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EFFECTIVE WAY TO DAMPING POWER OSCILLATIONS USING STATIC VAR COMPENSATOR WITH FUZZY LOGIC CONTROLLER

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Abstract- This paper presents an application of fuzzy control to determine the control signal of static Var compensator (SVC) for improvement of power system stability. SVC is a shunt type FACTS device which is used in power system primarily for the purpose of voltage and reactive power control. A fuzzy logic based supplementary controller for static Var compensator (SVC) is developed which is used for damping the rotor angle oscillations and to improve the transient stability of the power system. Generator speed and the electrical power are chosen as input signals for the fuzzy logic controller (FLC). The nonlinear fuzzy logic controller is used to overcome the problems generated by different uncertainties existing in power systems when designing electromechanical oscillation damping controllers. Generator speed and its derivative are used to design the controller. The control signal is calculated using fuzzy membership functions. The effectiveness and feasibility of the proposed control method is demonstrated by single machine infinite (SMIB) system and multi machine system.

Keywords: Fuzzy Logic Control, SVC, Transient Stability, PID Controller, Power Oscillations Damping.

I. INTRODUCTION

The challenge facing power system engineers today is to use the existing transmission facilities to greater effect. Transient stability analysis is considered when the power system is confronted with large disturbances. Sudden change in load, generation or transmission system configuration due to fault or switching is examples of large disturbances. Power system should retain its synchronism during and after all these kind of disturbances. Therefore the transient stability is an important security in power system design. So FACTS has come to help the power system engineer [1, 2]. FACTS are a new emerging technology which uses power electronic controlled devices to enhance existing transmission capability.

The SVC is one of the important FACTS devices whose effectiveness for voltage control is well known. The SVC in voltage control mode only, however, does not improve damping, and under certain critical situations, may amplify the power oscillations. Therefore the additional control must be implemented so that the terminal voltage of the SVC is allowed to vary.

The variations must be such that damping torque or accelerating power are provided as needed to reduce the oscillation of real power flow and provides damping enhancement to the electric power system. Both the developed and developing countries may find uses for these new devices. While perhaps less restricted by space or permission to build a transmission line, the developing world is short of capital resources [11-17].

If an investment in FACTS solves a transmission overloading problems without the need of a new transmission line, precious capital resources can be utilized elsewhere. The use of FACTS devices for this purpose is becoming increasingly attractive. FACTS have attracted many researches worldwide using this new technology for power system transient stability enhancement. It encompasses traditional PID [3], transient energy function [4], variable structure system [5, 6], eigen sensitivity [7], robust control [8] and fuzzy control [9, 10].

This paper present a method based on fuzzy logic control for SVC controller which damp out the oscillations at a faster rate. Global input signals such as machine speed (ω) and electrical power (P_e) are given as input to the fuzzy controller.

II. STATIC VAR COMPENSATOR

The Static Var Compensator is basically a shunt connected variable Var generator whose output is adjusted to exchange capacitive or inductive current to the system. One of the most widely used configurations of the SVC is the FC-TCR type in which a Fixed Capacitor (FC) is connected in parallel with Thyristor Controlled Reactor (TCR). The model of SVC is shown in Figure 1. The SVC characteristics is shown in Figure 2. The magnitude of the SVC is inductive admittance $B_L(\alpha)$ is a function of the firing angle α and is given as

$$B_L(\alpha)=\frac{2\pi-2\alpha+\sin 2\alpha}{\pi X_S} \tag{1}$$

where $\frac{\pi}{2} \le \alpha \le \pi$, $X_S = \frac{V_S^2}{Q_L}$, V_S is SVC bus bar voltage and Q_L is MVA rating of reactor.

As the SVC uses a fixed capacitor and variable reactor combination (TCR- FC), the effective shunt admittance is

$$B_S = \frac{1}{X_C} - B_L(\alpha) \tag{2}$$

where X_C is capacitive reactance.

