Hybrid Damping Controller for STATCOM to Enhance Power Quality in Multi-Machine System

Nguyen Huu Vinh, Le Kim Hung, Nguyen Hung

Abstract—**In this paper, the hybrid Proportional Integral plus Fuzzy Logic (PI+FL) damping controller is designed for static synchronous compensator (STATCOM) to improve the power quality of a multi-machine system was presented. The operating performance of the studied system is using the popular benchmark three-machine nine-bus system. The two-axis four-order model of synchronous generator (SG) is used. Time-domain scheme based on a nonlinear system model subject to a three-phase short-circuit fault at the load connected bus is utilized to examine the effectiveness of the proposed control schemes. It can be concluded from the simulation results that the designed PI+FL damping controller can enhance the power quality of the studied system.**

Index Terms— **Static Synchronous Compensator, Damping Controller, Multi-machine System, Power Quality.**

I. INTRODUCTION

Flexible AC transmission systems (FACTS) devices have been proposed and implemented in many power systems. In which, static synchronous compensator (STATCOM) plays an important role to improve the power quality. Such as, STATCOM is connected at the point of common coupling (PCC) to maintain stable voltage to improve the power quality by protecting DFIG-based wind farm interconnected to weak grid from going offline during and after the disturbances [1]. A design procedure for STATCOM with constantly updates the parameters of PI controller for voltage regulator to enhance the voltage profile of the multi-machine system under dynamic disturbances has been proposed in [2]. STATCOM can combine with Power System Stabilizer (PSS) in multi-machine power system connected to PV generation for eliminating transient stability is studied in [3]. In [4], the performance of the wind energy PMG-based system employing the dynamic voltage regulator (DVR) is compared to the performance of the system employing the STATCOM. This work recommends using STATCOM in systems with large loads where reactive power consumption from the grid could cause serious effects on connected loads. A state-based controlled doe STATCOM to support DFIG-based wind energy conversion systems during supply grid voltage sags is published in [5]. In another work, a STATCOM has been used to enhance the power stability using fuzzy logic controller (FLC) in the two-area four-generator interconnected power system [6]. Each controller has its advantages and disadvantages, thus in [7], Authors suggested of cooperating PI controller and FL controller to enhance dynamic and steady state performance of a speed controller based interior permanent magnet synchronous motor. In the distributed power system, a distributed STATCOM (D-STATCOM) is proposed and different topologies of FL controller with proportional plus integral control are used to control and maintain THD of the grid side current within the IEEE standards [8].

To enhance the damping of multi-machine power system, in this paper a hybrid PI plus FL damping controller for STATCOM is proposed. The STATCOM is connected to one of the load buses of a benchmark three-machine nine-bus system to absorb/inject reactive power to maintain the voltage at connected bus as well as to damp out the oscillations of the system.

The paper is organized as below. System configuration of the studied system and mathematical models are introduced in Section II. Design damping controller for STATCOM is depicted in Section III. Transient responses of the studied system with and without the designed damping controller are described in Section IV. Finally, specific important conclusions of this paper are drawn in Section V.

II. CONFIGURATION OF THE STUDIED SYSTEM

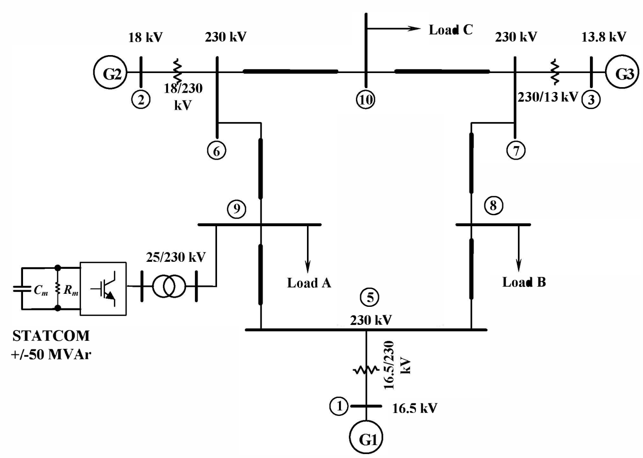

Figure 1. Configuration of the three-machine nine-bus system with STATCOM

Figure 1 shows the configuration of the studied system containing three Synchronous Generators (SGs) supply power to three loads at bus 8, bus 9 and bus 10. A ±50-MVAR STATCOM is proposed and connected to bus 9 of

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the three-machine nine-bus system. The employed mathematical models are described as below.

