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New performance indices for the optimization of controller gains of automatic generation control of an interconnected thermal power system

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ABSTRACT

This paper proposes four new performance index (PI) criteria for the optimal tuning of controller gains of automatic generation control. The peak sum squared error (PSSE), peak sum time multiple squared error (PSTSE), peak sum absolute error (PSAE) and peak sum time multiple absolute error (PSTAE) are the new performance Index criteria which have been proposed against the existing criteria given as integral squared error (ISE), integral time multiple squared error (ITSE), integral absolute error (IAE) and integral time multiple absolute error (ITAE), respectively. To demonstrate the robustness of the proposed performance index criteria, the investigations are carried out for non-reheat as well as reheat interconnected thermal power system. Further, the dynamic performance of the proposed performance index criteria have been investigated over the continuous and discrete AGC systems. To firmly testify the superiority of the proposed criteria, discrete AGC system has been analyzed for the wide range of sampling periods. The study also reveals some new findings in discrete data automatic generation control system.

1. Introduction

The research in the field of automatic generation control (AGC) started in 1950's. C. Concordia [1,2] studied the dynamic performance of both thermal and hydro power systems, mainly focused on frequency and tie-lie power control of the power system. In 1970's Olle Elgerd and Fosha [3–5] extended the work and named it as 'megawatt load frequency control problem'. The preliminary studies were conducted on isolated and interconnected power systems using classical control and optimal control theory for optimizing the controller gains and frequency bias parameters. The state space model of AGC interconnected power system was also developed. F.P. DeMello et al. [6] modeled the important power system elements which are useful in the simulation of automatic generation control such as electro-mechanical subsystem, prime mover/energy supply system etc. The various digital control techniques were also discussed for the application of digital AGC system [7]. Subsequently, AGC studies were extended to multi-area systems having reheat turbines [8,9]. Numerous intelligent control techniques were developed to optimize the controller gains such as fuzzy logic, neural network, particle swarm optimization, genetic algorithm, reinforcement learning approach, bacterial foraging algorithm, sliding mode etc. [10–15]. Further, the work was extended to discrete AGC system. In response to the area control error (ACE); supplementary controller adjusts the speed changer position continuously to eliminate the frequency and tie-line power deviations in continuous AGC system. Therefore, turbine's control valve will be continuously chasing the error signal resulting in more oscillations, wear and tear of turbine. To avoid such problem, the ACE signal was applied to the discrete supplementary controller, which changes the speed changer position only once, in a particular time interval known as sampling period. The continuous AGC system was represented by mathematical differential equations in AGC transfer function model [16,17]. The differential equations were replaced by difference equations to convert continuous AGC system into discrete system [18–22]. The sampling periods were selected in the range of 1–4 s for discrete AGC analysis. In the decades of 1980–90's, large numbers of papers appeared on discrete AGC system. These papers followed the same procedure of converting the continuous AGC system into discrete system. A. Kumar et al. [21] spotted a measure mistake in the conversion process of continuous AGC system into discrete system. Practically, power system is a continuous system and cannot be discretized. However, AGC supplementary controllers can be continuous or discrete. Therefore, while converting a continuous AGC system into

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Nomenclature

i & j	Index number referring to ith and jth area ($i = 1, 2, \ldots$)
Δf_i	Deviation in frequency of ith area (Hz)
$\Delta P_{tie\ ij}$	Deviation in tie-line power between area-i and area-j (p.u.)
ΔP_{ti}	Change in power output of turbine in ith area (p.u.)
ΔP_{gi}	Change in power output of generator in ith area (p.u.)
ΔX_{gi}	Change in valve position of governor in ith area (p.u.)
K_{pi}	Power system coefficient in ith area
ACE_i	Area control error signal in ith area
P_{ri}	Capacity of ith area (MW)
R_i	Regulation parameter in ith area (Hz/p.u. MW.)
T_{pi}	Power system time constant in ith area (s)
T_{ti}	Steam turbine time constant in ith area (s)
T_{ri}	Reheat time constant in ith area (s)
K_{ri}	Reheat coefficient in ith area
T_{12}	Synchronizing coefficient
a_{12}	Area's capacity ratio ($-P_{r1}/P_{r2}$)
B_i	Frequency bias constant of ith area (in p.u. MW/Hz)
J	Cost function/performance index
$\|L_r\|$	Peak magnitude at the rth local minima/maxima
ΔP_{di}	Step load perturbation ith area (in p.u.)
T	Sample period (s)

discrete system; sampling period of power system model should be kept very low in comparison to discrete AGC controller. The power system model having very low value of sampling period can be assumed to be a continuous system. Typically, sampling rates of power system model and discrete AGC controller are selected in the range of 0.008–0.02 s and 1–4 s, respectively. It was also found that the dynamic performance of discrete AGC system is affected by the sampling period of supplementary controllers.

