

Fuzzy Logic Control of Synchronous Generator Under the Condition of Transient Three Phase Short Circuit

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Abstract—This article is focused on the implementation of fuzzy logic excitation control of a synchronous generator. A simple fuzzy logic control scheme for voltage control and 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 transient three phase short circuit on the one transmission line. The behaviour of the excitation system with fuzzy logic stabilizing controller is compared with excitation system based on the PI voltage controller and conventional power system stabilizer.

I. INTRODUCTION

In classical regulation structure of the excitation control of a synchronous generator PI voltage controller is superior to excitation current controller. Instead PI voltage controller a simple fuzzy logic controller is used for voltage control and generator stabilization. Structures of the classical and fuzzy logic excitation control are presented on the figure 1.

Structure of the conventional power system stabilizer is presented on the figure 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 [4]. Generator active power is used as input signal of power system stabilizer.

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. In this case fuzzy logic synchronous generator control should be used.

II. FUZZY LOGIC CONTROLLER

A power system is highly nonlinear system. For tuning of fuzzy logic stabilizing controller there is no need for exact knowledge of power system mathematical model. The fuzzy controller parameters settings are independent due to nonlinear changes in generator and transmission lines operating conditions. Because of that proposed fuzzy voltage controller should perform better as well conventional controller.

The detailed structure of fuzzy logic stabilizing controller is presented on the fig. 3. The fuzzy controller has two control loops. The first one is the voltage control loop with the function of voltage control and the second one is the damping control loop with the function of power system stabilizer. A simple fuzzy polar control scheme is applied to this two control loops [1].

