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Robust hierarchized controllers using wide area measurements in power systems

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ABSTRACT

In this paper, we present a new method for robust centralized controller design using LMI's with applications to power systems. This method makes possible to increase the damping rate of the decentralized system (that is, power system with PSS's). It considers delays added to the signals that travel from the generators to the central controller. The robust hierarchized controller is composed by two control layers: the first one consists on decentralized controllers, that are applied independently to each machine of the system, what guarantees the stability and a minimum damping rate; the second one is composed by a centralized controller, that receives delayed information from all machines of the system, and it sends control signals to all generators. The centralized controller algorithm is robust, once it considers various operative conditions for the power system, and it also permits the choice of the communication delays.

Introduction

Centralized control strategies have been explored in some recent works related to power systems engineering. Making use of PMU's (*Phasor Measurement Units*), it is possible to integrate information from various power systems geographically disperse. Therefore, a central controller can be established, whose function is to integrate information coming from different generators. This central controller receives and processes the information and, after that, generates centralized control strategies to reach a goal (for example, increase the system damping). Centralized control systems have already been described, for example, in [1]. In these systems, information transmission delay must be considered during the controllers design, once it can affect the performance of the closed loop system. One work that describes the delay's influence on the performance and stability of power systems in the context of robust controller design is [2]. In [2], Padé approximation is used to represent the delays, and it is concluded that time delays during information transmission can depreciate the performance of a power system equipped with robust centralized controllers. It is also proposed a method for robust centralized controller design using LMI's, considering delays during the information transmission.

Another work that proposes a strategy to design robust centralized controllers considering delays during the data transmission in the system is [3]. The technique uses LMI's to design stabilizing controllers. These controllers are known as TCSC's (*Thyristor Controlled Series Compensators*).

In [4], it is proposed a hierarchized control scheme based on the integration of two control layers: the first one is composed by decentralized controllers that uses only local signals, and the second one is composed by the centralized controller, which integrates remote signals coming from all the generators of the power system. The objective of the controller is to guarantee the robust stability for the power system, increasing the damping of the electromechanical oscillations. The method is applied to the stabilization of a large system.

In [5], another method is proposed for the design of robust centralized controllers (the centralized controller uses local and remote signals); however, in this method the transmission delays are not considered during the controllers design, what is a drawback of the proposed technique. The strategy uses LMI's to define a H_2/H_∞ optimization problem, with pole placement constraints, and the main goal is to increase the damping of the critical modes.

In [6], a method is developed to design a supervisor controller whose aim is to increase the damping of the power system critical modes. This controller has as inputs measurements provided by a PMU's integrated system. The strategy for robust centralized controller design groups H_∞ with pole placement constraints making use of LMI's. The controller is applied to a four-machine system.

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The main drawback of this method is that it yields high-order controllers, being necessary to apply order reduction algorithms at the end of the process.

The main objective of this paper is to develop a novel method that places the poles of the closed loop power system in an adequate region of the complex plane through LMI's, using a hierarchized structure of control. The controllers must increase the dynamical performance of the system (that is, the damping of the electromechanical oscillations). Moreover, the controllers have to be robust, that is, increase the power system performance for a set of operating points. The aim of the centralized controller is to increase even more the performance reached through the decentralized controllers (PSS's). The implementation of the centralized controller depends on efficient data transmission between various generators, integrating information inside the power system. The new method proposed for robust hierarchized controller design, that considers transmission delays in the power system, makes use of two techniques in an integrated way: firstly, a technique for the design of robust PSS's is applied; then, in the second step, another technique is employed in order to design robust centralized controllers considering information transmission delays. Therefore, we have a hierarchized controller, that is composed by two layers: the decentralized control layer, which uses only local information, and the centralized control layer, which uses remote information coming with delays. The inclusion of transmission delays in the centralized controller design is another innovation of this work, being justified by the fact that the telemetry through GPS and PMU's adds different delays to the signals that arrive in various places of the power system.

