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Design of a robust load frequency control using sequential quadratic programming technique

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ABSTRACT

This paper presents a new methodology, named Sequential Quadratic Programming (SQP), to design a robust PID controller for Load Frequency Control (LFC) of nonlinear interconnected power systems. This method easily copes with the nonlinear constraints such as Generation Rate Constraint (GRC) and it can be directly used on a nonlinear model of a multi-machine power system. The proposed controller is simple, effective and can ensure that the overall system performance is desirable. The robust performance of the proposed controller is compared with that of a conventional PI controller, and also with two other different techniques named PID-MPRS and PID-PSO through the simulation of two multi-machine power system examples with a variety of disturbances. Results show that the proposed technique gives a better performance.

1. Introduction

Owing to the importance of the distribution of the electrical power, the organizations responsible for providing it have to satisfy various requirements regarding reliability, availability and efficiency. A power system normally consists of a number of interconnected subsystems. For each subsystem the requirements usually include matching system generation to system load and the associated system losses and then regulating system frequency and tie-line power exchanges. This is usually known as load frequency control, also called Automatic Generation Control (AGC) problem and is very important in the operation of power systems [1,2].

The most widely used controller in load frequency control is a fixed gain proportional integrator (PI) controller because of its simplicity and the ease of the implementation. Since a normally operated power system is only exposed to a small change in the vicinity of the load demand, a linearized model is usually enough to express the dynamic behavior of the system around the operating point. Therefore, the gain of the integral controller is mainly tuned based on a linear model of the system [3].

However, one of the most important constraints in LFC of the power system is the generation rate constraint, i.e. the practical limit on the rate of change in the generating power. The results in Refs. [4,5] indicated that GRC would influence the dynamic responses of the system significantly and leads to a larger overshoot and a longer settling time. As a result, it is necessary to consider the limits for avoiding large oscillations and this means that the system model will be nonlinear. Therefore, this nonlinearity must be taken into theoretical consideration in the LFC design procedure.

Usually, because of the inherent characteristics of changing loads, the operating point of a power system changes very much during a daily cycle. Hence, a fixed controller which is optimal under one operating condition may not be suitable in another status unless some precautions are considered. Consequently, robustness becomes a main issue in the attempt to design a controller to satisfy the basic requirements for zero steady state and acceptable transient frequency deviations. Many advanced control methods have been applied to LFC problem, such as H-infinity control [6,7], optimal control [8], variable structure control [9], adaptive and self-tuning control [10], and intelligent control [11–15].

Recently it has been shown that although optimized integrator has been designed for LFC problem, the system with this controller may have weak transient characteristics [3]. Therefore, some researchers proposed proportional-integrator-deviation (PID) controller to be used instead [16–20]. Two-degree-of-freedom Internal Model Control (IMC) method has been used in [16,17] for load frequency control tuning of a single-machine-infinite-bus (SMIB) system by considering GRC and hydro turbine systems. In [18] a PID controller tuning method called MPRS has been proposed for a SMIB system and this method has been extended for a two-area system in [19]. The performance of MPRS method has been also tested on a two-machine system with hydro turbines [20].

In [21] a Type-2 (T2) fuzzy approach is proposed for load frequency control of a two-area interconnected reheat thermal power system with the consideration of GRC. The simulation results indicated that the proposed Type-2 fuzzy controller can guarantee the

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stability of the overall system for large parametric uncertainty and a good performance is achieved even in the presence of GRC.

Motivated by the above observations, this paper aims at resolving the LFC problem for power systems subject to the nonlinearities; the governor limits and the GRC by proposing a new robust PID controller. This technique is based on Sequential Quadratic Programming (SQP) method [22–24] in which the nonlinearity can be easily handled. It directly utilizes the response of the system to tune the controller parameters.

The LFC design and simulations are carried out on both linear and nonlinear power system models with and without considering GRC. The comparative results with the conventional PI controller and also the PID controller given in [18] show the efficiency of this method in load frequency control tuning. The results obtained from SQP on a nonlinear model of the power system are also compared with the particle swarm optimization (PSO) algorithm. The latter has been shown in [25] to be a powerful methodology to design any controller for a real nonlinear power system. It is concluded that the proposed method demonstrates a more desirable response, especially when the parameters of the system change.

2. Power system modeling

A large power system consists of a number of interconnected control areas, which are connected by tie-lines. For the design of the LFC suggested in this paper, first a linearized model is used in which all required limiters for governors and then GRC are being considered for practical restrictions in power systems [5]. The computer simulations will be, however, carried out using the actual nonlinear system.

A two-area power system shown in Fig. 1 is taken as a test system in this study. In each area, all generators are assumed to be coherent. Each area includes steam turbine containing governor.