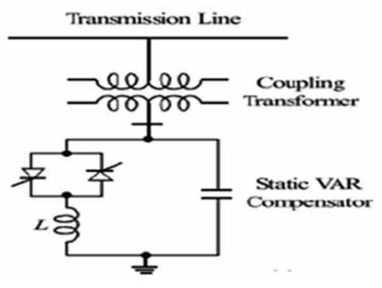

Figure 1. SVC basic model

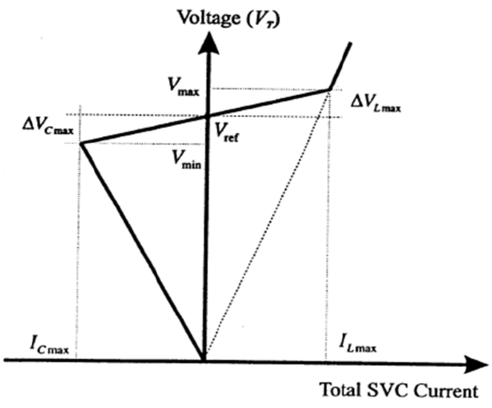

Figure 2. SVC characteristics

III. FLC BASED DAMPING CONTROLLER DESIGN

An SVC with firing control system can be represented for the sake of simplicity by a first order model characterized by a gain K_{SVC} and time constants T_1 and T_2 as shown in the Figure 3. Input signal for SVC is summation of reference voltage and terminal voltage of the generator. An additional damping signal could be drawn from generator to provide extra benefit in the stability performance. In this paper FLC is used to provide this additional damping signal.

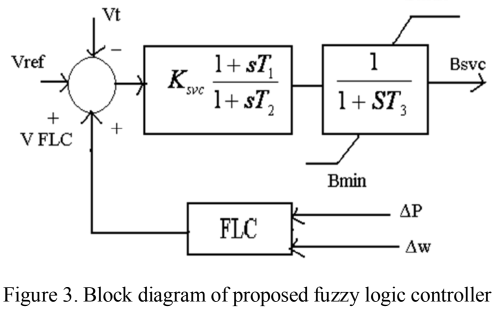

Figure 3. Block diagram of proposed fuzzy logic controller

IV. FUZZY LOGIC CONTROLLER

A Mamdani type double input single output (DISO) fuzzy linguistic controller has been designed which has the following four stages of (1) Fuzzification, (2) Rule-Base, (3) Inference Mechanism and (4) Defuzzification.

Fuzzification is the process of making a crisp quantity fuzzy. But before entering this stage the two input signals ($\Delta\omega$) and (ΔP) are properly scaled by using multiplication factors. These two scaled signals are then fuzzified into two fuzzy variables also called linguistic variables. Each of which consists of fire linguistic terms are also called hedges, they are positive big (PB), positive small (PS), zero (ZE), negative small (NS) and negative big (NB) as shown in Figure 4. Table 1 shows rule bases of membership functions in Figure 4.

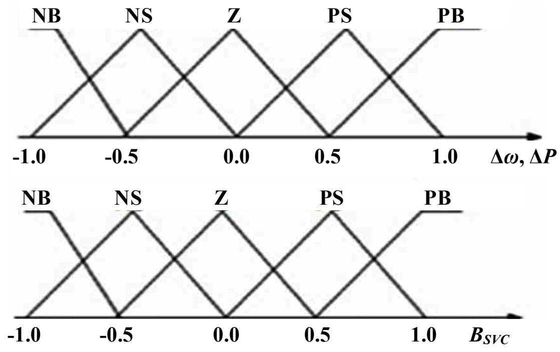

Figure 4. Membership functions of $\Delta\omega$, ΔP and B_{SVC}

Table 1. Rule bases of membership function

Fuzzy Inference Rules						
Output (B_{SVC})				ΔP		
		NB	NS	Z	PS	PB
$\Delta\omega$	NB	NB	NS	NB	NS	Z
	NS	NS	NB	Z	Z	PS
	Z	NS	Z	Z	PS	PS
	PS	Z	Z	PS	PS	PS
	PB	Z	PS	PS	PS	PB

Next the above mentioned linguistic quantification is used to specify a set of rules called a rule-base. The general form of the rules is IF premise THEN consequent. The design of these rules depends on the operators knowledge and experience with two inputs and five linguistic terms or each of these, there are 5×5=25 rules.

