Comparison of the Excitation Control of a Synchronous Generator with Fuzzy Logic Controller and PI Voltage Controller

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Abstract - This article is focused on the simulation and implementation of simple fuzzy logic excitation control of a synchronous generator. In MATLAB/SIMULINK is simulated model of the synchronous generator connected to an AC system. A simple fuzzy logic control scheme is simulated for voltage control and generator stabilization. This simulation is compared with the behaviour of the real laboratory model, which include digital regulation system (based on four DSPs) and synchronous generator connected to an AC system. The behaviour of the excitation system with fuzzy logic controller is compared with excitation system based on the PI voltage controller.

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. Structure of the fuzzy logic excitation control is presented on the figure 1.

II. CONFIGURATION OF THE FUZZY LOGIC CONTROLLER

The fuzzy controller has two control loops. The first one is the voltage control loop with the function of automatic 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 [8]. The detailed configuration of the fuzzy logic controller is presented on the fig. 2.

The voltage error signal is the difference between the voltage reference V_r and the actual voltage V_t. The PD information of the voltage error signal e is utilized to get the voltage state and to determine the reference for the PI control loop. The PI control loop is used to control the generator voltage without error. Output of the fuzzy logic stabilizing controller is the reference for the excitation current regulator. The damping control signal U_d is derived from the PD information of the generator speed. Za is a measure of the acceleration of generator and Zs is a measure of the speed deviation. Za and Zs are derived from active power of the generator through filters and an integrator. The damping control signal U_d is added to the input of the voltage control loop.

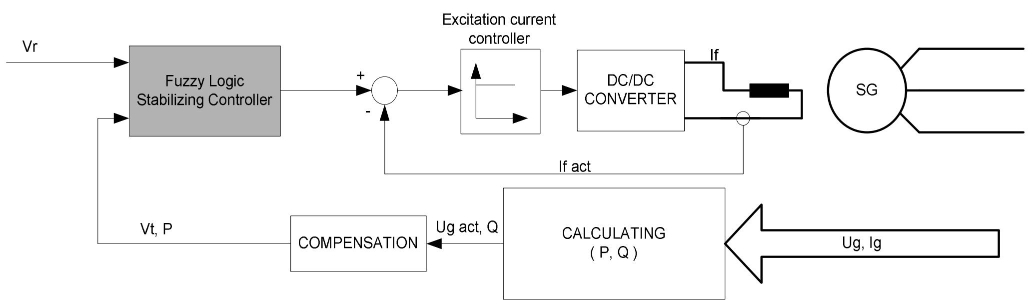


Fig. 1. Structure of the fuzzy logic excitation control

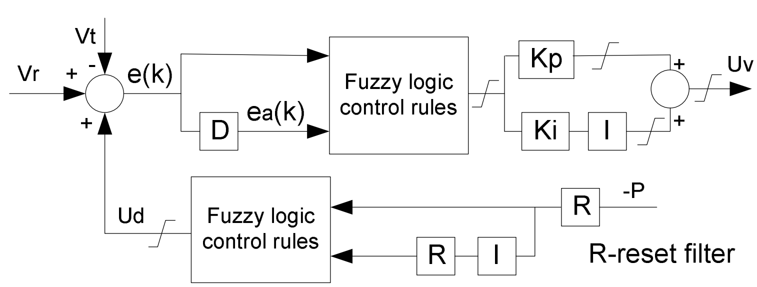


Fig. 2. Configuration of the fuzzy logic excitation controller

The fuzzy logic control scheme is applied to voltage and damping control loop [9]. The generator state is given by the point p (k) in the phase plane for the corresponding control loop (Fig. 3).

$$p\,(k) = (\,X(k),\, As \cdot Y(k)\,) \qquad (1)$$

where is $X(k)=e(k)$, $Y(k)=e_d(k)$ for voltage control loop, and $X(k)=Zs(k)$ and $Y(k)=Za(k)$ for damping control loop. *As* is adjustable scaling factor for $Y(k)$. Polar information, which represent the generator state, is determined by the radius $D(k)$ and the phase $\Theta(k)$ [10].

