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Damping inter-area oscillations using virtual generator based power system stabilizer

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ABSTRACT

In a power system, remote measurements are used by a controller to provide damping torque for inter-area oscillations. In this study, the operating conditions that give rise to inter-area oscillations are investigated using Stochastic Subspace Identification (SSI) based modal analysis. In a power system, generators can be grouped based on coherency and the groups can be represented by Virtual Generators (VGs). Damping inter-area oscillations using Virtual Generator based Power System Stabilizer (VG-PSS) that generates a supplementary control signal to the excitation system of one or more synchronous generators is presented. The generator choice for VG-PSS location is determined based on the generator that has maximum controllability on dominant weakly damped inter-area mode(s) in a power system. Modal analysis using SSI and real-time simulation results on the IEEE 68-bus power system are presented to illustrate the effectiveness of VG-PSSs in damping inter-area oscillations. In addition, the effect of time delays encountered as a result of wide area measurements and communications are considered in the studies presented.

1. Introduction

Nowadays due to increased load and limited transmission capability, power systems are constantly pushed towards their stability margin. As a result, oscillations caused by lack of damping torque can be frequently observed. Under different operating conditions, these oscillations may occur in various modes, generally classified as local, intra-area and inter-area modes. Traditional Power System Stabilizers (PSSs) are installed to damp local and intra-area oscillations. Generally, the PSSs use respective generator speed deviation signals as input signals to generate supplementary control signals that are provided to Automatic Voltage Regulators (AVRs). However, locally measured generator speed signal may not contain sufficient information to uncover the characteristics of inter-area oscillation modes [1]; as a result, local PSSs are not effective to damp inter-area oscillations. Fortunately, with the deployment of Phasor Measurement Units (PMUs) in the power system, speed signals from remote generators can be made available as additional input signals for the design of advanced damping controllers.

In literature, there exist a lot of papers on supplementary damping control; and a few relevant ones are discussed below [2–11]. An early approach is based on the analysis of power system oscillation modes using Prony Analysis (PA); local PSSs are designed as filters to get rid of specific modes [2]. A real-time implementation of a heuristic approach for online PSS tuning is presented in [3]. A coordinated design of local PSSs and AVRs is presented in [4]. Based on [4], a coordinated PSS design is presented to realize a near-optimal performance for enhanced power system stability in [5]. In [6], low-order power system transfer functions are identified from mathematical models to facilitate robust and practical PSS design. All these designs use local measurements and as a result suffer from insufficient feedback to damp inter-area oscillations.

As for damping controller design using remote measurements, an overview of a Wide Area Control (WAC) system structure is suggested in [7]; the importance of WAC using PMU data to maintain power system stability is elaborated. Though a fuzzy controller making use of PMU measurements of voltages and reactive powers is able to maintain voltage stability, the control approach by capacitor/reactor bank switching may not be swift and accurate enough to damp inter-area oscillations. A two-area system based real-time implementation of a wide-area controller by AVR supplementary control considering communication delays is presented in [8]. The design approach in [8] is completely data-driven, with the control law implemented by a neural network providing supplementary control signals to all generators. For large power systems, it may not be practical to provide supplementary control to all generators.

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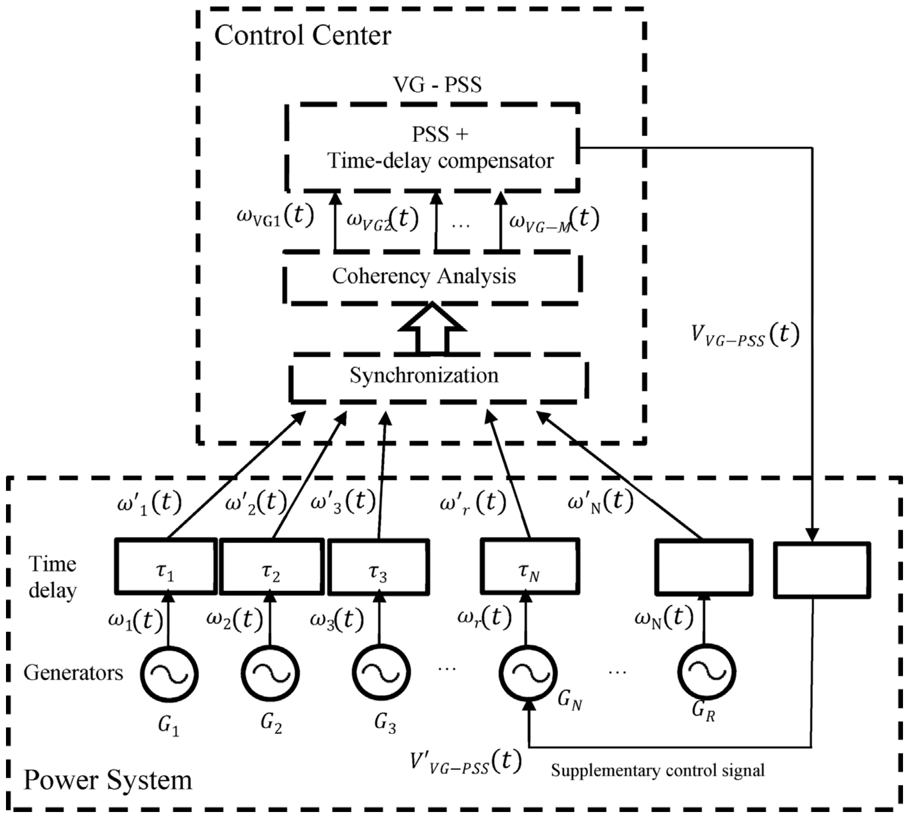

