# Excitation control of a synchronous generator using fuzzy logic stabilizing controller

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## Keywords

«Generator excitation system», «Fuzzy control», «DSP»

## Abstract

This article is focused on the implementation of simple 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 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.

## 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.

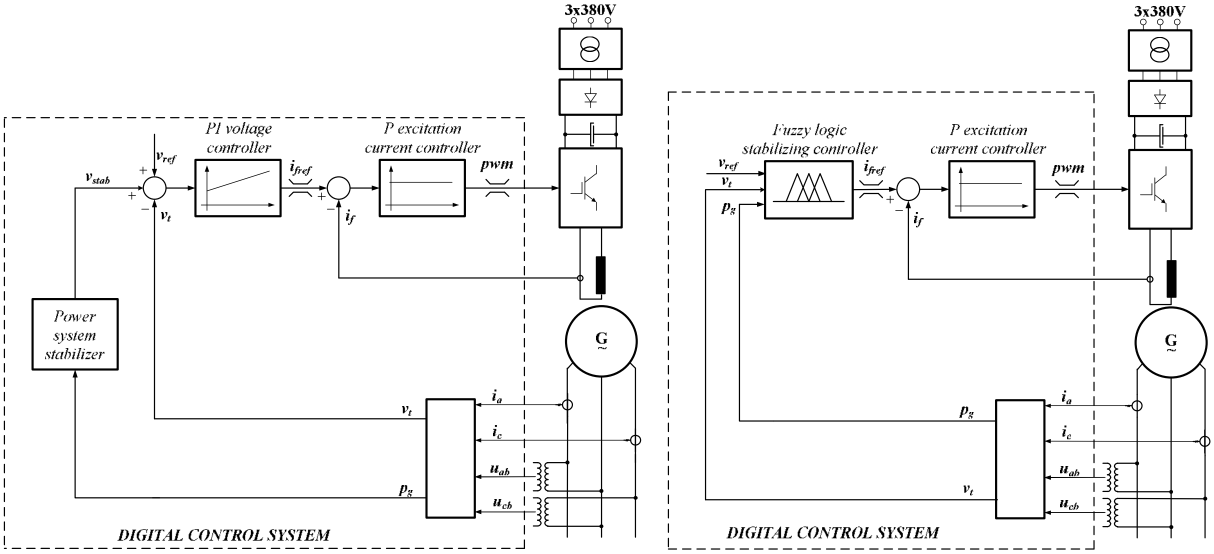

Fig. 1: Structures of the classical and fuzzy logic excitation control

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 [8]. 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.

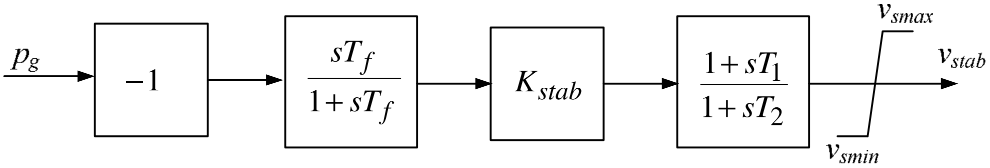

Fig. 2: Structure of the conventional power system stabilizer

## Fuzzy logic stabilizing 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.

The detailed configuration 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 [3].

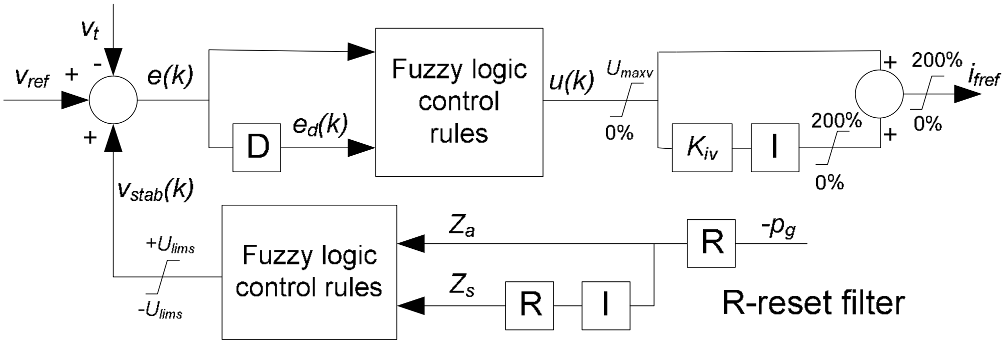

Fig. 3: Configuration of the fuzzy logic stabilizing controller

The voltage error signal *e(k)* is the difference between the voltage reference $v_{ref}$ and the actual voltage $v_t$. The PD information of voltage error signal *e(k)* is utilized to get the voltage state and to determine the reference $i_{fref}$ for the proportional excitation current 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 [4]. The generator state is given by the point *p(k)* in the phase plane 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 state, is determined by the radius $D(k)$ and the phase angle $\Theta(k)$ [5].