For example, rule 1 states that IF ($\Delta\omega$ is NB and ΔP is NB) THEN output is NB. In inference mechanism the premises of all the rules are compared to the inputs to determine which rules apply to the current situation. After this matching process the required rules are fired.

The defuzzification stage produces the final crisp output of FLC on the base of fuzzy input. The center of gravity (COG) law is employed as

$$O/P = \frac{\sum_{i=1}^{5} b_i \int \mu(i)}{\sum_{i=1}^{5} \int \mu(i)} \tag{3}$$

V. SIMULATION RESULTS

To assess the effectiveness of the proposed controller, simulation studies are carried out for the most severe fault conditions and overload conditions in both SMIB system and Multi machine system. The details of the simulation are presented as the following.

A. SMIB System

A SMIB system, equipped with Generator, Transmission line and SVC at the midpoint of the line is shown in Figure 5. The SVC with its controller is place at the midpoint of the transmission line. The fuzzy damping controller for the SVC is developed using Matlab/Simulink and its block diagram is shown in Figure 6. A three phase fault is simulated at the load end at *t* = 0.1 sec. and cleared after 0.05 sec. The system response without SVC is oscillatory and leads to instability.

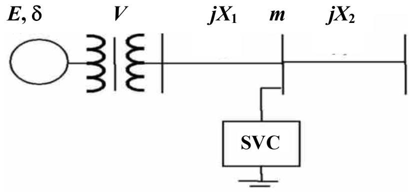

Figure 5. SMIB system with SVC - single line diagram

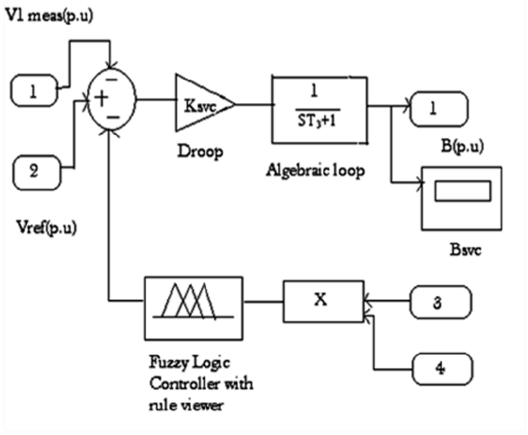

Figure 6. Simulink model of FLC controller for SVC

When the SVC with conventional PID controller is placed at bus 1 and the same fault condition is simulated, it is observed that the damping is improved but still oscillations are present. With the FLC based SVC the oscillations are fully damped out and the system comes back to original steady state. Figures 9, 10 and 11 show the dynamic response of the power angle δ and the speed deviation $\Delta\omega$, under fault conditions with different controllers.

B. Multi Machine System

The same SVC controller with FLC is implemented in the 3 machine nine bus system (WSCC system). The one line diagram of WSCC system is given in Figure 7. Power system data is given in [8]. Power system stabilizers with IEEE type DC1 exciter are equipped with the generators.

