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A wide area measurement based neurocontrol for generation excitation systems

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ABSTRACT

Power system is a highly interconnected nonlinear system that needs optimal and accurate control for continuous operation. Large power transfer through long transmission line between different electrical areas, stressed system and adverse interaction between local controllers, may give rise to slow frequency inter-area oscillations. The inter-area modes may not be visible from local measurements and hence it is useful to use remote measurement based centralized supplementary control. Wide area control systems (WACSs) using wide-area or global signals can provide remote auxiliary control to local controllers such as automatic voltage regulators, power system stabilizers, etc. to damp out inter-area oscillations. This paper presents a design and real time implementation of a nonlinear neural network based optimal wide area controller using adaptive critic design (ACD). The real time implementation of a power system model is carried out on a real time digital simulator (RTDS). The performance of the WACS as a power system stability agent is studied using a two-area power system under different operating conditions and contingencies. The WACS shows improvement in the damping of inter-area mode with the use of supplementary excitation control. In addition, results show that the designed controller can provide robust performance under small communication delay in remote signal transmission.

1. Introduction

The general configuration of a modern power system is that power sources and loads are widely dispersed. Generators and loads may be hundreds of miles away. The number of bulk power exchanges over long distances has increased as a consequence of deregulation of the electric power industry. Usually, distributed control agents are employed to provide reactive control at several places on the power network through power system stabilizers (PSSs), automatic voltage regulators (AVRs), FACTS (Flexible AC Transmission Systems) devices (special power electronic switch based controlled devices which can regulate power flow in transmission line or voltages at the buses), etc. The PSSs are designed to have fixed parameters derived from a linearized model around a certain operating point. Final settings are made using field tests at a couple of operating points. The inherent nonlinearity in the system becomes a major source of model uncertainty. The model uncertainty includes the inaccuracies in modeling the transformers, the transmission lines and the loads.

Although local optimization is realized by these agents (PSSs, AVRs), the lack of coordination among the local agents may cause serious problems, such as inter-area oscillations. In order to minimize the problems encountered in a distributed power network control, a centralized wide area control system (WACS) is proposed (Ni and Heydt, 2002; Taylor et al., 2005). The WACS coordinates the actions of the distributed agents by using SCADA (supervisory control and data acquisition), PMU (phasor measurement unit) or other wide-area dynamic information (Taylor et al., 2005; Kamwa and Grondin, 2002). The WACS receives information/data of different areas in the power system and based on some predefined objective functions, sends appropriate control/feedback signals to the distributed agents in the power network to enhance the system dynamic performance (Taylor et al., 2005; Abould-Ela et al., 1996). A WACS is typically composed of two parts, first part that identifies the system or a model which is referred to as a wide area monitor (WAM) in this paper; and the second part is the controller, which is referred to as a wide area controller (WAC).

The major motivation to have a wide area monitoring and control scheme is for the following benefits:

- transmission capacity enhancement can be achieved by online monitoring of the system stability limits and capabilities;
- power system reinforcement based on feedback obtained during analysis of system dynamics;

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- introduction of a coordinated approach for the execution of stabilizing actions in case of severe network disturbances;
- triggering of additional functions by a WACS;
- better understanding of the dynamic behavior of the system.

In classical modeling of a power system, the parameters of different devices are very important to know beforehand. Also, the linear models are only accurate for the operating point at which they are derived. Any excursion from nominal point of operation would make the model inaccurate. Though online update of linear model is possible, it is computationally intensive and designing a controller at each operating point is a difficult task to do online. Here comes the advantages of using neural network due to its inherent approximation capability.

Neural networks are able to identify and control multiple-input–multiple-output time varying systems as turbogenerators (Jung-Wook et al., 2005; Venayagamoorthy and Harley, 2002) and, with continually online training these models can track the dynamics of these systems thus yielding adaptive identification for changes in operating points and conditions. Adaptive critic designs (ACDs) have been reported in literature to provide nonlinear optimal control for complex processes and systems (Venayagamoorthy and Harley, 2002; Werbos, 1992; Jung-Wook et al., 2005; Govindhasamy et al., 2005).