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

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

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. 4). The principle of the fuzzy polar control scheme is explained in [1]. 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:

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

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

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

$$G(k) = D(k) / D_r \text{ for } D(k) \le D_r \tag{6}$$

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

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

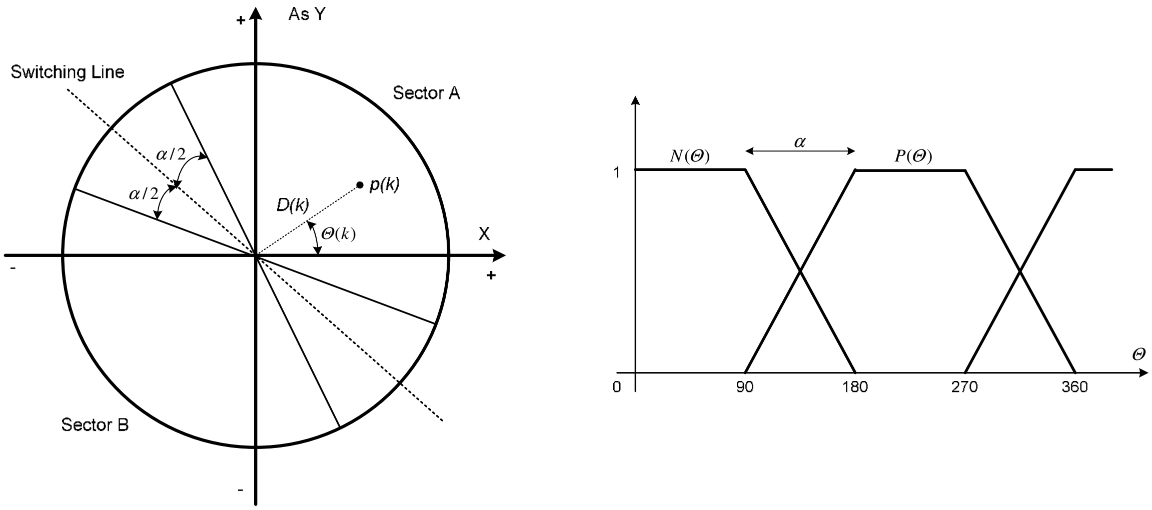

Fig. 4: Phase plane and angle membership functions

## Experimental verification

The experimental verification of synchronous generator excitation control system was made on the digital control system and laboratory model of aggregate (fig. 5.). Digital control system includes four DSPs ADMC300 [2]. The excitation winding of a synchronous generator is fed by IGBT converter.

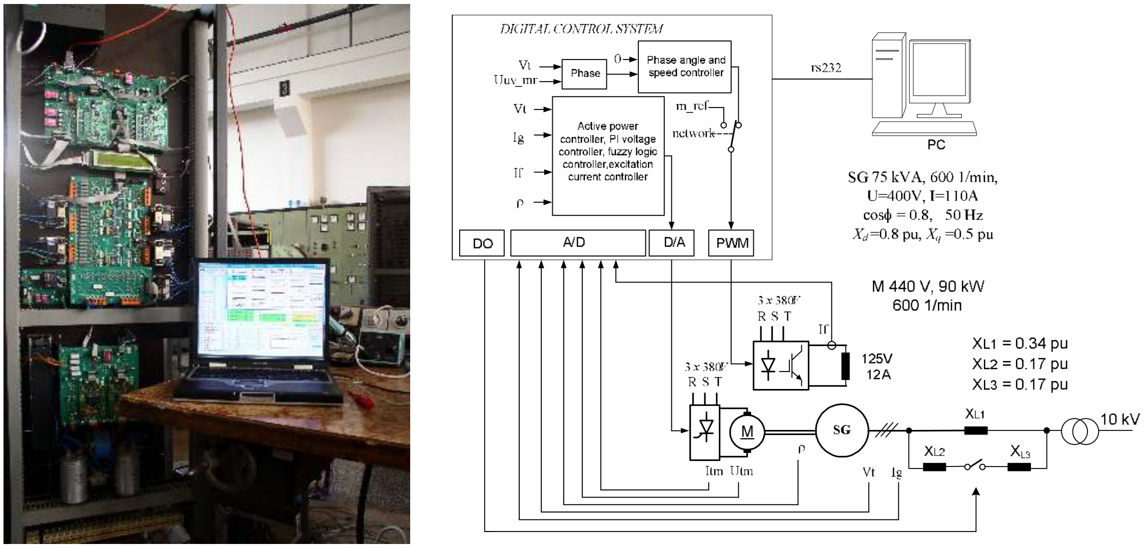

Fig. 5: Digital control system and laboratory model of aggregate

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

### 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 |

Parameters of the fuzzy logic stabilizing controller are presented in table III.