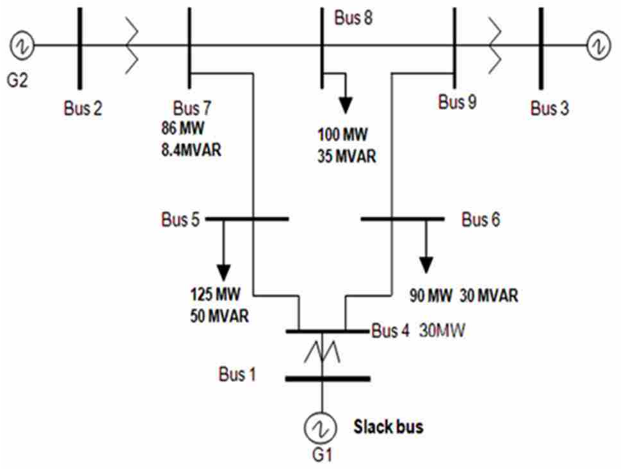

Figure 7. One line diagram of WSCC system

C. Simulation of SMIB System

The Simulink diagram of single machine infinite bus (SMIB) is shown in Figure 8. Figure 9 shows rotor angle changes with respect to time, here rotor oscillations maximum 58 degrees to minimum 8 degrees and also speed deviation changes from 1.8 to 0.8.