The dynamic performance of AGC system mainly depends upon the values of AGC controller gains which are obtained using one of the existing performance index criteria namely; ISE, ITSE, IAE and ITAE, respectively [23–30]. In the existing performance index criteria, area under the curves of frequency and tie-line power deviations are taken as an objective function. The minimization of objective function is considered as the optimization problem. The value of controller gains that renders minimum objective function represents the optimum controller gain settings of AGC system. The peaks of frequency and tie-line power deviations are more critical for the optimum operation of power system and consumers equipments. Although, the existing performance index criteria reduces the area under the curves of frequency and tie-line power deviations. However, they are not effective in reducing the peaks of frequency and tie-line power deviation curves. In this paper, peak based performance index criteria have been proposed. The sum of peak magnitudes of deviation curves are considered as an objective function. The value of controller gains that leads to the minimum value of objective function are known as the optimum controller gains. The results reveal that the peak based performance index criteria reduce the peaks of frequency and tie-line power deviation curves significantly, in comparison to the existing area based performance index criteria.

The proposed peak based performance index criteria are named as peak sum squared error (PSSE), peak sum time multiple squared error (PSTSE), peak sum absolute error (PSAE) and peak sum time multiple absolute error (PSTAE), respectively. The system dynamic performance using peak based performance index criteria have been compared to the existing area based criteria. The two area interconnected reheat thermal power system has been considered for the investigation. Also, the studies are carried out for continuous as well as discrete controls of AGC system.

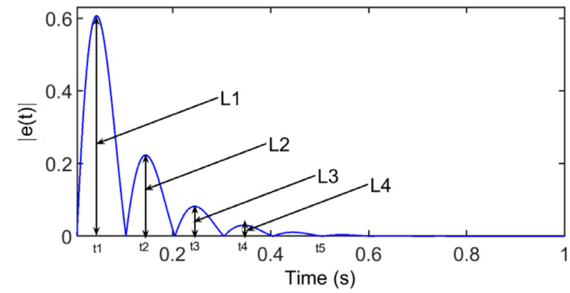

Fig. 1. Random curve of error signal $e(t)$ for illustration.

2. Proposed performance index criteria for AGC system

The existing area based performance index criteria used for the optimization of AGC controllers are as follows:

$$\text{ISE}: \quad \text{Min}\, J = \int_0^\infty \left|e(t)^2\right| dt \tag{1}$$

$$\text{ITSE}: \quad \text{Min}\, J = \int_0^\infty t \left|e(t)^2\right| dt \tag{2}$$

$$\text{IAE}: \quad \text{Min}\, J = \int_0^\infty |e(t)|\, dt \tag{3}$$

$$\text{ITAE}: \quad \text{Min}\, J = \int_0^\infty t\, |e(t)|\, dt. \tag{4}$$

The performance index/objective function 'J' is the area under the curve of error signal (absolute/squared) which has to be minimized. That particular value of controller gains at which the objective function gives minimum value is known as the optimum gain setting of the controller. In the proposed criterion, instead of calculating the area under the curves, authors have taken the absolute/squared sum of all local peak points of the error signal. For the sake of understanding, a random curve of an error signal $|e(t)|$ with peaks points have been considered as shown in Fig. 1. All the peaks of the curve are marked as $L_1, L_2, L_3, \ldots$ and the time at which these peaks are occurring are marked as $t_1, t_2, t_{3,\ldots}$ so on. Hence, the new PI function which is to be minimized can be written as:

$$\text{Min}\, J = |L_1| + |L_2| + |L_3| + \cdots + |L_\infty| \tag{5}$$

$$\text{or} \quad \text{Min}\, J = \sum |L_{Peak}|. \tag{6}$$

This proposed criterion is named as 'Peak Sum Absolute Error' (PSAE) criterion which has been proposed against the IAE performance index criterion. All the new performance index criteria have been listed with their counterpart existing criteria in Table 1.

The existing area based performance index criteria in context to AGC system are as follows:

$$\text{ISE}: \quad \text{Min}\, J = \int_0^\infty \left(|\Delta f_1|^2 + |\Delta P_{tie\ 12}|^2\right) dt \tag{7}$$

$$\text{ITSE}: \quad \text{Min}\, J = \int_0^\infty t\left(|\Delta f_1|^2 + |\Delta P_{tie\ 12}|^2\right) dt \tag{8}$$

$$\text{IAE}: \quad \text{Min}\, J = \int_0^\infty \left(|\Delta f_1| + |\Delta P_{tie\ 12}|\right) dt \tag{9}$$

$$\text{ITAE}: \quad \text{Min}\, J = \int_0^\infty t\left(|\Delta f_1| + |\Delta P_{tie\ 12}|\right) dt. \tag{10}$$