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

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

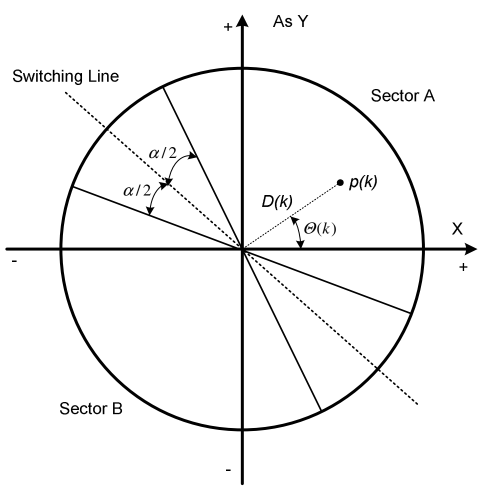


Fig. 3. Phase plane

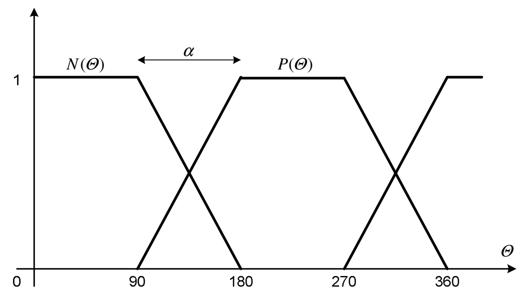


Fig. 4. Angle membership functions

The phase plane is divided into sector A and sector B which are defined by using the two angle membership functions $N(\Theta(k))$ and $P(\Theta(k))$ (fig. 4). The principle of the fuzzy polar control scheme is explained in [9]. By using membership functions $N(\Theta(k))$ and $P(\Theta(k))$ the output control signal U(k) for each control loop is given by:

$$U(k) = \frac{N(\Theta(k)) - P(\Theta(k))}{N(\Theta(k)) + P(\Theta(k))} \cdot G(k) \cdot U_{\max} \qquad (4)$$

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

$G(k)=D(k)/D_r$ za $D(k) \le D_r$ (5)

$G(k)=1$ za $D(k) > D_r$ (6)

U_{max} gives the maximum value of the output signal U(k) for each control loop. Parameters As, Dr and α are adjustable control parameters for voltage control loop and damping control loop.

III. SIMULATION MODEL OF THE EXCITATION CONTROL OF SYNCHRONOUS GENERATOR

Simulated model with fuzzy logic controller or PI voltage controller is presented on the fig. 5.

