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Load frequency control using Bat inspired algorithm based dual mode gain scheduling of PI controllers for interconnected power system

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ABSTRACT

This paper highlights the load frequency control using dual mode Bat algorithm based scheduling of PI controllers for interconnected power systems. The bat inspired algorithm based on the echolocation of bats has been developed in 2010. In this study, the bat inspired algorithm based dual mode PI controller is applied to the multi-area interconnected thermal power system in order to tune the parameter PI controllers. The proposed controller is simple in structure and easy for implementation. The proposed controller was compared with those from conventional the PI controllers and Fuzzy gain scheduling of PI controllers. The simulation results show the point that the proposed bat inspired algorithm, based dual mode gain scheduling of PI controllers (BIDPI), provides better transient as well as steady state of response. It is also found that the proposed controller is less sensitive to the changes in system parameters.

Introduction

Load frequency control (LFC) is of importance in electrical power system design and operation. The objective of the LFC, in an interconnected power system, is to maintain the frequency of each area and to keep tie-line power flows within some pre-specified tolerances by adjusting the MW outputs of the LFC generators so as to accommodate the fluctuating load demands.

A number of control strategies have been employed in the design of load-frequency controllers in order to achieve better dynamic performance [1–8]. Among the various types of load frequency controllers, the most widely employed is the simple conventional controllers. These conventional controllers for LFC are still popular with the industries because of their simplicity, easy realization, low cost, and robust nature. The conventional proportional plus integral control strategy, which is widely used in power industry, is to take the integral of area control error (*ACE*), which is a linear combination of net-interchange and frequency errors as the control signal. Generally, the conventional approach using the proportional plus integral controller results in relatively large over shoots in transient frequency deviations. Further, the settling time of the system frequency deviation is also relatively long [9].

It is well known that if the control law employs integral control, the system will have no steady – state error. However, it increases the type of the system by one. Therefore, the response with the integral control is slow during the transient period. In the absence of integral control, the gain of the closed loop system can be increased significantly to improve the transient response since the proportional plus integral control which does not eliminate the conflict between the static and dynamic accuracy. This conflict may be resolved by improving the principle of dual mode control [9,10].

Usually, a linear model around a nominal operating point is used in the load frequency controller design. However, because of the inherent characteristics of the changing loads, the operating point of a power system changes very much during a daily cycle. Therefore, a fixed controller which is optimal under one operating condition may not be suitable in another status unless some precautions are considered.

Gain scheduling is a technique commonly used in designing controller for non-linear systems. Its main advantage is that the controller parameter can be changed very quickly in response to changes in the system dynamics because no parameter estimation is required. Besides being an effective method to compensate for non-linear and other predictable variations in the system dynamics, it is simpler to implement than automatic tuning or adaptation. However, the conventional gain scheduling also has its drawbacks. One drawback is that the system parameter may

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Nomenclature

List of symbols

f	area frequency in Hz
i	subscript referred to area i (1–2)
P_{ei}	the total power exchange of area i in p.u. MW/Hz
P_{Di}	area real power load in p.u. MW
P_{ci}	area speed changer output in p.u. MW
X_e	governor valve position in p.u. MW
P_{gi}	incremental generation change in area i p.u. MW
K_p, K_i	electric governor proportional and integral gains respectively
T_P	area time constant in seconds
R	steady state regulation of the governor in Hz/p.u. MW
T_g	time constant of the governing mechanism in seconds
k_r	reheat coefficient of the steam turbine
T_r	reheat time constant of the steam turbine in seconds
T_t	time constant of the steam turbine in seconds
β_i	frequency bias constant in p.u. MW/Hz
ACE	Area controller error
B	Bias constant
ISE	integral square error
FGPI	Fuzzy gain scheduling PI
N	number of interconnected areas
Δ	incremental change of a variable
Δf_i	incremental change in frequency of area i in Hz
ΔP_G	change in generated power
ΔP_D	change in load demand
ΔP_c	change in speed governor
T_P	power system time constant
$\Delta P_{tie\ i-j}$	incremental change in tie line power connecting between area i and area j in p.u.
N	number of interconnected areas
Δ	incremental change of a variable
S	laplace frequency variable
$\underline{v_i}$	velocities of bat
$\underline{x_i}$	position of bat
$\underline{f_{\min}}$	minimum frequency of bats emits sound pulses
$\underline{f_{\max}}$	maximum frequency of bats emits sound pulses
$\underline{r_i}$	pulse emission rate of ith bat
$\underline{r_0}$	initial pulse emission rate of bats
$\underline{A_0}$	initial loudness of sound produce by the bats
$\underline{A_{\min}}$	minimum loudness of sound produce by the bats
$\underline{x_*}$	current global best solution
$\underline{\beta}$	random vector
$\underline{\lambda}$	wavelength of sound