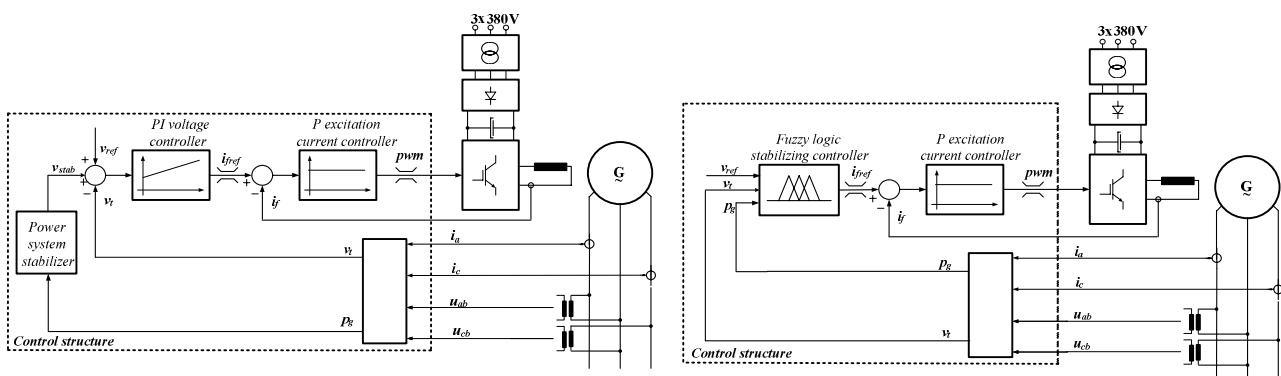


Fig. 1. Structures of the classical and fuzzy logic excitation control

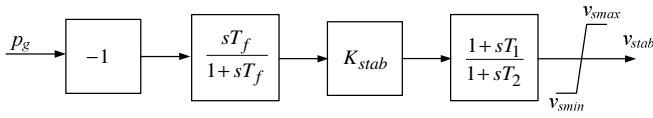


Fig. 2. Structure of the conventional power system stabilizer

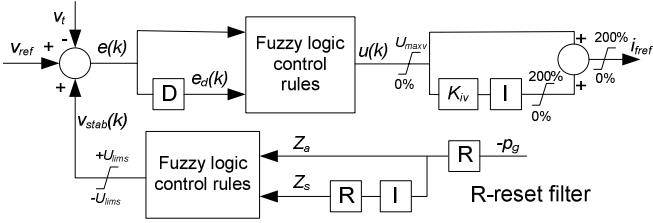


Fig. 3. Structure of the fuzzy logic stabilizing controller

The voltage error signal $e(k)$ is the difference between the voltage reference v_{ref} and the actual voltage v_t . The signal $e_d(k)$ is the derivation of the signal $e(k)$. The PD information of voltage error signal $e(k)$ is utilized to get the voltage state and to determine the reference i_{ref} for the proportional excitation current controller. To eliminate voltage error integral part of the controller with parameter K_{iv} must be added to the output of the controller. The damping control signal v_{stab} is derived from generator active power p_g . The signal Z_a is a measure of generator acceleration and the signal Z_s is a measure of generator speed deviation. Signals Z_a and Z_s are derived from generator active power through filters and integrator. The damping control signal v_{stab} is added to the input of the voltage control loop.

The fuzzy logic control scheme is applied to voltage and damping control loop [3]. The generator operating point in the phase plane is given by the $p(k)$ for the corresponding control loop (Fig. 4).

$$p(k) = (X(k), A_s \cdot Y(k)) \quad (1)$$

where is $X(k) = e(k)$, $Y(k) = e_d(k)$ for voltage control loop, and $X(k) = Z_s(k)$ and $Y(k) = Z_a(k)$ for damping control loop. Parameter A_s is adjustable scaling factor for $Y(k)$. Polar information, representing the generator operating point, is determined by the radius $D(k)$ and the phase angle $\Theta(k)$ [5].

$$D(k) = \sqrt{X(k)^2 + (A_s \cdot Y(k))^2} \quad (2)$$

$$\Theta(k) = \arctg\left(\frac{A_s \cdot Y(k)}{X(k)}\right) \quad (3)$$

The phase plane is divided into sectors A and B defined by using two angle membership functions $N(\Theta(k))$ and $P(\Theta(k))$ (fig. 5). The principles of the fuzzy polar control scheme and selection of the membership functions are explained in [2]. By using membership functions $N(\Theta(k))$ and $P(\Theta(k))$ the output control signals $u(k)$ and $v_{stab}(k)$ for each control loop are given by:

$$u(k) = \frac{N(\Theta(k)) - P(\Theta(k))}{N(\Theta(k)) + P(\Theta(k))} \cdot G(k) \cdot U_{maxv} \quad (4)$$

$$v_{stab}(k) = \frac{N(\Theta(k)) - P(\Theta(k))}{N(\Theta(k)) + P(\Theta(k))} \cdot G(k) \cdot U_{lims} \quad (5)$$

$G(k)$ is radius membership function given by:

$$G(k) = D(k) / D_r \text{ for } D(k) \leq D_r \quad (6)$$

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

Parameters U_{maxv} and U_{lims} give the maximum values of the output signal for each control loop. Parameters A_s , D_r and α for voltage control loop and damping control loop are adjustable.

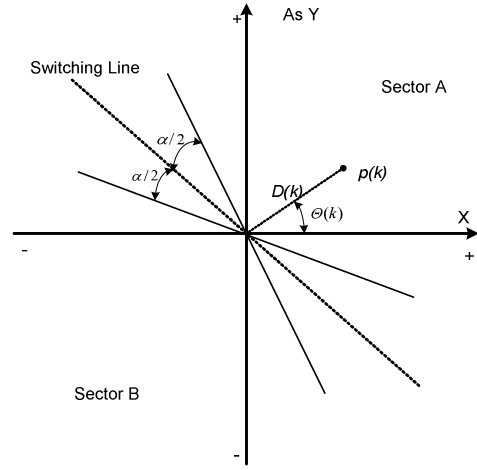


Fig. 4. Phase plane

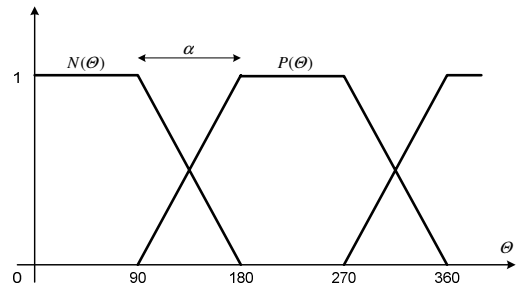


Fig. 5. Angle membership functions

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. 6 and 7). Digital control system includes four DSPs ADMC300. The excitation winding of a synchronous generator is fed by IGBT converter. Synchronous generator with prime mover DC motor is presented on the figure 8. Inductances used as parallel transmission lines are presented on the figure 9.