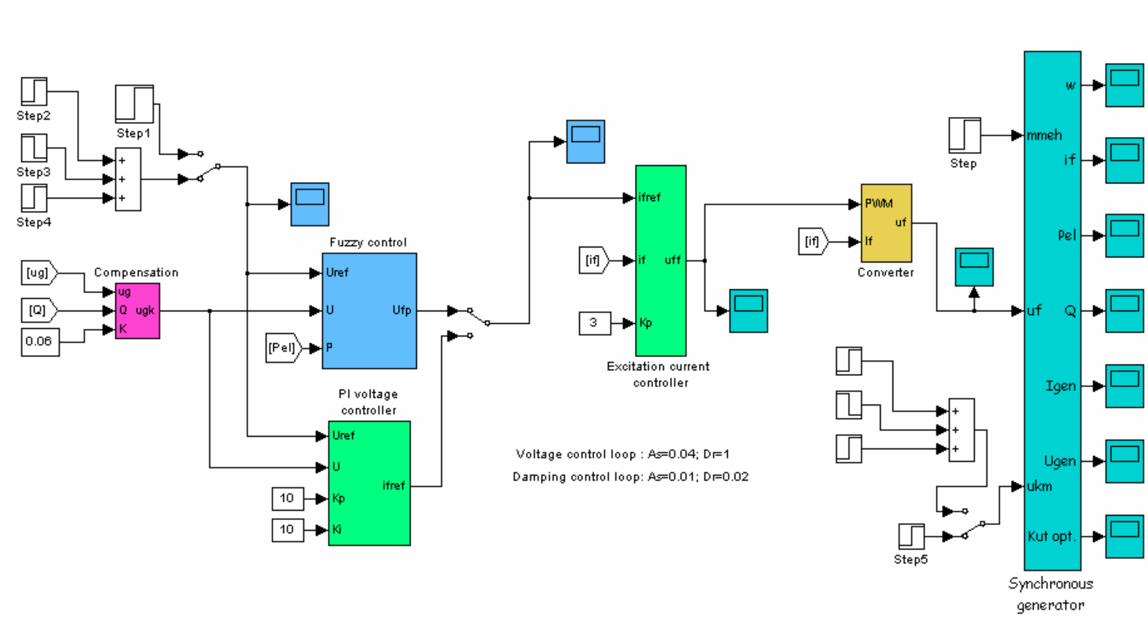
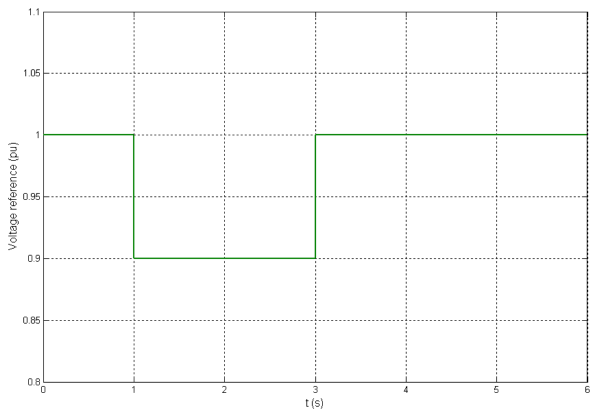


Fig. 5. MATLAB/ SIMULINK model of the fuzzy logic excitation control

Simulated model of the synchronous generator is connected to an AC system with all parameters from experimental setup. The behaviour of the fuzzy logic excitation controller is simulated and compared with PI voltage controller for two characteristic operation conditions.

In the first simulation voltage reference is changing from 100% to 80% and then back to 100% with 80% of active power. On the fig. 5. is presented active power response with fuzzy logic stabilizing controller and with classical PI regulator.



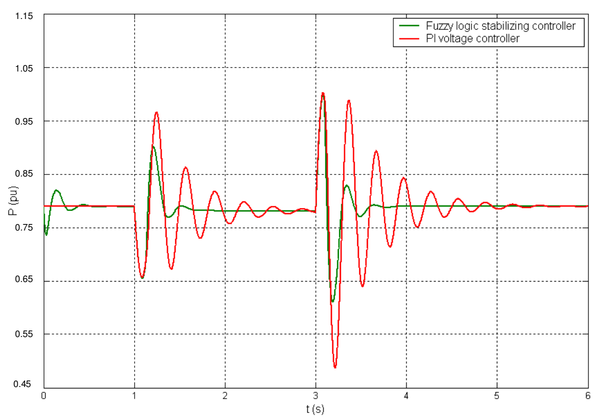
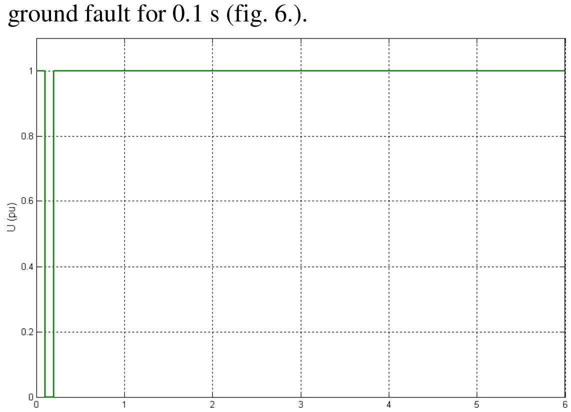


Fig. 6. Active power P (pu) during voltage reference changing in the operating point of synchronous generator (P=0.8 pu, Q=0 pu) with fuzzy logic stabilizing controller and with PI voltage controller

In the second experiment is simulated a three phase to ground fault for 0.1 s (fig. 6.).



