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Utilizing synchrophasor-based supplementary damping control signals in conventional generator excitation systems

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ABSTRACT

A supplementary function of Excitation Control Systems (ECSs) for synchronous generators is that of a Power System Stabilizer (PSS). The PSS implementation in these ECSs only allows the use of a limited type of pre-defined local input measurements and built-in PSS algorithms. To adapt existing ECSs to take advantage of synchrophasors technology, this paper proposes and implements a prototype wide-area damping controller (WADC) that provides synchrophasor-based damping input signals to existing ECSs. The developed WADC comprise (i) a real-time mode estimation module, (ii) synchrophasor's communication latency computation module, and (iii) phasor-based oscillation damping algorithm executing in a real-time hardware prototype controller.

Through Real-Time Hardware-in-the-Loop (RT-HIL) simulations, it is demonstrated that synchrophasor-based damping signals from the WADC can be utilized together with a commercial ECS, thus providing new options for selection of the best feedback signal for oscillation damping.

1. Introduction

In addition to synchronous generator's terminal voltage regulation, a commercial Excitation Control System (ECS) [1] may also provide Power System Stabilizer (PSS) functions to damp power system oscillations [2]. Small disturbances may result in undamped oscillations in a heavily loaded interconnected power system [3]. Undamped oscillations, if not mitigated, result in loss of synchronism of one or a group of machines from the rest of the power system and may lead to a system collapse [4].

Different vendors have deployed diverse PSS types in their ECS units, which can be configured to provide damping for power system oscillations. These built-in PSSs utilize single or multiple *local* input measurements (e.g. rotor speed, rotor angle deviation and generator's accelerating power) to damp oscillations. These input measurements are pre-configured and cannot be modified by the user. The user must tune the available pre-defined parameters to provide oscillation damping. These configurations have to be deployed locally at the power plant and cannot be modified remotely by the system operators.

With the deployment of Phasor Measurement Units (PMUs) in the power grid, there is a possibility of utilizing wide-area measurements for enhancing real-time detection and control of small-signal instability [5,6].

1.1. Paper motivation

With the currently available commercial ECS, power system operators cannot exploit wide-area measurements from PMUs as an input damping signal to generator AVRs. This is primarily because the ECS's are not yet capable of exploiting synchrophasor technology.

However, there is a possibility to disable the ECS's PSS function and instead supply it with PMU-based external damping signals configured as an analog input to the commercial ECS at the internal AVR's summing junction.

1.2. Literature review

Power system researchers, over the years, have demonstrated through power system simulation studies, the effectiveness of PMU-based wide-area measurements for power oscillation damping (POD) [6–14]. These wide-area measurements may provide better observability of inter-area modes which might not be available in local signals utilized by conventional damping controllers.

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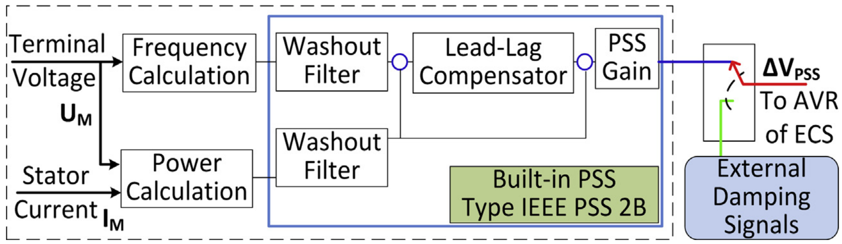

Fig. 1. Model of the PSS incorporated in Unitrol 1020 ECS.

Even though the prospects of wide-area damping control implementations are quite promising, to the knowledge of the authors, there are relatively very few of such deployments in the field. One pilot test was carried out in the Norwegian power system utilizing voltage phase angle measurements from PMUs as reported in Ref. [15]. This WADC provides damping signals to the voltage regulator of a Static Var Compensator (SVC). Although the field trials were successful, they were insufficient to conclude whether the WADC performs more satisfactorily than the local measurement-based damping controller. The design and testing of a WADC in China Southern Power Grid (CSG) is reported in Ref. [16]. This WADC utilizes PMU measurements as its input and modulates two HVDC systems for power system damping. Even though the closed-loop field testing of CSG's WADC was successful, it remains in open-loop trial operation mode to further study its impact on system's dynamics. A WADC hardware prototype controller is currently undergoing open-loop testing at the Bonneville Power Administration (BPA) synchrophasor laboratory as reported in Ref. [17]. This WADC utilizes PMU measurements to calculate frequency difference between two areas, which is used to compute a directional power command used to modulate the controllers for oscillation damping.

