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A new PID controller design for automatic generation control of hydro power systems

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ABSTRACT

This paper presents a new robust PID controller for automatic generation control (AGC) of hydro turbine power systems. The method is mainly based on a maximum peak resonance specification that is graphically supported by the Nichols chart. The open-loop frequency response curve is tangent to a specified ellipse and this makes the method to be efficient for controlling the overshoot, the stability and the dynamics of the system. Comparative results of this new load frequency controller with a conventional PI one and also with another PID controller design tested on a multimachine power system show the improvement in system damping remarkably. The region of acceptable performance of the new PID controller covers a wide range of operating and system conditions.

1. Introduction

In the interconnected power systems there are a number of control areas or regions and each control area is obliged to generate power to cover the customers load requirements as well as maintaining the systems frequency and the interchanged power at the scheduled values. Therefore, automatic generation control (AGC) or in other words, load frequency controller (LFC) [1,2], is designed and implemented to automatically balance generated power and load demand in each control area so that the quality of the power delivered is maintained at the requisite level.

For LFC design the proportional-integral (PI) decentralized controller is widely used in power industry. This gives adequate system response considering the stability requirements and the performance of its regulating units. Conventional PI controllers of fixed structure and constant parameters are usually tuned for one operating condition. Since the characteristics of the power system elements are non-linear, these controllers may not be capable of providing the desired performance for other operating conditions [3,4]. Therefore, the response of this controller is not satisfactory enough and large oscillations may occur in the system [5,6]. Moreover, the dynamic performance of the system is highly dependent on the selection of the PI controller gain. A high gain may deteriorate the system performance having large oscillations and in most cases it causes instability [1–4]. Subsequently, a number of decentralized load frequency controllers were developed to eliminate the above drawback [7,8]. However, most of them are complex state-feedback or high-order dynamic controllers, which are not practical for industry practices.

To cope with the variation of the plant parameters the adaptive techniques have been applied [9,10] but they require information on the system states or an efficient on-line identifier. The model reference approach may be also difficult to apply since the order of the power system is large.

More recently artificial neural networks (ANN) and fuzzy set theoretic approaches have been proposed for load frequency control [11,12]. Both techniques have their own advantages and disadvantages. Training of an ANN is a major exercise, because it depends on various factors [12] such as the availability of sufficient and accurate training data, suitable training algorithm, number of neurons in the ANN, number of ANN layers. In order to also have a robust controller it is usually required to use adaptive techniques with ANN and fuzzy techniques.

It is well known that the speed governor of the hydro turbine needs to be equipped by a transient droop compensator. This ensures that the system will be stable when the load changes [1]. However, this makes the system response to be comparatively sluggish [1].

In control theory Poulin [13] introduces a new method to obtain the parameters of the PI (or PID) controllers based on an optimization technique using the constant-M circles in Nichols chart. The main idea is to keep the maximum overshoot of the system response in a predetermined value following a step change in the reference input. The predetermined bandwidth and phase margin guarantee the stability of the system.

This technique has been modified and applied for the first time in power systems by Khodabakhshian [14] to design a new PID

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load frequency controller for a single-machine infinite-bus hydro system. This paper extends and applies this technique to design a robust PID controller for a decentralized LFC in a multimachine system. Comparative results will be given for the conventional PI controller with the proposed one for a multimachine hydro power system example. The controller given in this paper is also compared with another PID controller designed by using QFT method [15]. The performance is shown to be comparably desirable and robust, especially when there are large changes in the parameters of the system. More importantly, since for the speed governor a compensator is not used, a much faster response is achieved.

2. System model

Most hydro turbo-generators (and also steam turbines) now in service are equipped with turbine speed governors. The function of the speed governor is to monitor continuously the turbine-generator speed and to control the gate position in hydro turbines (or control the throttle valves which adjust steam flow into the steam turbines) in response to changes in "system speed" or frequency.