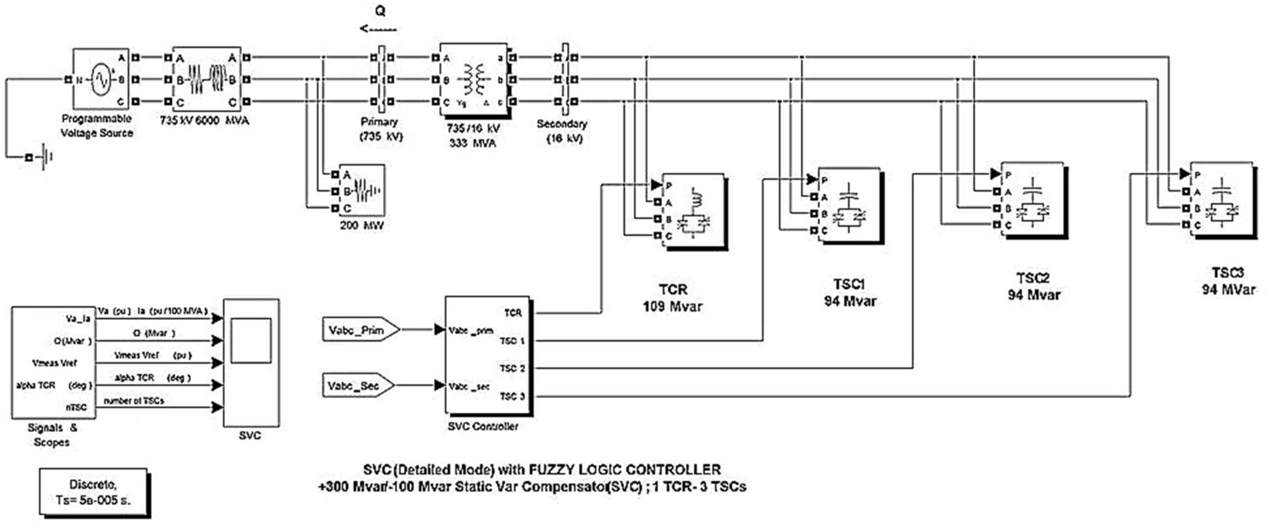

Figure 8. Simulink diagram of single machine system

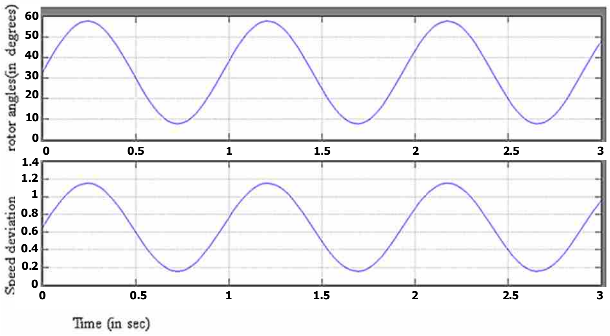

Figure 9. Variation in rotor angle and speed deviation with no controllers

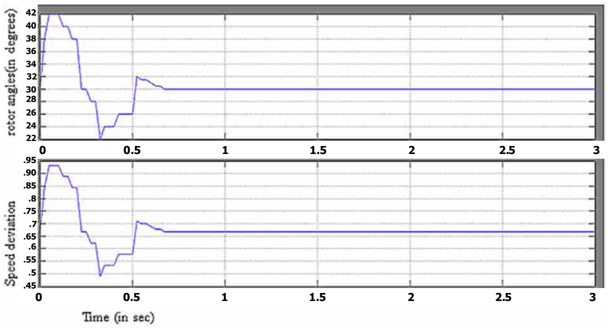

Figure 10. Variation in rotor angle and speed deviation with PID controllers

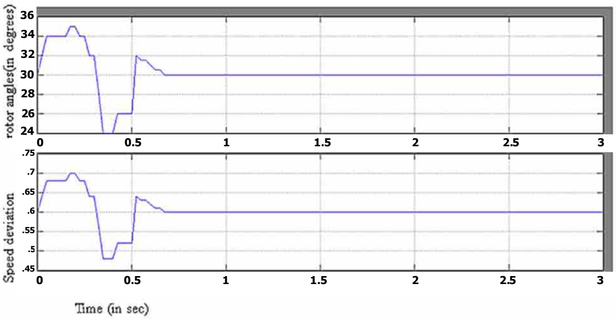

Figure 11. Variation in rotor angle and speed deviation with fuzzy controllers

Figure 10 shows rotor angle changes with respect to time, here rotor oscillations maximum 46 degrees to minimum 22 degrees and also speed deviation changes from 0.94 to 0.5. Figure 11 shows rotor angle changes with respect to time, here rotor oscillations maximum 35 degrees to minimum 24 degrees and also speed deviation changes from 0.7 to 0.48.

D. Simulation of Multi Machine System

D.1. Case 1: Three-Phase Fault Condition

The FLC based SVC is installed at bus 8 in Figure 7 near the generator 2. With the initial power flow conditions, a three phase to ground short circuit was simulated near bus 7. In Figures 13 to 20 the variation of rotor angle δ, SVC voltage, speed deviation $\Delta\omega$, and the suceptance B_{SVC} of SVC with PID controller and with FLC based SVC controller are plotted.

In this study case, fault condition at 0.3 seconds, existing for the period of 0.1 second and cleared at 0.4 seconds. It is clear that the rotor angle damping using fuzzy controller is more effective than PID controller. The settling time of both controllers is found to be same, but the amplitude of rotor angle is reduced in FLC controller. Figure 12 shows SVC voltage in pu fault with FLC for three-phase fault at bus 7 fuzzy controller which the variations are from 1.2 pu to 0.2 pu when fault occurred but it settled quickly to 1 pu.

From Figure 13, it is observed that the bus voltage of SVC with the proposed FLC is reduced during fault conditions which the variations are from 1.3 pu to 0.1 pu when fault occurred but it settled slowly compared to fuzzy controller to 1 pu.

If PID controllers employed, the SVC voltage increases during fault period which causes additional voltage injection in the system instead of current injection. This will be the remarkable advantage while using a FLC based controller.

From Figure 14, it is identified that the angular speed deviations $\Delta\omega$ for fuzzy controller which is same for the PID controller and in post fault period, the angular speed deviations are quickly reduced using FLC controller.

In Figure 15, the injection of B_{SVC} during fault condition for fuzzy controller is demonstrated which is same for the PID controller. When the fault occurs, the suceptance injected will be at maximum of 1.25 pu and due to the firing angle control through FLC; it was immediately thrown off to inductive effect from capacitive effect.

D.2. Case 2: Over Loaded Condition

In this case, with the same location of SVC at bus 8, power of load bus 7 is increased to 1.5 pu at 0.5 second with 0.5 second duration. The system response is studied with both PID and FLC based SVC controller. For this overloaded condition also, SVC supplies reactive power during this period and quickly maintains the system stability.

