The Appliance of the Estimated Load Angle in the Fuzzy Power System Stabilizer

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***Abstract*—This paper investigates the application of the fuzzy logic power system stabilizer. Proposed stabilizer use estimated load angle of synchronous generator as the input. The load angle estimation is based on the real parameters of a synchronous generator, which are given by the corresponding voltage-current vector diagram. A fuzzy logic control scheme for synchronous generator stabilization is tested on the real laboratory model that includes digital system for excitation control (based on four DSPs) and synchronous generator connected to an AC system through transformer and two parallel transmission lines. The experiments were performed for step change of voltage reference. The behavior of the excitation system with fuzzy logic stabilizer is compared with excitation system based on the PI voltage controller and conventional power system stabilizer.**

I. INTRODUCTION

In classical excitation control structure of a synchronous generator PI voltage controller is superior to excitation current controller. Classical power system stabilizer (with the generator active power as input signal) is also included in the control structure. Instead classical power system stabilizer a fuzzy logic stabilizer is used for power system stabilization. The output signal of both stabilizers is v_{stab}. Input signal of fuzzy logic stabilizer is estimated load angle. The load angle estimation is based on the real parameters of a synchronous generator, which are given by the corresponding voltage-current vector diagram [8]. Excitation control structure is presented on the figure 1.

Structure of the classical power system stabilizer is presented on the fig. 2. The basic function of a power system stabilizer is to provide damping to the system oscillations of concern. These oscillations are typically in the frequency range of 0.1 to 3.0 Hz, and insufficient damping of these oscillations may limit the ability to transmit power [3]. To provide damping, the power system stabilizer must generate electrical torque component in phase with the rotor speed deviation. Power system stabilizer must compensate the phase lag of the generator excitation system. The parameters of conventional power system stabilizer are determined for nominal operating point to give good performance. However, the system dynamic response may regress with change of the operating point.

II. FUZZY LOGIC STABILIZER

A power system is highly nonlinear system. For tuning of fuzzy logic stabilizer there is no need for exact knowledge of power system mathematical model. The fuzzy stabilizer parameters settings are independent due to nonlinear changes in generator and transmission lines operating conditions.

The fuzzy stabilizer has damping control loop with the function of power system stabilizer. A simple fuzzy control scheme is applied to this control loop [1].

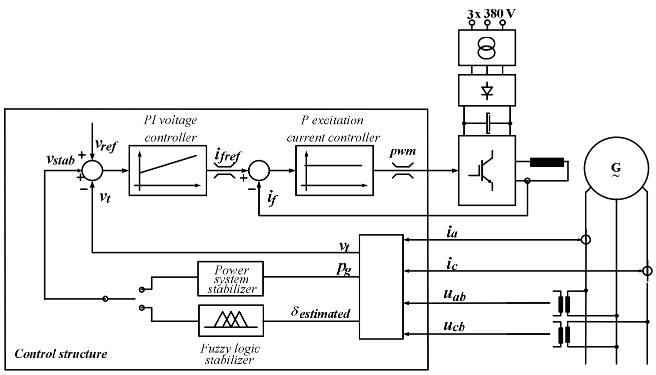

Fig. 1. Excitation control structure

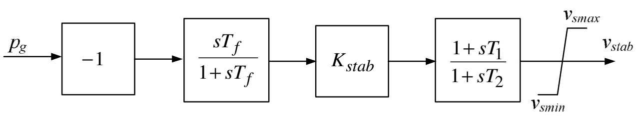

Fig. 2. Structure of the classical power system stabilizer

The damping control signal v_{stab} as output of fuzzy logic stabilizer is derived from measure of generator speed deviation Z_s. The signal Z_s is derived from estimated load angle $\delta_{estimated}$ through filter and derivation. The damping control signal v_{stab} is added to the input of the voltage control loop.

The generator state is given by the point *p(k)* :

$$p(k) = (Z_s(k)) \quad (1)$$

where is $Z_s(k)$ measure of generator speed deviation.