Parameters of the PI voltage controller and conventional power system stabilizer are presented in tables I and II. Parameters of the fuzzy logic controller 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 controller.

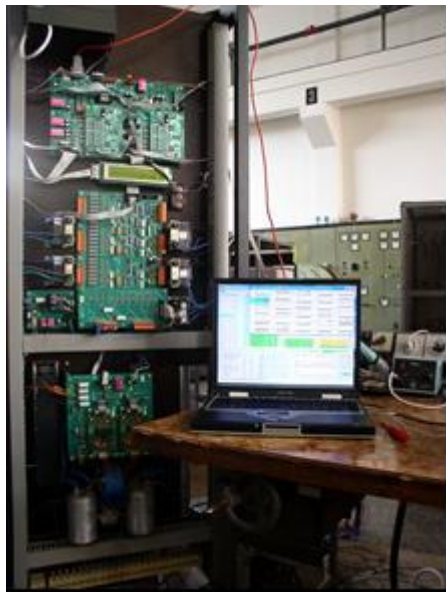


Fig. 6. Digital control system

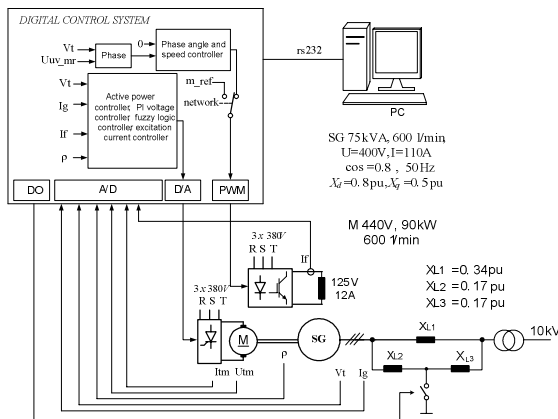


Fig. 7. Laboratory model of aggregate



Fig. 8. Synchronous generator with prime mover DC motor



Fig. 9. Inductances used as parallel transmission lines

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 CONVENTIONAL 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 CONTROLLER

Voltage control loop					Damping control loop			
A_s	D_r	K_{iv}	U_{max} (%)	α (°)	A_s	D_r	U_{lims} (%)	α (°)
0.1	1	5	200	90	0.01	0.01	10	90

The experiments were performed for transient three phase short circuit on the one transmission line. Duration of fault is 0.1 second. Experiment was made for excitation control with PI voltage controller (fig. 10), PI voltage controller and conventional power system stabilizer (fig. 11) and fuzzy logic stabilizing controller (fig. 12) for generator operating point $P = 50\%$, $Q = 30\%$ (cap).

