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A WACS exploiting generator Excitation Boosters for power system transient stability enhancement

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ABSTRACT

Excitation Boosters (EB) are designed to improve transient stability of synchronous generators equipped with bus fed static excitation systems. They can be controlled using either local or remote signals following a disturbance. This paper explores how critical clearing times (CCT) can be improved by EBs controlled using remote signals. Particularly, Pseudo Center of Inertia (PCOI) and Dominant Interarea Path (DIP) signals derived from Phasor Measurement Units (PMU) within a Wide Area Control System (WACS) are used. Prototype controllers are tested by means of a Real Time (RT) Hardware-in-the-Loop (HIL) experimental setup.

1. Introduction

1.1. Previous work

The Excitation Booster [1] is an ultracapacitor-based device that helps improving the transient stability performance of synchronous generators equipped with bus fed static excitation system. This technology was patented by Alstom Power (currently GE Power) to remedy the limitations of this kind of excitation systems to comply with grid codes Fault Ride Through (FRT) capability requirements. Both, "on–off" control using local measurements and a modulated control exploiting remote signals from a Wide Area Control System (WACS), were explored through simulations in [2].

1.2. Motivation

WACS performance depends on the characteristics of different components comprising it: Phasor Measurement Units (PMU), Phasor Data Concentrator (PDC), communication network and the control systems driving a power component. This kind of systems can be analyzed in better using Real-Time Hardware-in-the-Loop (RT-HIL) simulation can be used to simulate the power system and the Excitation Booster (EB), while closing the loop with actual WACS hardware. In practice, very few WACS have been developed, implemented and tested; with notable exceptions for damping enhancement and voltage control [3–9]. While, no actual prototypes of RT WACS to improve transient stability has been reported in the literature (to the knowledge of the authors), the well-known implementation of Ref. [9] can be considered a precursor of WACS for transient stability enhancement. However, it did not use Phasor Measurement Units (PMU) at the time, and it's coordination with a tripping scheme makes it more similar to a Special Protection Integrity Scheme (SIPS), whereas the authors' approach conforms to the concept of closed-loop control systems.

Previous references suggest using Flexible Alternative Current Transmission Systems (FACTS) devices such as Static Var Compensators (SVC) [3,4,6,8], Static Synchronous Compensators (STATCOM) [6], Synchronous Condensers (SC) [6,8] or HVDC [5,7] as the actuators of their damping or voltage controllers. However, the WACS EB controller presented herein takes advantage of the capability of the synchronous generators' excitation systems as actuators of the controller. The only tested precursor on using the excitation system is Ref. [9] with the difference that it merely raises the voltage reference after a fault detection. By contrast, the WACS EB controller under discussion uses modulation of an ultracapacitor that can be installed in pre-existent facilities as an upgrade. The WACS EB controller uses remote signals based on voltage phase dif-

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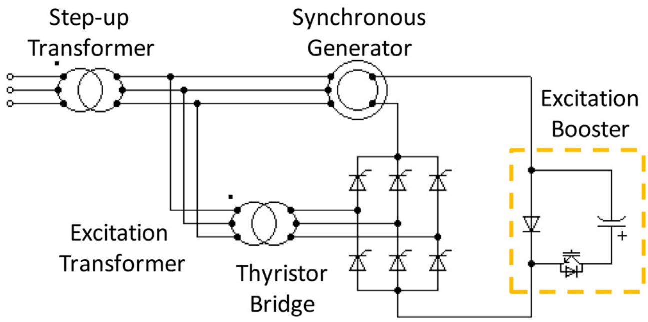

Fig. 1. Bus fed static excitation system with EB.

ferences as Refs. [3,4], and also uses voltage phase signals related to the Center of Inertia (COI).

1.3. Paper contributions, scope and limitations

Although some simulation studies have explored the use of WACS for transient stability enhancements, e.g. Ref. [10], to the authors' knowledge, none of such applications have been implemented nor tested. The contributions of this paper are:

- Use of Pseudo Center of Inertia (PCOI) and Dominant Interarea Path (DIP) based signals to modulate EB voltage to improve transient stability.
- The implementation of the proposed WACS control system in a hardware platform.
- Concept validation trough a Real Time (RT) Hardware-in-the-Loop (HIL) experimental setup including industrial PMUs and PDCs, communicated through standard protocols.