The objective of the LFC is to satisfy the following conventional requirements [3]:

- Each area regulates its own load variations.
- Desirable transient behavior should be reached.
- In steady state, system frequency in all areas and net tie-line power interchanges are returned to their nominal and scheduled values respectively.

To satisfy the above requirements, LFC determines the input control signals (u_1, u_2) to be designed for each participating generation unit. The input of PID controller is Area Control Error (ACE). ACE is defined for each area as a linear combination of the total exchanged power and the frequency deviations from the respective scheduled and nominal values and is given in the following equation [1]:

$$\text{ACE} = \Delta P_{Tie} + \beta \cdot \Delta f \qquad (1)$$

where β is called area bias coefficient and obtained from $\beta = 1/R + D$ [2] in which R is the droop characteristics of governor and D is damping coefficient of each machine.

The PID controller output (u) will be obtained as follows:

$$u = \left(K_P + \frac{K_I}{s} + K_d \cdot s\right) \cdot \text{ACE} \qquad (2)$$

where K_P, K_I, K_d and are PID controllers parameters. It should be noted that with respect to industrial considerations, in order to remove high frequency noise effects when a PD controller is used, it is imperative that $K_d s/(1 + T_d s)$ (in which $T_d \ll K_d$) be used rather than $K_d s$.

3. Tuning methodology

This paper proposes a method that directly utilizes the time-domain responses of the system to tune the controller parameters. Therefore, the method could be more effective than the optimization techniques based on linear system theories.

The aim in load frequency problem is to tune PID controller parameters so that frequency and tie line power remain in their nominal values after any load disturbance occurs, or in other words, area control error must remain at zero value. The ACE signal after disturbance at zero value can be shown as a straight line in Fig. 2. Following any disturbance the ACE signal begins to oscillate

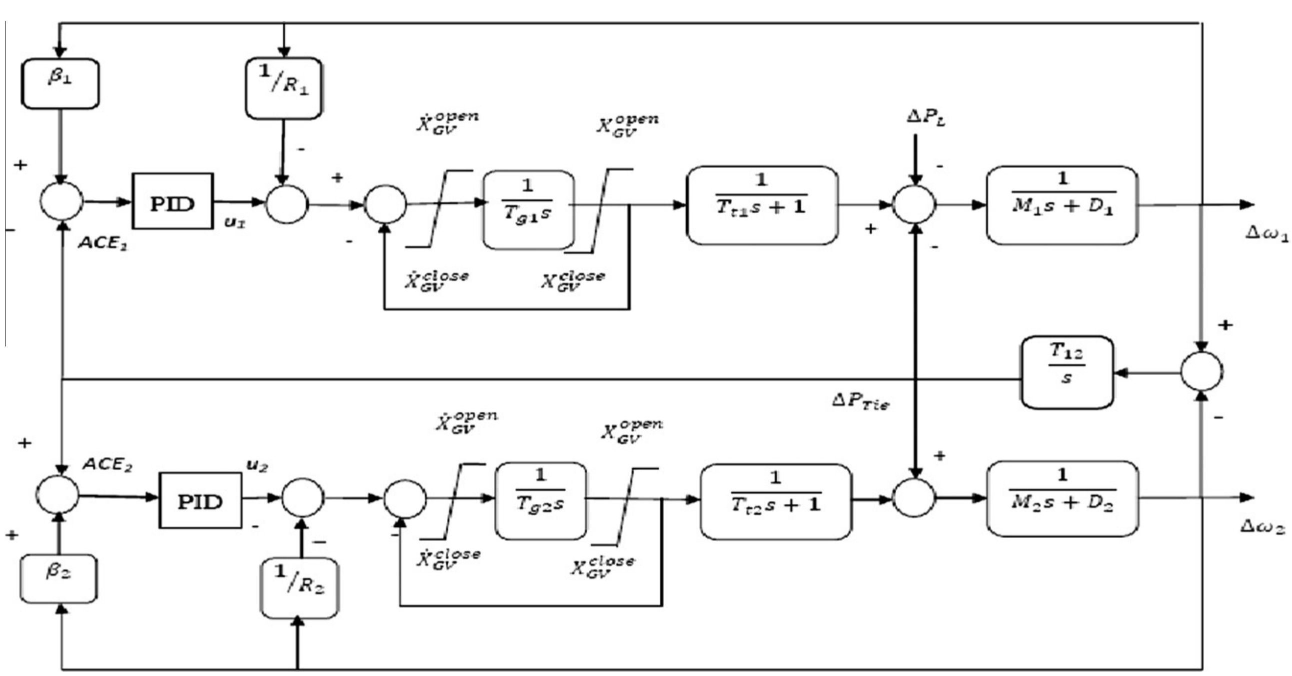

Fig. 1. Two-area power system block diagram.