Methodology

Based on the recent evolution of the data acquisition systems and information transmission related to power systems, the present suggests that in the near future we will make use of hierarchized controllers, which will work with information exchange between generators geographically disperse. Then, there will be a local controller, actuating in each machine of the system, that uses only information from this machine (as it is done in the decentralized controllers), and a central controller, that sends control signals for all machines of the system. This central controller will use feedback signals coming from all the machines of the system to generate control signals, considering that the signal which comes from each machine to the central controller has a transmission delay, τ. Therefore, we will have a hierarchized controller, as it is shown in Fig. 1.

Note that we could consider delays (τ_2) in the communication net between the central control system and the machines of the power system. However, as we have considered that the delays have the same value for all the information transmission between a machine and the central control system, it can be proved that it would be equivalent to add the new delays (τ_2) to the existing delays (τ), by simply increasing the delays τ.

Decentralized controllers

The decentralized control policy consists on applying an output feedback to the input of the power system. Also, each PSS is linked to a machine, having as input the output of this machine (that is, measurements of rotor's angular velocity); the output of the PSS is the control input to be applied to the machine. In Fig. 1, the input of each PSS (the PSS is denoted by K_i) is the rotor's angular velocity; the output of each PSS is a stabilizing voltage signal. This signal is compared to a reference voltage, and the resulting voltage is applied to the input of the generator (through the automatic voltage regulator) [7].

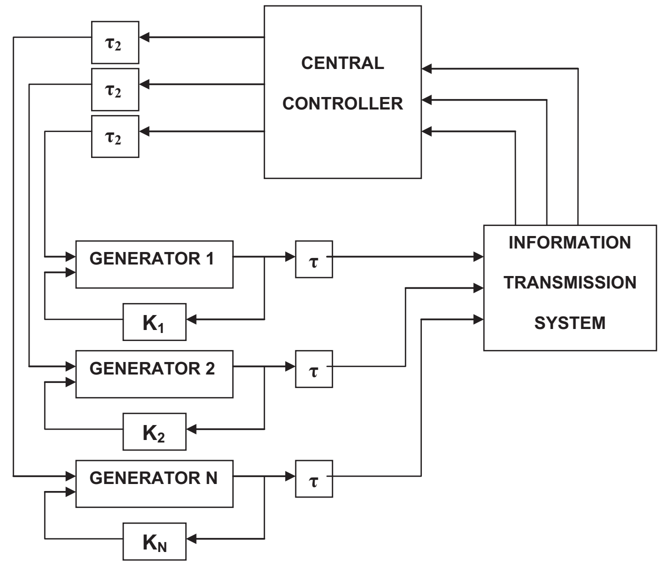

Fig. 1. Scheme of the hierarchized controller applied to the power system.

Each decentralized controller guarantees the stability and the minimum performance for the power system (for example, a damping rate of 0.15). The centralized controller can be used to increase the system performance (for example, increase the damping of the closed loop eigenvalues to 0.2). In case of loss of communication with the transmission system (which is composed by a GPS and an integrated system of PMU's, the minimum damping and system stability are guaranteed by the decentralized controllers (that is, the PSS's).

The decentralized controller design algorithm for pole placement in a conic region of the complex plane is the following [8,9] ($*$ indicates symmetric term in the matrix):

Algorithm 1 (Design of Robust PSS's)

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1. Firstly, consider that we have m dynamic models of the power system, each one representing the system in a specific operating point.
   The power system mathematical model at the i-th operating point is ($i = 1, \ldots, m$):

$$\dot{x} = A_i x + Bu$$
$$y = Cx$$

   $A_i \in R^{p \times p}$, $B \in R^{p \times n}$ and $C \in R^{n \times p}$. The structure of the j-th power system stabilizer is the following:

$$K_j(s) = \frac{a_i s^2 + b_i s + c_i}{s^2 + (p_1 + p_2)s + p_1 p_2}$$

   The dynamic controller structure is the following:

$$\dot{x}_C = A_C x_C + B_C y$$
$$u = C_C x_C + D_C y$$

   $A_C \in R^{2n \times 2n}$, $B_C \in R^{2n \times n}$, $C_C \in R^{n \times 2n}$ and $D_C \in R^{n \times n}$. Once we are working with controllers with the same structure of PSS's, they may have pre-defined poles (p_1 and p_2).

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