The scope of the paper covers first swing transient stability in a weak power system and how to improve it through EBs distributed across the network and controlled by a WACS.

1.4. Paper organization

The remainder of this paper is organized as follows. Section 2 provides background on the EB device. Section 3 explains the WACS design for EB control. Section 4 deals with the experimental implementation of such a device and describes the architecture of the setup, the constraints that have been found, and means to overcome them. Section 5 presents an analysis from experiments using the HIL prototype, and finally, Section 6 draws the conclusions.

2. Background: Excitation Booster (EB)

2.1. The EB and its operation

Bus fed static excitation systems are among the fastest, cheapest and most reliable ones. However, during faults in the grid; (a) their ability to provide the generator with maximum field voltage is compromised, as their output depends on the generator terminal voltage; and (b) their field voltage must be increased.

The Excitation Booster (EB) [1] is an upgrade to bus-fed static excitation systems to improve their FRT capability as required by grid codes. Fig. 1 depicts a power plant excited by a bus fed static excitation system and equipped with an EB.

The EB is comprised of a fast switch (usually an IGBT), a diode and an ultracapacitor. If a fault is detected in the grid, the IGBT switches on and connects the ultracapacitor to the diode. As they are connected in such a way that the diode's anode to cathode voltage becomes negative, the diode switches off and the field current flows through the ultracap. This reduces the acceleration of the generator and increases its critical clearing time (CCT).

Therefore, the field voltage is reinforced by the addition of the ultracap voltage to the output of the static exciter. The EB can be controlled through either an on–off or a modulated control scheme [2]. On one hand, under the on–off control scheme, the IGBT connects the ultracap during a finite timespan, so the whole ultracap voltage is applied. On the other hand, under a modulated control scheme, a variable voltage is applied due to commutation of the IGBT at a certain frequency and duty ratio. This feature opens the opportunity to develop more sophisticated controls.

2.2. WACS EB control

Fig. 2 shows the block diagram of the field-voltage controllers in a generator, including the proposed WACS EB control and the EB itself. The EB output is modeled as a supplementary voltage, V_{EB}, that is added to the static exciter output to produce the field voltage E_{FD}. V_{EB} is obtained from the modulation of the ultracap voltage, V_{CAP}. The WACS control that produces the modulation signal is described in Section 3. V_{CAP} is computed using an ideal capacitor model, which is the integration of the ultracap current, I_{CAP}, divided by the capacitance C. The ultracap current is obtained from the product between the field current, I_{FD}, and the modulation signal. A limiter with U_{emax} and U_{emin} has been set in E_{FD} to model the rotor insulation protection. This value is equal to 15 pu in the non-reciprocal per unit system. The ultracap ratings in the non reciprocal per unit system are a capacitance of 1 s and a voltage of 9 pu. The description of the sizing method can be consulted in Ref. [11].

3. WACS design for EB control

3.1. Control proposal & design

The impact of the EB is measured in this paper through two cases: in the first one the network has no EB, whereas in the second one, every generator is equipped with an EB that can be operated under different control schemes.

A basic scheme of the EB control that elaborates the modulation signal is shown in Fig. 2. The controller receives as input voltage phasors from PMUs situated at different bus locations of the grid and the voltage phase angles are extracted. The voltage phases are confined between ±p, so they need to be unwrapped. After that, they are smoothed using a digital Bessel filter. Then the filtered phases are processed by a discrete derivative function, subjected to a dead band to limit the action of the controller for small disturbances, and multiplied by a constant gain. Finally, a saturation block is used to limit the values of the modulation signal between 0 and 1. This modulation signal multiplies the ultracap voltage output. However, when interfacing with an actual (hardware) EB, this signal would be used in the power electronic stage to obtain a modulated voltage output.

The discrete derivative is defined by two parameters, a filtering time constant and a gain. The filtering time constant is equal to the reporting rate, 20 ms, whereas the gain is obtained using a heuristic computation approach. Firstly, the gain range is limited to those values that produce an output between 0.1 and 3 times (some saturation is allowed) the EB voltage after a critical fault. After that, the gain value that maximizes the critical clearing time for that fault is chosen. Finally, the gain value is tested for other relevant faults in the system. If the critical clearing time for those faults exceeds the clearing time of first zone (120 ms) the design of the gain is finished, otherwise the process is repeated.