This paper presents the design of an optimal WACS based on adaptive critics and neural networks for a power system. The controller shows robustness for different operating conditions and small communication delays. The WACS is implemented on the M67 digital signal processor (DSP) which is interfaced to the real time digital simulator (RTDS) that simulates the power system. The rest of the paper is organized as follows. Section 2 describes the multimachine power system studied. Section 3 describes the WACS proposed in this work. Section 4 explains the implementation platform for the WACS—the RTDS and the M67 DSP. Section 5 presents the implementation results. Finally, the conclusion is given in Section 6.

2. Multimachine power system

In spite of being a small test system, the two-area power system of Fig. 1 mimics certain behavior of typical systems in actual operation and is a useful system in the study of inter-area oscillations like those seen in large interconnected power systems (Klein et al., 1991; Kundur, 1994). The two-area system shown in Fig. 1 consists of two fully symmetrical areas linked together by two transmission lines. There are 11 electrical buses in the system and each generator low voltage bus is connected to the 230 kV transmission system through a step up transformer. Each area is equipped with two identical synchronous generators rated 20 kV/900 MVA. All the generators are equipped with identical speed governors and turbines, and exciters and AVRs (Fig. 2). Though there are four generators (G1, G2, G3 and G4) in the system only G1 and G3 are equipped with PSSs. This is because each area has one low frequency oscillatory mode and it can be damped using the excitation control of one generator in each area. Switch S_1 is used to add either the PRBS or WACS supervisory signal to the input of the AVR. Switch S_2 is used to connect or disconnect PSS. During the training of the WACS, S_1 is connected to PRBS signal while during normal operation S_1 is connected to the WACS signal. Load is represented as constant impedances and split between the areas in such a way that area 1 is transferring about 413 MW to area 2. Three electromechanical modes of oscillation are present in this system; two inter-plant modes at 1.1 and 1.2 Hz, one in each area, and one inter-area mode at 0.63 Hz, in which the generating units in one area oscillate against those in the other area. The parameters of the system are given in the Appendix. The two-area power system is simulated

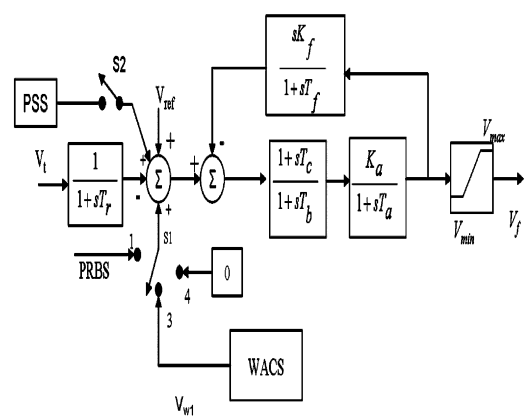

Fig. 2. AVR–exciter model for the generators with supplementary signal from WACS.

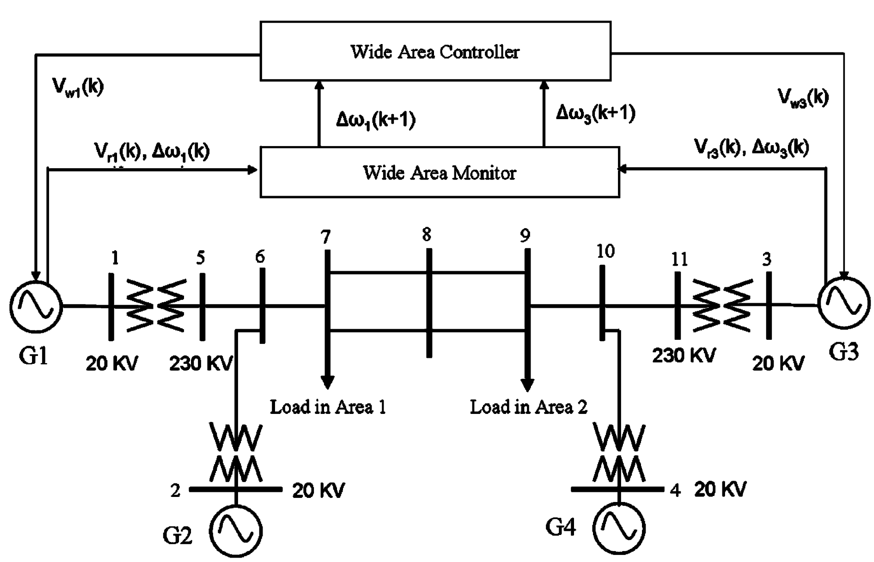

Fig. 1. Two-area power system with WACS consisting of a WAC and a WAM.