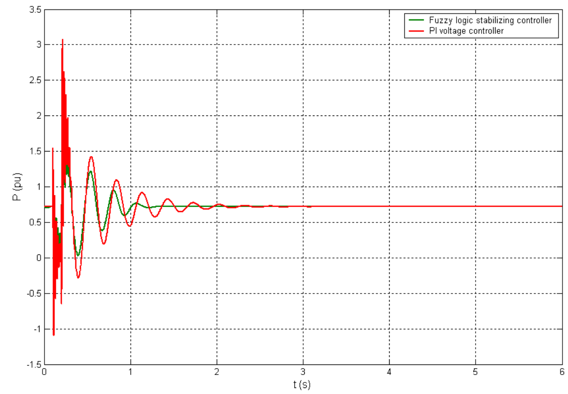


Fig. 7. Active power P (pu) during three phase to ground fault (AC system voltage is equal to zero for 0.1 s) in the operating point of synchronous generator (P=0.8 pu, Q=0 pu) with fuzzy logic stabilizing controller and with PI voltage controller

According to the simulation results parameters of the fuzzy logic controller are:

-for voltage control loop As = 0.04, Dr = 1

-for damping control loop As = 0.01, Dr = 0.02.

IV. EXPERIMENTS

Experimental verification of the excitation control system of a synchronous generator is made on the laboratory model of the aggregate (figs. 6. and 7.). Digital control system (fig. 5.) includes four DSPs ADMC300 [2]. The excitation winding of a synchronous generator is fed by IGBT converter.

