_4 are mode integral of ACE_1, ACE_2, ACE_3 and ACE_4 respectively.

Control methodology used is mentioned in the next preceding sections.

3. Automatic controller

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