The output control signal $v_{stab}(k)$ for damping control loop is given by:

$$v_{stab}(k) = G(k) \cdot U_{lims} \quad (5)$$

G (k) is membership function given by:

$$G(k) = Z_s(k) / D_r \text{ for } Z_s(k) \le D_r \quad (6)$$

$$G(k) = 1 \text{ for } D(k) > Dr \quad (7)$$

Parameter U_{lims} give the maximum value of the output signal for damping control loop v_{stab}. Parameter D_r is adjustable for damping control loop.

III. EXPERIMENTAL VERIFICATION

The experimental verification of synchronous generator excitation control system was made on the digital control system and laboratory model of aggregate (figs. 3,4 and 5).

Fig. 3. Digital control system

Fig. 4. Synchronous generator with prime mover DC motor

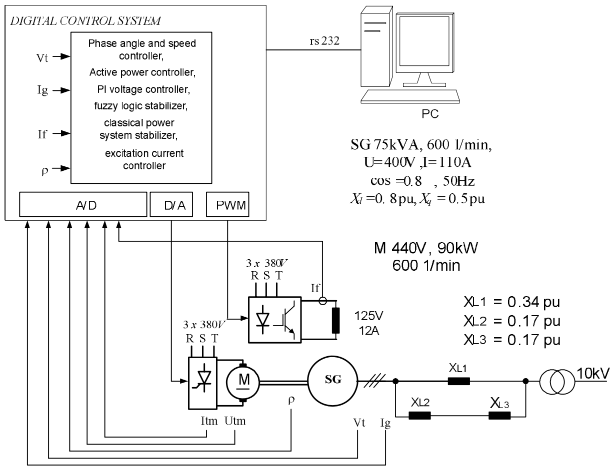

Fig. 5. Laboratory model of aggregate

Digital control system includes four DSPs ADMC300. The excitation winding of a synchronous generator is fed by IGBT converter.

Parameters of the PI voltage controller and classical power system stabilizer are presented in tables I and II. Parameters of the fuzzy logic stabilizer are presented in table III. Parameters in tables I, II and III are tuned for excitation system fed by IGBT converter. Many generators with power system stabilizer employ brushless excitation. In that case parameters of the PI voltage controller and conventional power system stabilizer must be changed, but there is no need to change parameters of the fuzzy logic stabilizer.

TABLE I. PARAMETERS OF THE PI VOLTAGE CONTROLLER

PI voltage controller		Excitation current controller
K_p	K_i	K_p
5	5	10

TABLE II. PARAMETERS OF THE CLASSICAL POWER SYSTEM STABILIZER

T_f (s)	K_{stab}	T_1 (s)	T_2 (s)	v_{smax} (%)	v_{smin} (%)
1	1	0.01	0.1	10	-10

TABLE III. PARAMETERS OF THE FUZZY LOGIC STABILIZER

Damping control loop	
D_r	$U_{lims}(\%)$
0.01	10

The experiments were performed for the step change of voltage reference from 1.0 p.u. to 0.9 p.u. and back to 1.0 p.u. Duration of change is 2.0 seconds. Experiment was made for excitation control with PI voltage controller, PI voltage controller and classical power system stabilizer and PI voltage controller and fuzzy logic stabilizer for generator operating point $P \approx 0.42$ p.u., $Q = 0.04$ p.u. (ind) (fig. 6).

Fig. 6 shows improved performance of excitation system with fuzzy logic stabilizer compared to classical power system stabilizer. The load angle oscillations are reduced.