The above mentioned WADC systems have been implemented as supplementary controls for Flexible AC Transmission Systems (FACTS) or HVDC systems to damp oscillations. Although these deployments are valuable advances for oscillation damping, their realization requires either a new installation of FACTS/HVDC system or to modify the existing control loops in order to support both local (conventional) signals and PMU-based signals. Note that the number of FACTS and HVDCs in today's power system is relatively small and installing such a system for the sole purpose of oscillation damping is not economically sound [18]. Furthermore, utilizing wide-area measurement based control loops on FACTS/HVDC systems together with the existing PSSs of a commercial ECS may result in interference between the controllers, which is not desirable [19,20].

As many of the ECSs of large generators are equipped with built-in PSSs, it is attractive to explore the possibility of providing wide-area based external damping signals to these ECS while minimizing changes to the existing installations and the ECS itself.

1.3. Paper contributions

The goal of this paper is to demonstrate the utilization and effectiveness of supplying synchrophasor-based external damping signals to a commercial ECS for oscillation damping. The presented approach utilizes wide-area measurements from PMUs to generate damping signals, which are fed to the commercial ECS as an analog input. The novelty of the approach is that it utilizes the existing ECS installation without making any substantial changes to it and/or its associated electrical installation. In addition, this approach allows the user to select the input signals utilized to generate the damping signal, and allows remote tuning of the controller parameters before supplying them to the ECS. Therefore, the proposed approach can be used to generate damping signals adaptive to the changes in operating conditions or network topology, which can be configured remotely (e.g. by TSOs).

1.4. Paper organization

The paper is organized as follows: Section 2 provides information about ABB's Unitrol 1020 ECS and its PSS functionality. Section 3 presents the proposed synchrophasor-based WADC prototype to provide external damping signals to the ECS. The hardware interface and the RT-HIL experimental setup used for experimental testing are shown in Section 4. Performance assessment of the ECS when coupled to the WADC is compared against its internal PSS in Section 5, while the results are discussed in Section 6. In Section 7, conclusions are drawn.

2. Unitrol 1020 ECS overview

2.1. Unitrol 1020 Excitation Control System

Unitrol 1020 is an automatic voltage regulator (AVR) that provides excitation control of indirectly excited synchronous machines and rotors [21]. The primary purpose of the device is to maintain the generator's terminal voltage while taking into account all the operational limits of the generator.

2.2. PSS feature of Unitrol 1020 excitation system

The PSS feature available in Unitrol 1020 ECS is described by the IEEE Std. 421.5-2005 PSS 2A/2B model [22] and its representation is shown in Fig. 1. The PSS2B type has a dual structure that uses two *local* signals (rotor speed "ω" and power "P").

This built-in PSS is usually tuned once (during commissioning) for a specific electromechanical oscillatory mode, through design methods [23] that rely on linear power system models (i.e. for a limited range of system's operating conditions). Once tuned, the PSS settings can only be modified locally at the power generation station, where the ECS is located. This limits the ability of TSOs to calibrate PSS settings to adapt to changes in system.

3. PMU-based WADC

3.1. Oscillation damping algorithm/function

The damping algorithm used in the proposed WADC was first proposed in Ref. [24] and is shown in Fig. 2. For illustrative purposes, consider a measurement signal that contains both a change in the average and the onset of an oscillation. This signal can be described as:

$$u(t) = u_{pref} + \Delta u_{av} e^{-\frac{t-t_{event}}{T_{av}}} + \Delta u_{osc} e^{-\frac{t-t_{event}}{T_{osc}}} \cos\left(\Omega t + \varphi_{osc}\right) \quad (1)$$

$$u(t) = U_{av} + \left\{ \vec{U}_{osc} e^{j\Omega t} \right\} \quad (2)$$