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Load frequency control of a realistic power system with multi-source power generation

K.P. Singh Parmar [a,*], S. Majhi [b], D.P. Kothari [c,1]

[a] CAMPS, National Power Training Institute, Faridabad, Haryana 121 003, India
[b] Indian Institute of Technology, Guwahati, India
[c] RAISONI Group of Institutions, Nagpur, India

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ABSTRACT

In this paper, load frequency control (LFC) of a realistic power system with multi-source power generation is presented. The single area power system includes dynamics of thermal with reheat turbine, hydro and gas power plants. Appropriate generation rate constraints (GRCs) are considered for the thermal and hydro plants. In practice, access to all the state variables of a system is not possible and also their measurement is costly and difficult. Usually only a reduced number of state variables or linear combinations thereof, are available. To resolve this difficulty, optimal output feedback controller which uses only the output state variables is proposed. The performances of the proposed controller are compared with the full state feedback controller. The action of this proposed controller provides satisfactory balance between frequency overshoot and transient oscillations with zero steady state error in the multi-source power system environment. The effect of regulation parameter (R) on the frequency deviation response is examined. The sensitivity analysis reveals that the proposed controller is quite robust and optimum controller gains once set for nominal condition need not to be changed for ±25% variations in the system parameters and operating load condition from their nominal values. To show the effectiveness of the proposed controller on the actual power system, the LFC of hydro power plants operational in KHOZESTAN (a province in southwest of Iran) has also been presented.

1. Introduction

Automatic Generation Control (AGC) is an important function in modern Energy Management Systems (EMSs). The successful operation of interconnected power system requires the matching of total generation with total load demand and associated system losses. As the demand deviates from its nominal value with an unpredictable small amount, the operating point of power system changes, and hence, system may experience deviations in nominal system frequency and scheduled power exchanges [1–5]. The main tasks of automatic generation control are to hold system frequency at or very close to a specified nominal value and to maintain the correct value of interchange power between control areas [6].

A literature survey shows that the systems considered for AGC were of single area thermal or hydro and/or two area thermal–thermal or hydro-thermal [4–12]. Moreover, the thermal systems considered generally non-reheat type turbines and therefore, relatively lesser attention has been devoted to the AGC of thermal system with reheat type turbines [4,5,7,13]. Keeping in view the present power scenario, combination of multi-source generators in a control area with their corresponding participation factors is more realistic for the study of LFC. The control area may have the combination of thermal, hydro, gas, nuclear, renewable energy sources, etc. [14].

Most recently many researchers [15–18] have studied the LFC problem of hydro, thermal systems using PID controller, fuzzy controller, decentralized controller and optimal MISO PID controller based on different algorithms and optimization techniques. Alireza et al. [18] studied the LFC of the hydro power system (operational in Iran) using optimal MISO PID controller. Decentralized load frequency controller is presented for the LFC of an interconnected thermal power system [16] which uses large number of states for the controller feedback. Challa et al. [19] has presented the analysis and design of controller for two area hydro-thermal-gas AGC system. They have shown that for LFC study, optimal PI state feedback controller is more robust and performs better than conventional genetic algorithm based PI controller. However, this optimal PI state feedback controller uses all the states for feedback purpose which is practically difficult and results in the increased complexity and cost of the controller. All these controllers discussed have their own advantages and disadvantages.

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[*] Corresponding author.
E-mail address: kpsingh_jss@rediffmail.com (K.P.S. Parmar).
[1] Formerly with IIT, Delhi, India