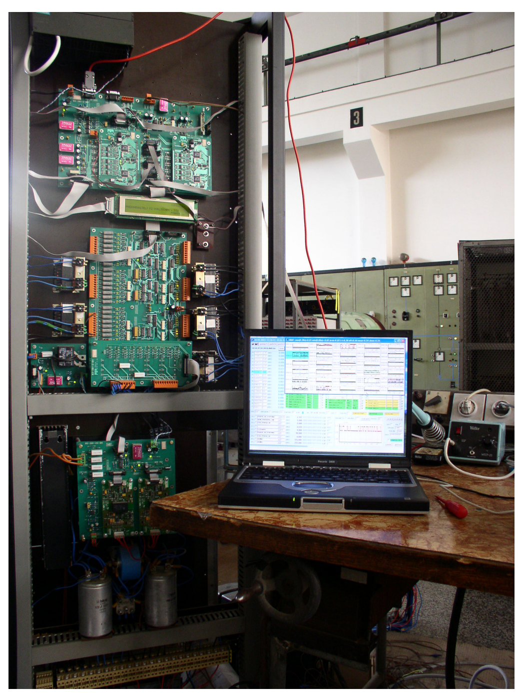


Fig. 5. Digital control system

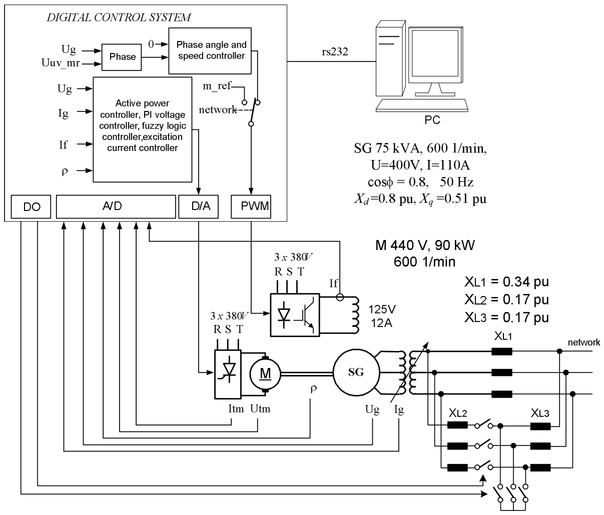


Fig. 6. Laboratory model of the aggregate

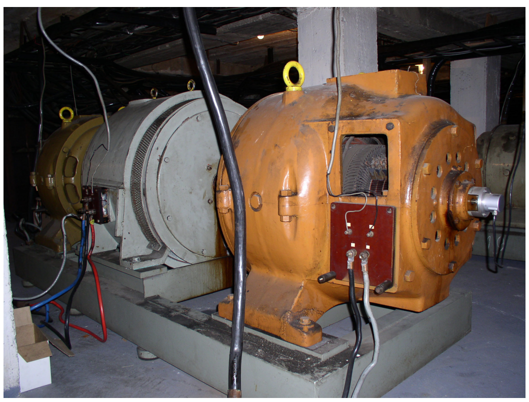
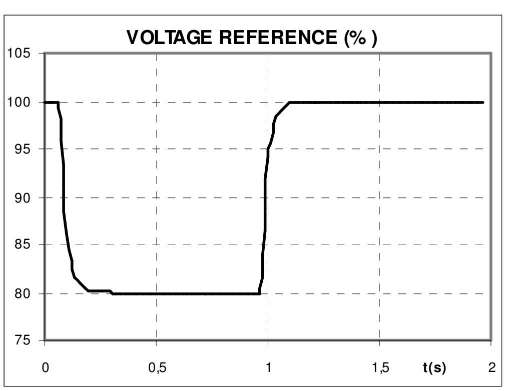


Fig. 7. Synchronous generator with prime mover DC motor

The analysis is made with PI voltage controller and fuzzy logic controller. Experimental responses of the excitation system of the synchronous generator in operating point P=0.8 pu, Q=0.1 pu on the step change of voltage reference are shown on the fig. 8.

Experimental responses in operating point P=0.5 pu, Q=0.05 pu on the step change of voltage reference are shown on the fig. 9.