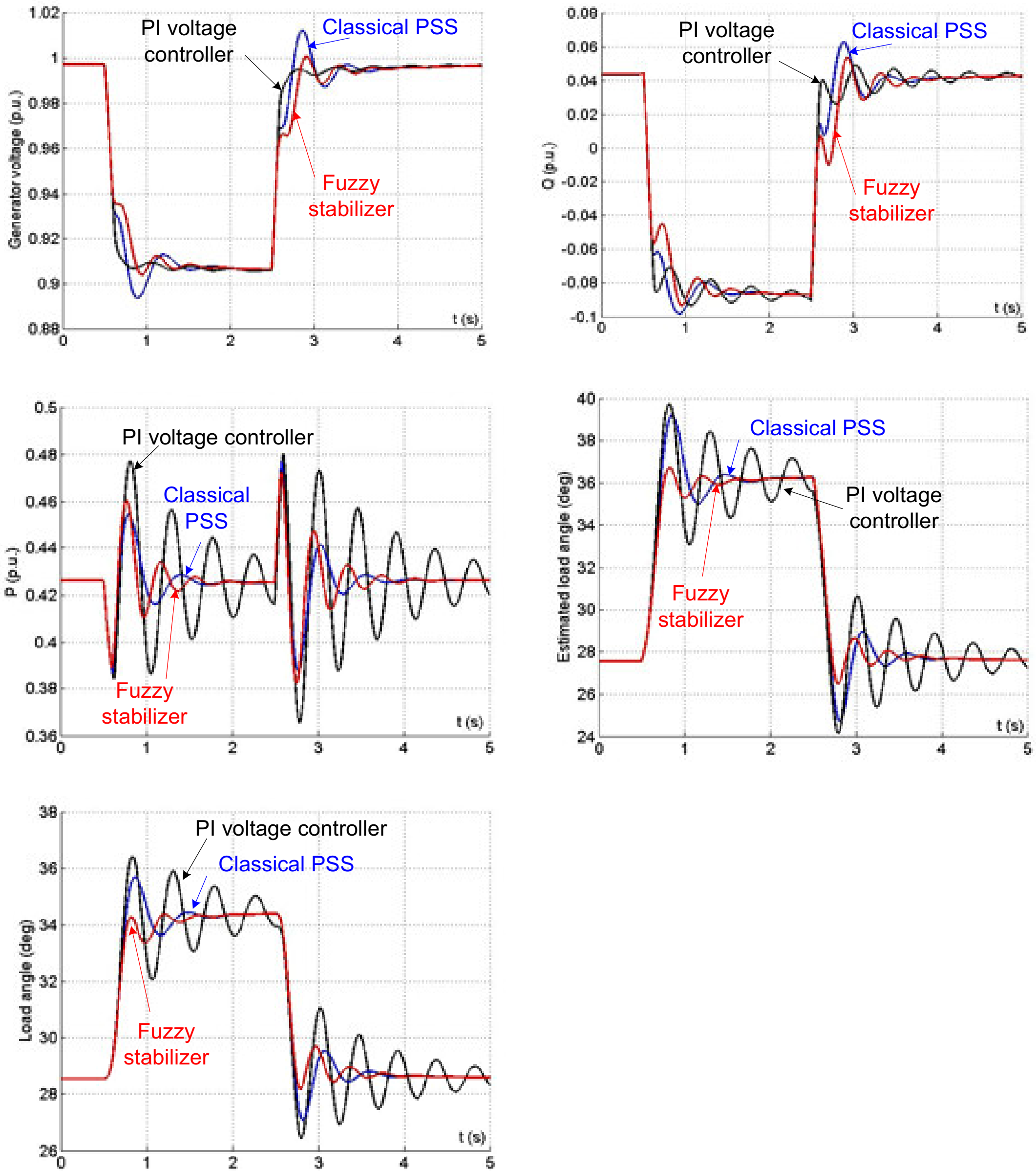

Fig. 6. Experimental responses of excitation system on the step change of voltage reference

IV. CONCLUSION

In classical excitation control system PI voltage controller with included classical power system stabilizer is superior to excitation current controller. Instead classical power system stabilizer fuzzy logic stabilizer for generator stabilization is used. The estimated load angle is used as input of fuzzy logic stabilizer. The experimental verification of synchronous generator excitation control was made on the digital control system and laboratory model of aggregate. Compared to classical power system stabilizer experimental results show improved performance of the fuzzy logic stabilizer for stability of a synchronous generator in static as well as in dynamic operating conditions.

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