A. SG model

In this paper, the generating units are modeled by its fourth order dynamic model, including a static excitation system [9]. The set of equations for each generator becomes:

$$\frac{d\delta}{dt} = \omega - \omega_0 \tag{1}$$

$$\frac{d\omega}{dt} = \frac{1}{M}\left(T_m - T_e - D\omega\right) \tag{2}$$

$$\frac{dE_d^{'}}{dt} = \frac{1}{T_{q0}^{'}}\left(-E_d^{'} + \left(x_q - x_q^{'}\right)i_q\right) \tag{3}$$

$$\frac{dE_q^{'}}{dt} = \frac{1}{T_{d0}^{'}}\left(E_{fd} - E_q^{'} - \left(x_d - x_d^{'}\right)i_d\right) \tag{4}$$

$$\frac{dE_{fd}}{dt} = \frac{1}{T_A}\left(-E_{fd} + K_A\left(V_{ref} - V_t\right)\right) \tag{5}$$

where:

δ (rad) and ω (rad/s) represent the rotor angular position and angular velocity;

$E_d^{'}$ (pu) and $E_q^{'}$ (pu) are the internal transient voltages of the synchronous generator;

E_{fd} (pu) is the excitation voltage;

i_d (pu) and i_q (pu) are the d- and q-axis currents;

$T_{d0}^{'}$ (s) and $T_{q0}^{'}$ (s) are the d- and q-open-circuit transient time constants;

$x_d^{'}$ (pu) and $x_q^{'}$ (pu) are the d- and q- transient reactance;

x_d (pu) and x_q (pu) are the d- and q- synchronous reactance;

T_m (pu) and T_e (pu) are the mechanical and electromagnetic nominal torque;

M is the inertia constant;

D is the damping factor;

K_A and T_A (s) are the system excitation gain and time constant;

V_{ref} is the voltage reference;

V_t is the terminal voltage magnitude.

B. STATCOM model

For analyzing the STATCOM, the mathematical model is used. In which, the output voltage is separated into two components represented in d and q axes as follow:

$$v_{dsta} = V_{dcsta} \cdot km_{sta} \cdot \sin(\theta_{bus} + \alpha_{sta}) \tag{6}$$

$$v_{qsta} = V_{dcsta} \cdot km_{sta} \cdot \cos(\theta_{bus} + \alpha_{sta}) \tag{7}$$

where:

v_{dsta} and v_{qsta} are the voltages of d and q axes at the output terminals of the STATCOM, respectively;

km_{sta} is the modulation index of the STATCOM

α_{sta} is phase angle of the STATCOM

θ_{bus} is the voltage phase angle of the common AC bus

V_{dcsta} is the pu DC voltage of the DC capacitor C_m.

The relationship between DC voltage and current of the DC capacitor can be described as

$$(C_m)p(V_{dcsta}) = \omega_b[I_{dcsta} - (V_{dcsta}/R_m)] \tag{8}$$

In which:

I_{dcsta} is the pu DC current flowing into the positive terminal of V_{dcsta}

R_m is the pu equivalent resistance considering the equivalent electrical losses of the STATCOM

i_{qsta} and i_{dsta} are the currents in q and d axes flowing into the terminals of the STATCOM, respectively.

The fundamental control block diagram of the STATCOM including damping controller is shown in Figure 2. The DC voltage V_{dcsta} is controlled by the phase angle α_{sta} while the voltage v_{sta} is varied by changing the modulation index km_{sta}.