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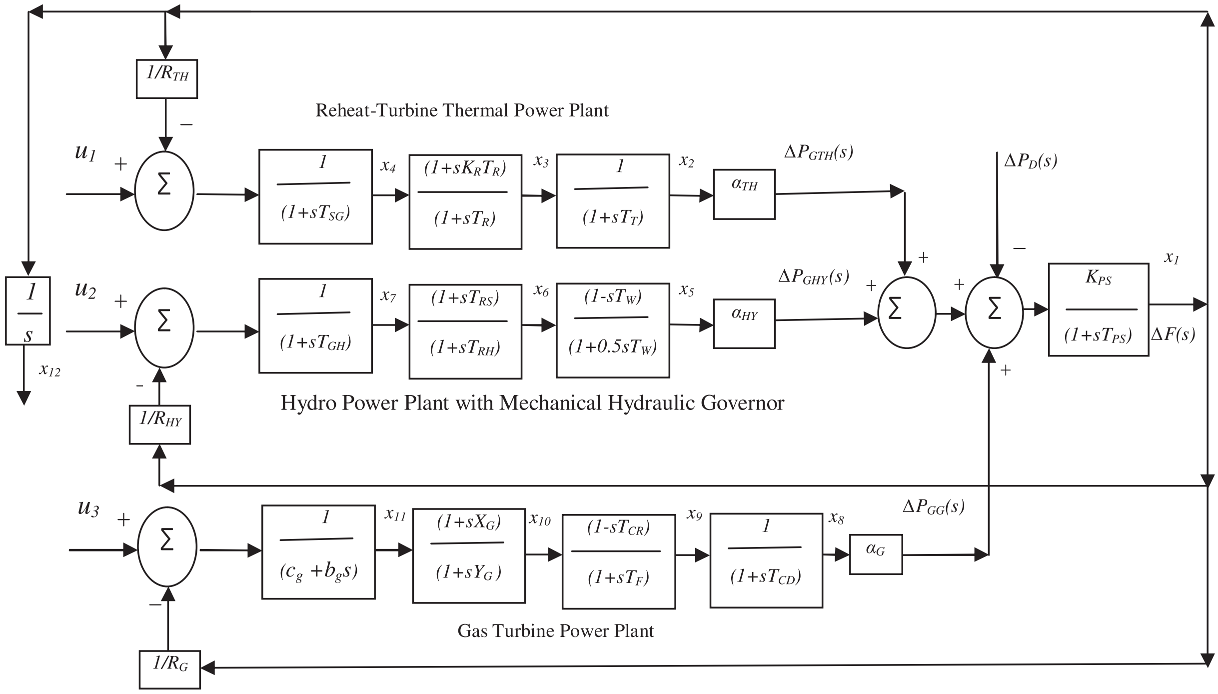

Fig. 1. Block diagram of the single area power system comprising reheat-thermal, hydro and gas generating units.

In this paper, a single area system comprising hydro, thermal with reheat turbine and gas units [14,19] as shown in Fig. 1 is presented for designing controller for the system with corresponding nomenclature given in Appendix A. The linearized models of governors, reheat turbines, Hydro turbines, Gas turbines are used for simulation and LFC study of the power system [5–7,20–23].The effect of generation rate constraints of Hydro and Thermal units on area frequency deviation response is also presented in this paper [1,7]. Using the modern optimal control theory, control engineers can handle a large multivariate control problem with ease. Application of the optimal control theory to power system has shown that an optimal load frequency controller can improve the dynamic stability of a power system [1,13,24]. In this paper, the dynamical response of the LFC problem is improved with a practical point of view. Practically, access to all of the state variables of a system is limited and measurement of all of them is not feasible and also costly. An output feedback controller design is presented in this paper to overcome this problem [1,13,24]. Literature survey shows that most of the researchers applied optimal control theory on non-reheat thermal-thermal power systems only [1,4,8–11,13]. To the best of authors' knowledge, no work has been reported in the literature of AGC for design of the optimal output feedback controller for such a realistic single area power system having generation from a combination of Hydro, thermal and gas units. In view of the above, the following are the main objectives of the present work.

i. To consider a practical combination of generating units in present power scenario for AGC study, i.e. Thermal reheat type, hydro and gas in a single area power system.
ii. To propose optimal output feedback controller for AGC of the proposed realistic power system.
iii. To optimize the optimal output feedback controller gain and full state feedback controller gain and hence study the dynamic performance for the proposed power system.
iv. To compare the dynamic performance of optimal output feedback controller with full state feedback controller for AGC of the proposed power system.
v. To simulate the proposed power system with and without GRC and hence to examine the effect of GRC on the system response.
vi. To examine the effect of speed regulation parameter (R) on the dynamic response of the system and hence selection of best value of R for the proposed power system.
vii. To carry out the sensitivity analysis for ±25% variation in system parameters and operating load condition
viii. To study the LFC system of the hydro power plants operational in KHOZESTAN, Iran using proposed controller.

2. Controller design

In modern control theory approach, inputs u_1, u_2, and u_3 are generated by a linear combination of all the system states (full state feedback approach) or a linear combination of states to be controlled/measurable states (output feedback approach) [1,13,24,25]. The generalized linear model of the power system may be described in state space form as [1,24]

$$\dot{x} = Ax + Bu \tag{1}$$

with the initial condition $x(0) = x_0$ and

$$y = Cx \tag{2}$$

where x is a state vector of the dimension $n \times 1$, n is no. of state variables, u is a control vector of the dimension $m \times 1$, m is no. of control variables, y is a output vector of the dimension $p \times 1$, p is no. of output variables, and A, B and C are constant matrices with dimensions of $n \times n$, $n \times m$ and $p \times n$, respectively. The performance of the system is specified in terms of a performance index or cost function (J),

$$J = \frac{1}{2}\int_0^\infty (x^T Q x + u^T R u)dt \tag{3}$$

which is minimized for obtaining parameters of an optimal controller. In the Eq. (3), Q is $n \times n$, symmetric positive semi-definite state cost weighting matrix and R is $m \times m$, symmetric positive semi-definite control cost weighting matrix.