Fig. 1. The diagram of the proposed control scheme with VG-PSS ($\omega'_i(t) = \omega_i(t + \tau_i)$).

In [9], WAC is applied to a large power system based on a linearized mathematical model; effective measurement and control signals to damp inter-area oscillations are selected using geometric approach. However, the damping control signal is based on a single remote measurement; and an accurate model of a large power system is difficult to obtain. An innovative damping control method is implemented without designing any wide area controllers in [10]. The local PSSs' outputs are combined a matrix gain to generate modulated PSS signals to the AVRs in a 12 bus power system with three generators. The optimal matrix for modulating the initial PSS signals was obtained using the particle swarm optimization algorithm. However, this approach is not directly applicable for larger power systems due to increased matrix size; besides, since the local controllers have been designed only to address the local and intra-area oscillations, they may not work effectively at the frequency range of inter-area oscillations. A typical H_∞ wide-area PSS design is proposed in [11]. Despite of the robustness of designed controller to uncertain system parameters, the design with pole-placement constraints may not have a solution; also, since general H_∞ design achieves a controller with the same order with system states; it has to be further reduced to form a PSS at the risk of reduced efficacy. In [12], the concept of Virtual Generator (VG) (elaborated in the following sections) is applied in design of a single-input multiple-output controller using adaptive critic designs; it is indicated that a VG is a mathematical equivalent of a group of generators that tend to oscillate coherently in response to disturbances. However, the damping controller uses only one VG speed; this may not provide sufficient information to damp inter-area oscillations over a wide range of operating conditions.

In this study, power system conditions that give rise to inter-area oscillations using Stochastic Subspace Identification (SSI) based modal analysis are studied; and a new approach to implement supplementary PSS based on VGs (VG-PSS) to damp inter-area oscillations is presented, as shown in Fig. 1. Speed deviations from all the large generation units are remotely measured and sent to a control center, which implements coherency analysis and uses the proposed VG-PSS to generate a supplementary control signal. The generator choice for the supplementary control location is determined based on the generator that has maximum controllability on dominant weakly damped inter-area mode(s) in a power system. The overall flowchart of the suggested design approach is shown in Fig. 2, which is further elaborated in theoretical details in Section 2. The rest of paper is organized as follows: In Section 2, the theory of the proposed method to carry out SSI based modal analysis, the emergence of inter-area oscillations mode(s) in a power system, identification of possible generator excitation system(s) to damp the mode(s), and the development of VG-PSS are described. In Section 3, typical real-time implementation results on the Real-Time Digital Simulator (RTDS) platform for an IEEE 68-bus power system are reported and finally, the conclusion is given in Section 4.

2. Development of VG-PSS

In this section, a VG-PSS that is heuristically tuned according to modal analysis results, is proposed for supplementary damping control. The modal analysis presented is based on a data-driven system identification approach. In addition, the determination of virtual generator(s) based on coherency analysis is presented and the tuning of VG-PSS is elaborated in the following sub-sections.

2.1. Stochastic subspace identification (SSI) based modal analysis

Besides facilitating controller design, modal analysis also provides a way to exam the efficacy of a controller. Prior to performing modal analysis, it is necessary to obtain a model for the power system without detailed mathematical model of every component that captures the full dynamics. Despite the nonlinearity of power systems, representation of power systems through linear state