### Table III: Parameters of the fuzzy logic stabilizing controller

| Voltage control loop | | | | | Damping control loop | | | |
|---|---|---|---|---|---|---|---|---|
| $A_s$ | $D_r$ | $K_{iv}$ | $U_{maxv}(\%)$ | $\alpha\,(°)$ | $A_s$ | $D_r$ | $U_{lims}(\%)$ | $\alpha\,(°)$ |
| 0.1 | 1 | 5 | 200 | 90 | 0.01 | 0.01 | 10 | 90 |

Parameters in tables I, II and III are tuned for excitation system fed by IGBT converter. However, 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 stabilizing controller.

The experiments were performed for switching off of the one transmission line. Each experiment was made for excitation control with PI voltage controller (fig. 6), PI voltage controller and conventional power system stabilizer (fig. 7) and fuzzy logic stabilizing controller (fig. 8) for generator operating point *P* = 100 %, *Q* = 30 % (cap).

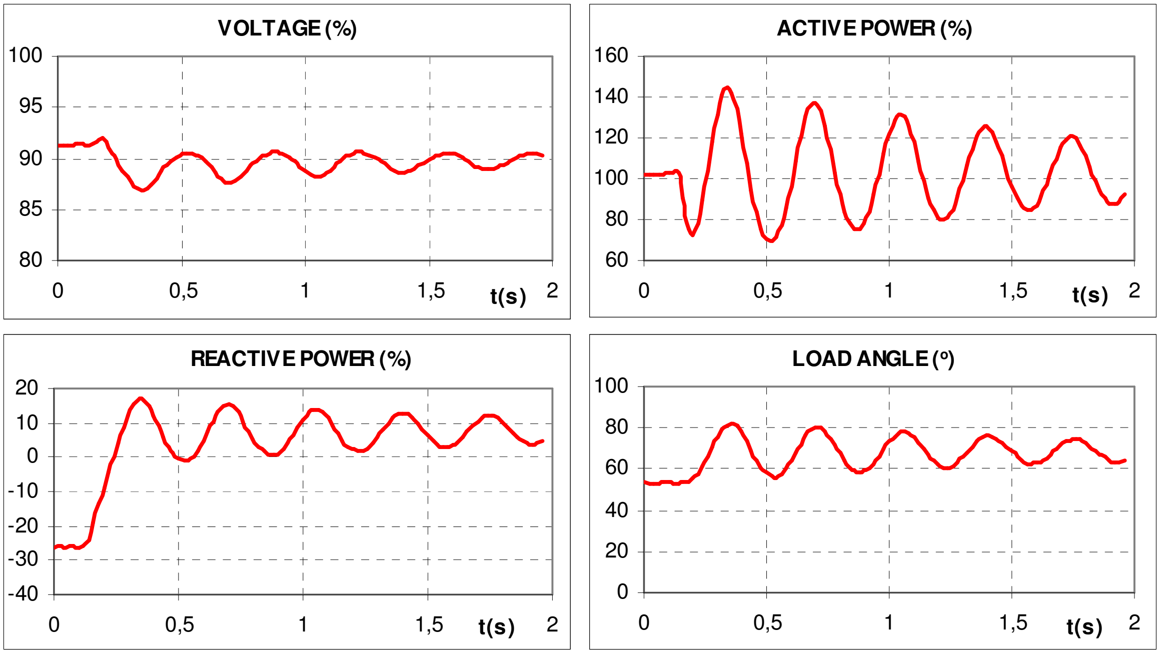

Fig. 6: Experimental responses of excitation system with PI voltage controller

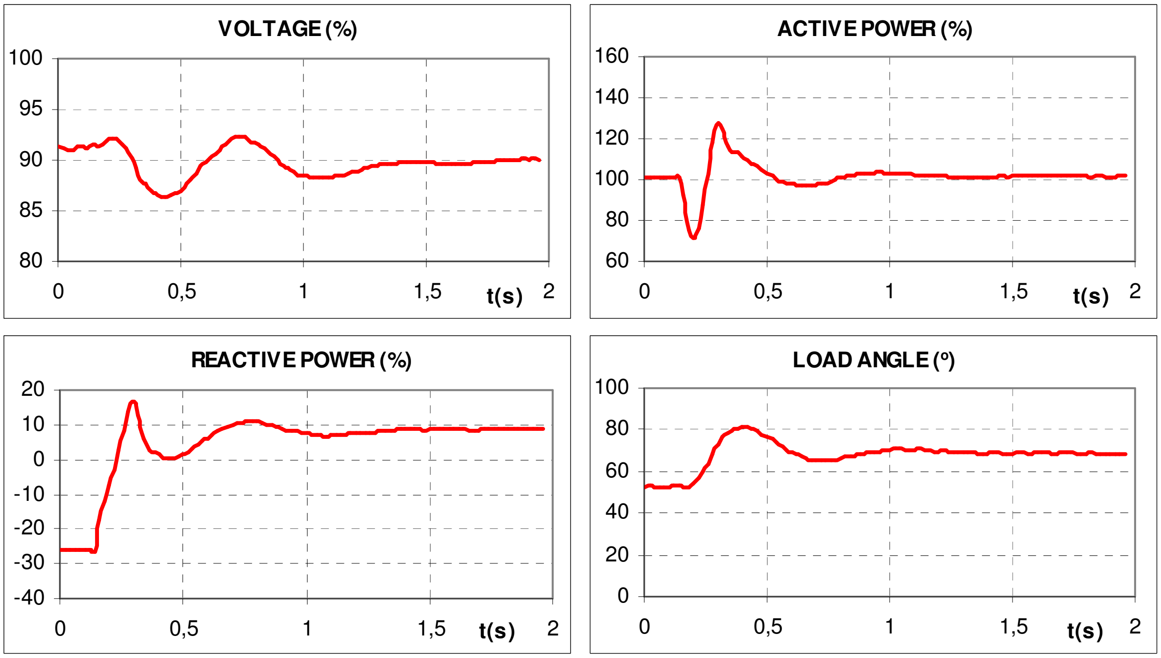

Fig. 7: Experimental responses of excitation system with PI voltage controller and conventional power system stabilizer

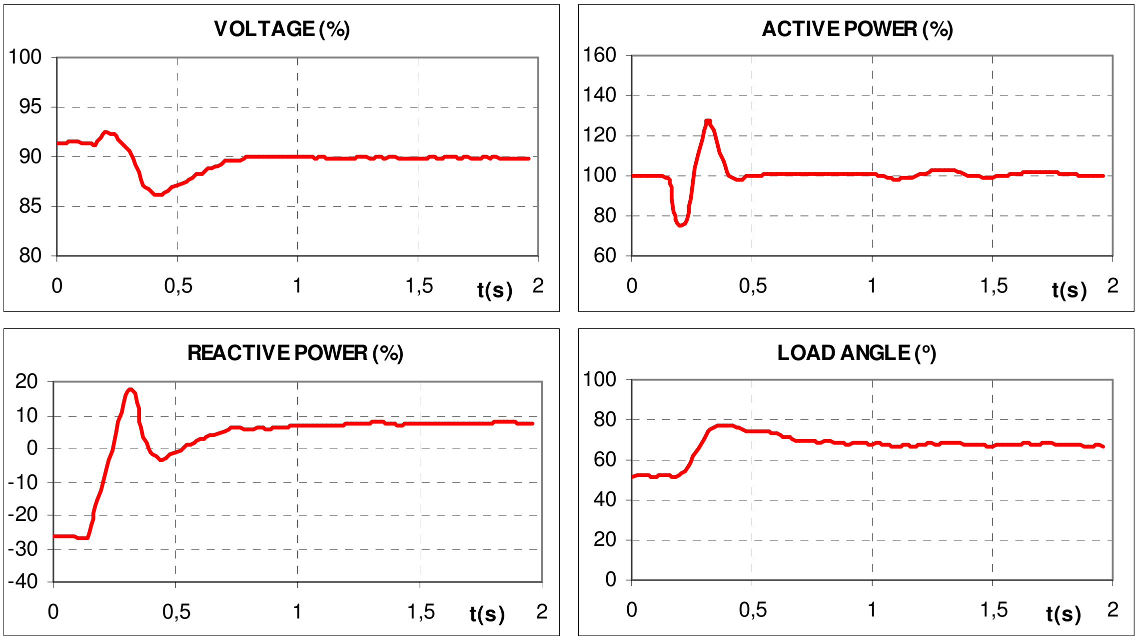

Fig. 8: Experimental responses of excitation system with fuzzy logic stabilizing controller

Figures 6, 7 and 8 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.

## 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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