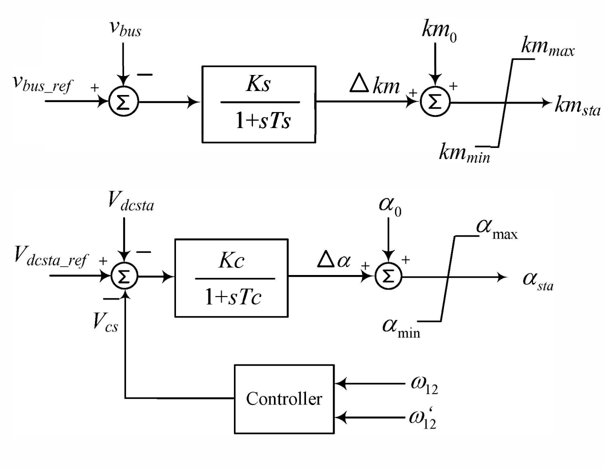


Figure 2. Control scheme of STATCOM

III. DESIGN DAMPING CONTROLLER

The idea for designing the hybrid PI plus Fuzzy logic controller is to compensate for the weakness of the PI controller in cases of large variation to the working equivalent point. The control block diagram is presented in Figure 3 with two inputs are the difference between rotor speed of SG_1 and SG_2 and it derivative.

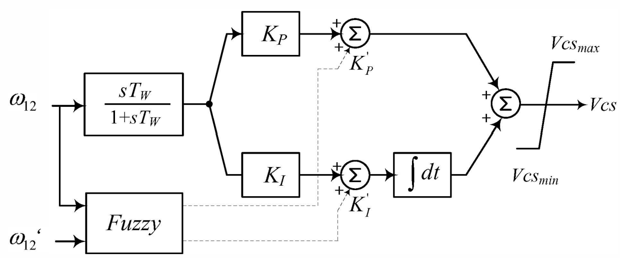


Figure 3. Block diagram of the hybrid PI+FL controller

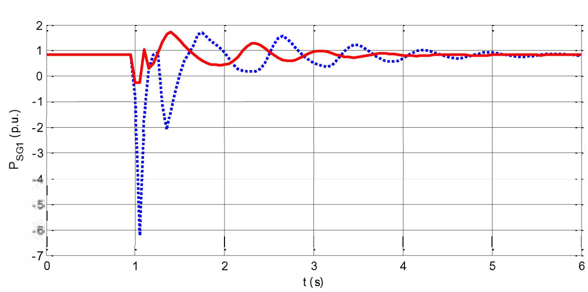
For the PI controller, the parameters are selected by using tuning tool in Matlab, for the Fuzzy logic controller, in this research, five linguistic variables for each input variable are used and denoted as Negative Big_**NB**, Negative Small_**NS**, Zero_**ZR**, Positive Small_**PS**, and Positive Big_**PB**. There are also five linguistic variables for output variable, namely, Increase Big_**IB**, Increase Small_**IS**, Keep Value_**KV**, Decrease Small_**DS** and Decrease Big_**DB**. The control rules subject to the two input signals and the output signal are listed in Table I.

TABLE I. CONTROL RULES OF THE FL

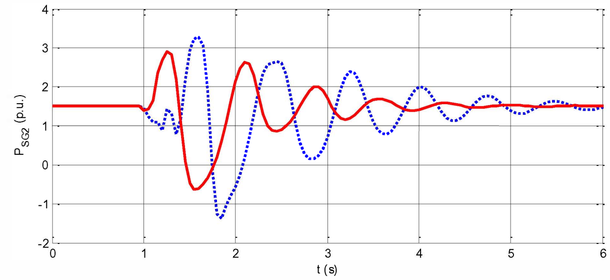
ω_{12}' \ ω_{12}	**NB**	**NS**	**ZR**	**PS**	**PB**
PB	IB	IS	KV	IS	IB
PS	IS	IS	KV	IS	IS
ZR	DS	DS	KV	IS	IS
NS	DS	DS	KV	DS	DS
NB	DB	DS	KV	DS	DB

IV. SIMULATION RESULTS

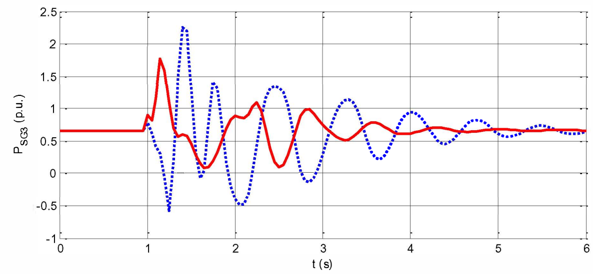
For simulating the studied system, the nonlinear system model is used. The results are performed in MATLAB/SIMULINK toolbox.