Superscript

T	transpose of a matrix

Subscripts

i, j	area indices (i, j = 1, 2,. . ., N)

be rather abrupt across the regional boundaries, which may result in unsatisfactory or even unstable performance across the transition regions. In order to solve the above mentioned problems of conventional gain scheduling, the Fuzzy gain scheduling of PI/PID controllers is reported in the literature [11–16]. But Fuzzy gain scheduling a sophisticated technique is easy to design and implement. Nevertheless, the determination of membership function and control rules is an essential part of the design. To achieve satisfactory membership functions and control rule the designer's experience is necessary. Generally, it is difficult for a human expert to search for a number of proper rules for the Fuzzy system. The application of artificial intelligence techniques have been successfully employed to many optimization problem [18,19]. In this article, simple bat algorithm (BA) is used as an optimization tool to obtain the optimal gains for dual mode gain scheduling of PI controllers

Yang [20,21] proposed the bat algorithm. BA is inspired by the research on the social behavior of bats. The BA is based on the echolocation behavior of bats. Keeping the above point in view, the load frequency control using bat inspired algorithm based dual mode gain scheduling of PI controllers is proposed for load frequency control of interconnected power systems. The proposed controller is practically as simple as that of the conventional controller and can be implemented with very little additional cost. Application of this controller to a two area interconnected power system demonstrates the effectiveness of the proposed controller. Moreover, it has also been observed that the proposed controller is less sensitive to system parameter variations.

Statement of the problem

The state variable equation of the minimum realization model of the 'N' area interconnected power system is expressed as [10]

$$\begin{aligned} \dot{X} &= Ax + Bu + \Gamma d \\ \upsilon &= Cx \\ y &= Hx \end{aligned} \tag{1}$$

where $x = \left[x_1^T, \Delta P_{ei}, \ldots, x_{(N-1)}^T, \Delta P_{e(N-1)}, \ldots, x_N^T\right]^T$; $n = \sum_{i=1}^{N} n_i + (N-1)$, n-state vector; $u = [u_1, \ldots, u_N]^T = [\Delta Pc_1, \ldots, \Delta Pc_N]^T$, N-control input vector; $d = [d_1, \ldots, d_N]^T = [\Delta P_{D_1}, \ldots, \Delta P_{D_N}]^T$, N-disturbance input vector; $\upsilon = [\upsilon_1, \ldots, \upsilon_N]^T$, N-control output vector; $y = [y_1, \ldots, y_N]^T$, $2N$-measurable output vector.

Where A is system matrix, B is the input distribution matrix, Γ is the disturbance distribution matrix, C is the control output matrix distribution matrix, H is the measurable output distribution matrix, x is the state vector, u is the control vector, and d is the disturbance vector of load changes.

Output feedback control scheme

It is a known fact that by incorporating an integral controller, the steady-state requirements can be achieved. In order to introduce an integral function to the controller, the system, Eq. (1) is augmented with new state variables defined of as a integral of ACE_i ($\int \upsilon_i\,dt$), i = 1, 2,. . ., N. The augmented system of order ($N + n$) can be described as:

$$\dot{\overline{X}} = \overline{A}x + \overline{B}u + \overline{\Gamma}d \tag{2}$$

Where $\bar{x} = \begin{bmatrix} \int \upsilon dt \\ x \end{bmatrix} \begin{matrix} \}N \\ \}n \end{matrix}$, $\overline{A} = \begin{bmatrix} 0 & C \\ 0 & A \end{bmatrix}$, $\overline{B} = \begin{bmatrix} 0 \\ B \end{bmatrix}$ and $\overline{\Gamma} = \begin{bmatrix} 0 \\ \Gamma \end{bmatrix}$.

As the newly added state variables ($\int \upsilon_i\,dt$), i = 1, 2,. . ., N will also be available for feedback in each area, the new measurable output 'y' can be written $\bar{y} = \overline{H}\bar{x}$

Where $\bar{y} = [\bar{y}_1^T, \ldots, \bar{y}_N^T]^T$ $\overline{H} = [\overline{H}_1^T, \ldots, \overline{H}_N^T]^T$ and

$$\overline{H}_i = \left[\begin{array}{c:c} 0\cdots1\cdots0 & 0 \\ \hdashline 0 & H_i \end{array}\right]$$