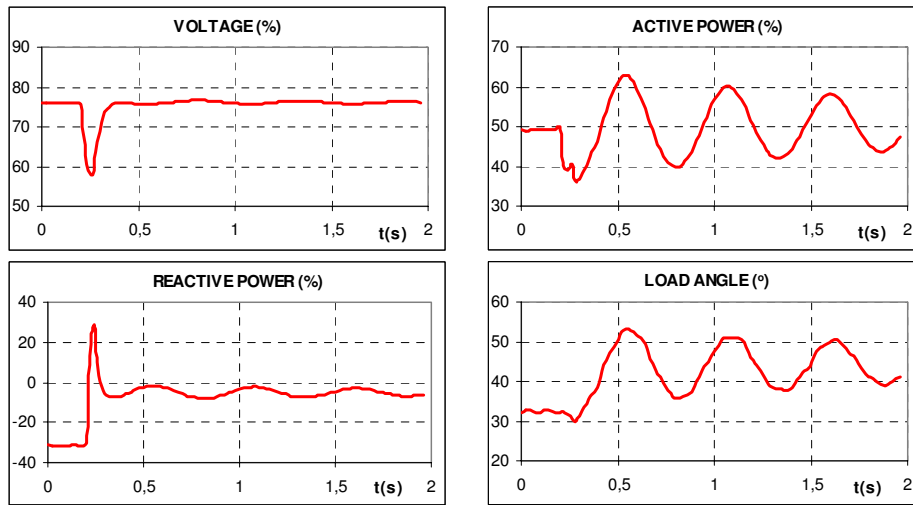


Fig. 10. Experimental responses of excitation system with PI voltage controller

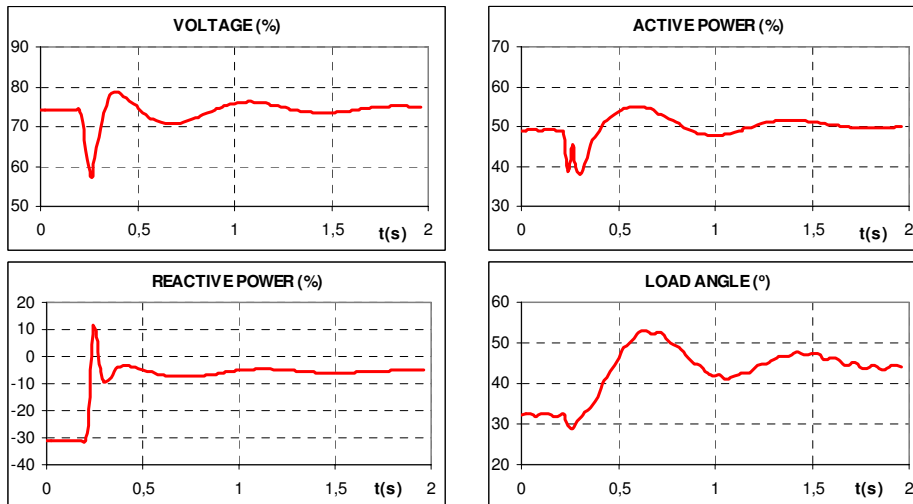


Fig. 11. Experimental responses of excitation system with PI voltage controller and conventional power system stabilizer

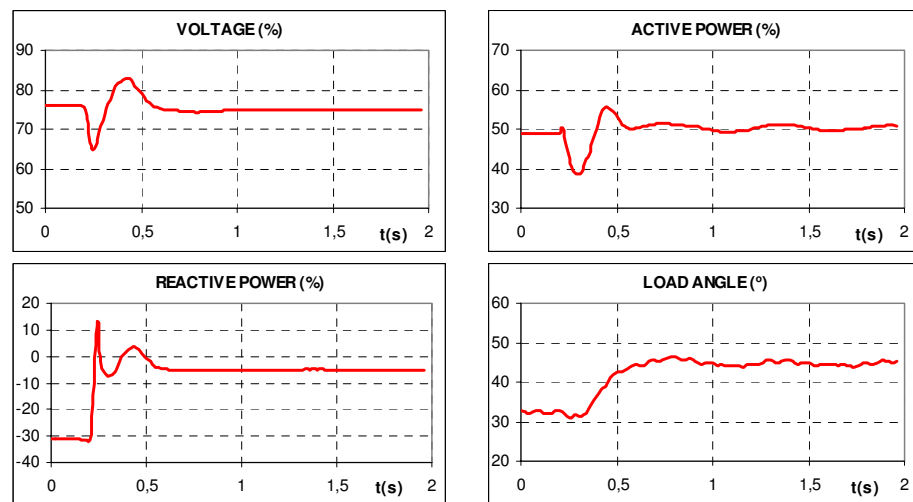


Fig. 12. Experimental responses of excitation system with fuzzy logic stabilizing controller

Figures 10, 11 and 12 shows improved performance of excitation system with fuzzy logic stabilizing controller compared to PI voltage controller and conventional power system stabilizer. Settling time of the active power oscillation is reduced.

IV. CONCLUSION

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

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