Since all the movements are small the frequency–power relation for turbine-governor control can be studied by a linearized block diagram [1]. However, the computer simulation will be carried out using the actual non-linear system. The linear model is shown in Fig. 1 for a single-machine infinite-bus (SMIB) [1,2] where the blocks are

$$\text{Hydro turbine} = \frac{1 - T_W s}{1 + 0.5 T_w s}$$

$$\text{Load and machine} = \frac{1}{2Hs + D}$$

$$\text{Droop characteristics} = 1/R_P$$

The R_p, T_w, D and H are the regulation constant, water starting time, damping ratio and machine inertia, respectively.

2.1. Transient droop compensator

Hydro turbine transfer function is inherently non-minimum-phase because of water inertia. Therefore, any step change on valve position creates negative reflex on output power of turbine. Using the nominal values for the speed governor, turbine and machine parameters implies that in order to have a stable system the permanent regulation constant of the speed governor should be 20% [1]. However, this coefficient is usually about 5% and this makes the gain margin and phase margin both to be negative and, therefore, the system response following a small change in load will be unstable [1]. A compensator is then suggested to be included in the speed governor as shown in Fig. 2 to solve this problem [1].

The compensator transfer function is:

$$G_C(s) = \frac{1 + sT_R}{1 + (R_T/R_P)T_R s}$$

where T_R and R_T are obtained using the equations given in [1] as follows:

$$\begin{cases} R_t = [2.3 - 0.15(T_w - 1.0)](T_w/T_M) \\ T_R = [5.0 - 0.5(T_w - 1.0)](T_w) \end{cases}$$

in which T_M = 2H.

2.2. Multimachine system

Although the design of any supplementary controller on a one-machine system is logically the best place to begin an evaluation of the controller, a more through investigation has to be done with a multimachine model. For a multimachine case the linearized block diagram which is an extension of Fig. 1 with also considering the effect of tie-line power is shown in Fig. 3 [1].

3. Performance requirements

In load frequency control each control area has a central facility called the energy control center, which monitors the system frequency and the actual power flows on its tie-lines to neighboring areas. The deviation between desired and actual system frequency is then combined with the deviation from the scheduled net interchange to form a composite measure called the area control error, or simply ACE.

In general, for satisfactory operation of power units running in parallel it is most desirable to have the frequency and tie-line power fixed on their nominal and scheduled values even when the load alters and, therefore, to remove area control error (ACE = 0).

In a vertically integrated electric power system made up of interconnected control areas the dynamics of the system is usually non-linear and the parameters change, and, therefore, special cares must be taken into account for designing any fixed parameter controller. In this regard, the following conventional requirements are considered [1,15].

- Each area contributes to the control of system frequency.
- Each area regulates its own load variations.
- Optimal transient behavior should be reached.
- In steady-state, system frequency in all areas and tie-line power interchanges are, respectively, returned to their nominal and scheduled values (ACE = 0).
- The controller should be robust when the system parameters change. Many robust control design methodologies rely on prescribed parameterizations of the system uncertainty set. Due to the complexity of actual uncertainties in power systems such pre-formatted descriptions are often either unavailable or very conservative. As shown by [16] since a power system, especially for circuits and electro-mechanical parts, is frequently passive, closed-loop passivity, rather than the dynamic model, can be the key factor in the robustness of the control design. For a scalar

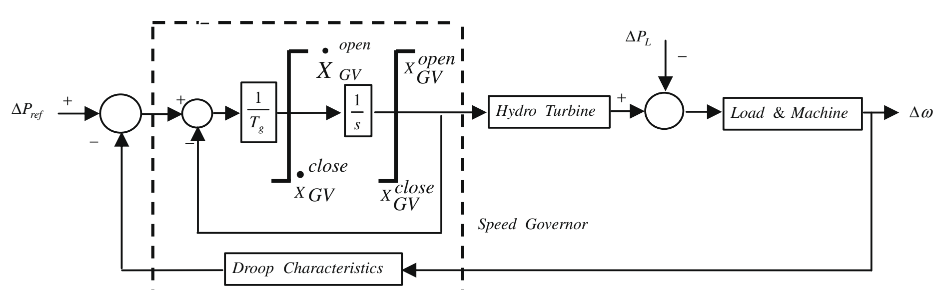

Fig. 1. Block diagrams of turbine, governor, load and machine.