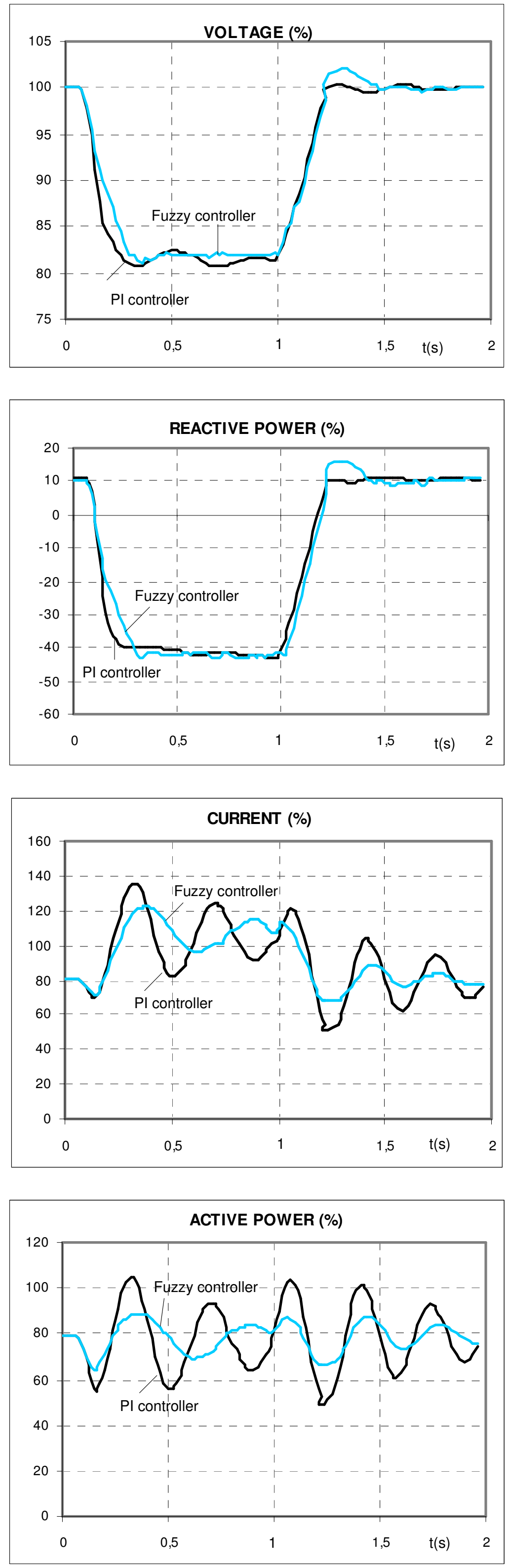
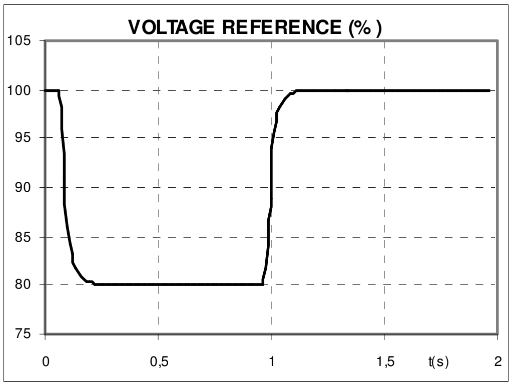
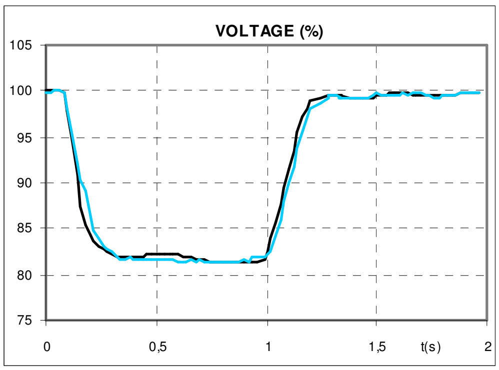
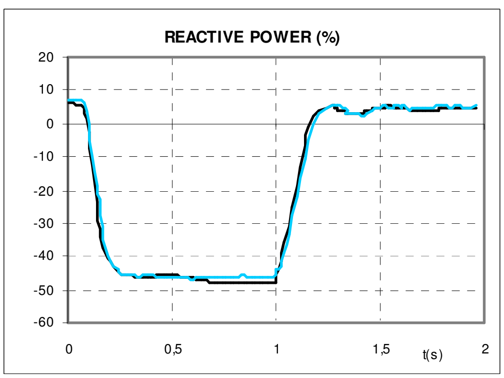
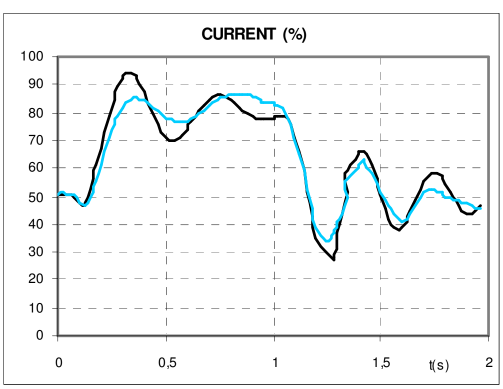


Fig. 8. Experimental responses on the step change of voltage reference in operating point P=0.8 pu, Q=0.1 pu









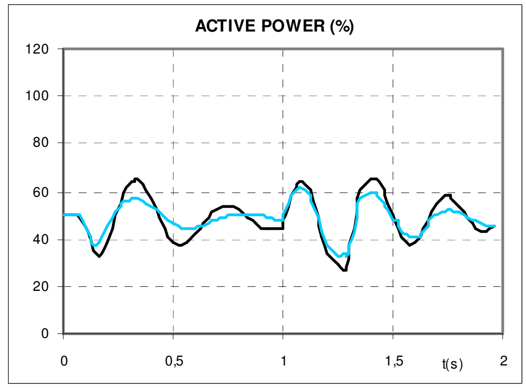


Fig. 9. Experimental responses on the step change of voltage reference in operating point P=0.5 pu, Q=0.05 pu

V. CONCLUSIONS

In conventional excitation control system PI voltage controller with eventually conventional PSS is superior to excitation current controller. Instead PI voltage controller fuzzy logic controller is used for voltage control and generator stabilization. From simulation results are obtained parameters of the fuzzy logic controller. Experimental results show positive performance of the fuzzy logic controller on the voltage control and stability of a synchronous generator in static as well as in dynamic operating conditions.

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