For the time interval of 0.5 seconds, the suceptance is included and at the period of 1 second, the capacitive effect is changed over to inductive effect and regains its state at quicker time with the presence of FLC-SVC controller.

Figure 16 shows control of B_{SVC} not effective way when using PID controller compared to fuzzy controller. Figure 17 shows effective way to control of B_{SVC} when using fuzzy controller.

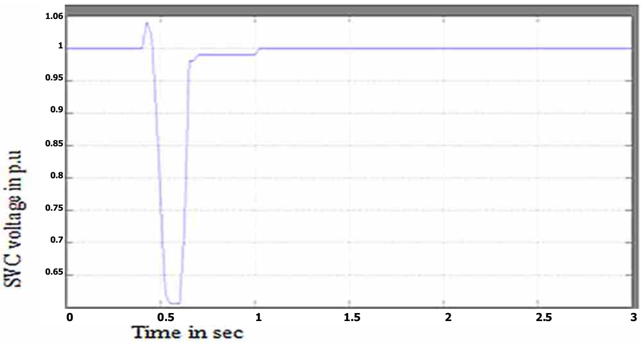

Figure 12. SVC voltage in pu fault with FLC for 3-phase fault at bus 7

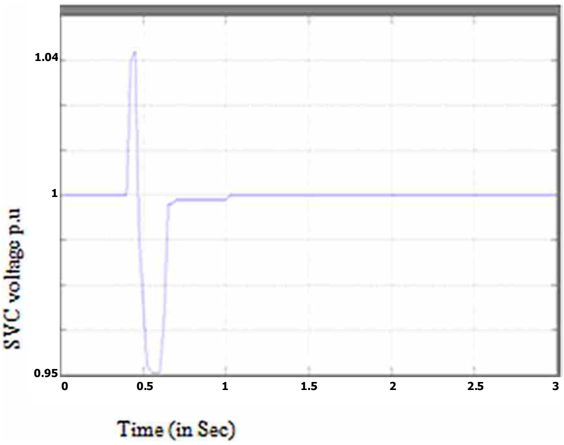

Figure 13. SVC voltage in pu fault with PID for 3-phase fault at bus 7

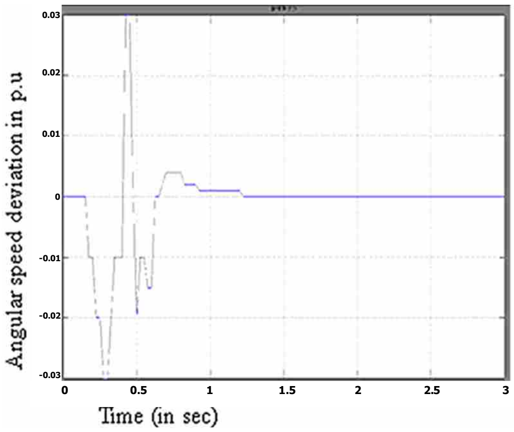

Figure 14. Angular speed deviation in pu unit for 3-phase fault at bus 7 using fuzzy controller