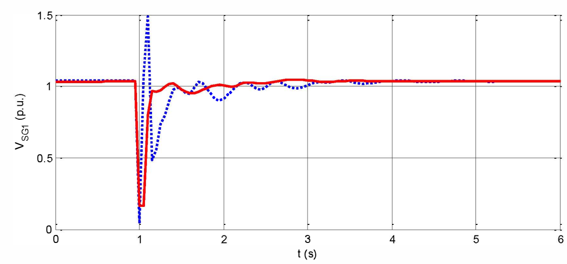
a. Active power of SG_1



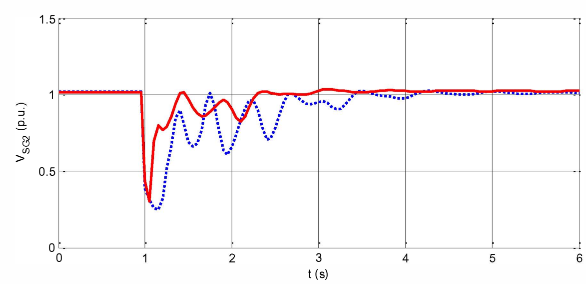
b. Active power of SG_2



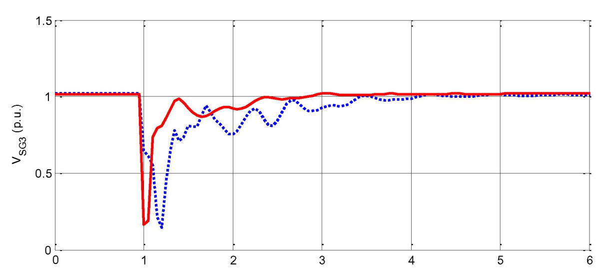
c. Active power of SG_3



d. Voltage of SG_1



e. Voltage of SG_2



f. Active power of SG_3

Figure 4. Simulation results

It is assumed that the three-machine system operates under stable condition as referred to [6]. Simulation results have been presented in Figure 4. This figure plots the comparative transient responses of the studied system with the proposed STATCOM in cases of without controller (blue dotted lines) and with the designed PI+FL (red lines) subject to a three-phase short-circuit fault at bus 9. The three-phase short-circuit fault is suddenly applied to the grid at t = 1 s and is cleared after 0.1 s. In which, Figures 4a to 4c are represented for active power of SG_1, SG_2 and SG_3 respectively. While Figures 4d to 4f are represented for voltage at SG_1, SG_2 and SG_3. It is clearly observed from the comparative transient simulation results shown in Figure 6 that the proposed STATCOM with the damping controller can offer better damping characteristic.

V. CONCLUSION

This paper has presented the stability improvement of a multi-machine system with the STATCOM and the designed PI+FL damping controller. The proposed STATCOM joined with the designed damping controllers on suppressing inherent oscillations of the studied system and improving system stability as well as the power quality of the system under different operating conditions. It can be concluded that the proposed STATCOM joined with the designed damping controller has better damping characteristics to improve the performance of the studied multi-machine system under severe fault.

VI. REFERENCES

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VII. APPENDIX

TABLE II. EMPLOYED SG PARAMETERS

Generator	G1	G2	G3
Rated MVA	247.5	192.0	128.0
Rated kV	16.5	18.0	13.8
Power factor	1.0	0.85	0.85
x_d (pu)	0.146	0.8958	1.3125
x'_d (pu)	0.0608	0.1198	0.1813
x_q (pu)	0.0969	0.8645	1.2578
x'_q (pu)	0.0969	0.1969	0.25
T'_{do} (s)	8.96	6.0	5.89
T'_{qo} (s)	0.31	0.535	0.6
M (s)	23.64	6.4	3.01