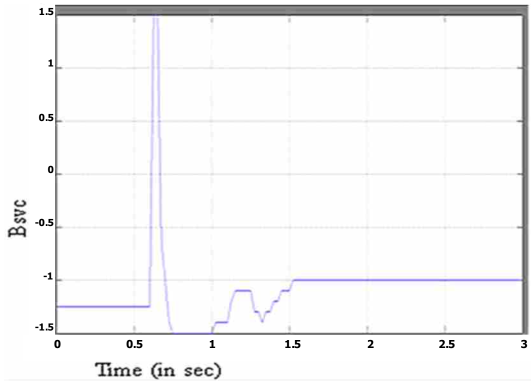

Figure 15. Control of B_{SVC} with fuzzy based SVC for 3-phase fault at bus 7

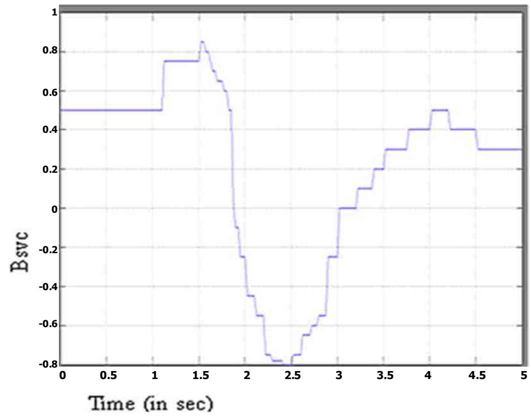

Figure 16. Control of B_{SVC} for PID-SVC and loading conditions of 1.5 pu

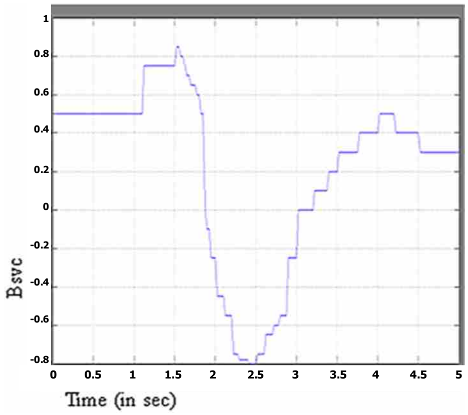

Figure 17. Control of B_{SVC} for FLC SVC and loading conditions of 1.5 pu

VI. CONCLUSIONS

This study presented the method of improving power system oscillation using a SVC. The mathematical model of power system equipped with a SVC was systematically derived. It was found that a SVC affects on the line Voltage. The dynamic performance of the power system can be controlled by a SVC. This study applied fuzzy logic control to determine the control law of SVC. From the simulation results, it indicates that a SVC based fuzzy logic control can improve the power system oscillation.

The proposed FLC for SVC is proved to be very effective and robust in damping power system oscillations and thereby enhancing system transient stability. Fuzzy rules are easily derived from the measurable global signals like line active power flow, and remote generator speed deviation. The performance of various controllers is compared based on non linear simulation. Among these the performance of the proposed controller is found to be better and damp out the system oscillations at faster rate. The proposed FLC for SVC is proved to be very effective and robust in damping power system oscillations and thereby enhancing system transient stability.

APPENDICES

Appendix 1. Modeling of Power System Components

Generator: The generator is represented by third order model comprising the electromechanical swing equation and generator internal voltage equations are [10]:

$$\dot{\omega} = \frac{1}{M}(P_m + G + K_d\omega - P_e) \tag{4}$$

$$\dot{E}'_q = \frac{1}{T'_{do}}(E_{fd} + (x_d - x'_d)i_d - E'_q) \tag{5}$$

where,

δ: Rotor angle in degrees

P_m: Mechanical power developed by the generator

K_d: Damping constant of the generator

P_e: Electrical Power delivered in pu

X_d, X_q: Direct and quadrature axis reactance of the generator in pu

E_d, E_q: Direct and quadrature axis voltages behind the transient reactance in pu

Appendix 2. Solution for Multimachine Systems

$$P_{ei} = \sum_{j=1}^{m} E_i E_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j) \quad (6)$$

$$\frac{H_i}{\pi f_0} \frac{d^2 \delta_i}{dt^2} = P_{mi} - \sum_{j=1}^{m} E_i E_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j) \quad (7)$$

Appendix 3. System Data

Synchronous Machine Data:

$X_d = 1.8,\ X'_d = 0.3,\ X''_d = 0.15$

$X_q = 1.8,\ X'_q = 0.0,\ X''_q = 0.15$

$T'_{do} = 6.0,\ T''_{do} = 0.04$

$T'_{qo} = 0.2,\ T''_{qo} = 0.0$

$H = 4,\ K_d = 0.0$

$R = 0.002,\ X_1 = 0.0$

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BIOGRAPHIES

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