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Improving Transient Stability in Power Systems by Using Fuzzy Logic Controlled SVC

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ABSTRACT

This paper presents the capability of a fuzzy logic based stabilizer used for generating the supplementary control signal to voltage regulator of static VAR compensator (SVC) for improving damping oscillations in power systems. Generator speed deviation and line active power were chosen as input signals for the fuzzy logic controller (FLC). The quantity of reactive power supplied/absorbed by SVC is determined based on the two input signal and deviation of terminal voltage at each sampling time. The effectiveness and feasibility of the proposed control is demonstrated with Single Machine Infinite Bus (SMIB) system and multi machine system which show improvement over the use of a fixed parameter controller. It has been observed that a robust controller is obtained with fuzzy logic controller.

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1. INTRODUCTION

Power system Stability is the ability of the system to regain its original operating conditions after a disturbance to the system. Power system transient stability analysis is considered with large disturbances like sudden change in load, generation or transmission system configuration due to fault or switching. Dynamic voltage support and reactive power compensation have been identified as a very significant measure to improve the transient stability of the system. Flexible AC Transmission Systems (FACTS) devices with a suitable control strategy have the potential to increase the system stability margin [1-2]. SVC is one of the important flexible AC transmission systems (FACTS) devices whose effectiveness for voltage control is well known. Compared with conventional switched reactors or shunt capacitors, SVC can provide control actions continuously and rapidly. Also, it has been successfully used to damp out power system oscillations [3]. Recently, much effort has been directed towards the applications of fuzzy control in power systems [1-5], also there are a few papers with an application of fuzzy control to SVC [6-8].

A significant contribution to system damping can be achieved when a SVC is controlled by some auxiliary signals superimposed over its voltage control loop [9]. It is possible to design a FLC by taking into account the non linearity of Power system. In this paper a fuzzy based SVC stabilizer used for generating the supplementary Signal to voltage control loop of SVC is proposed. The supplementary signal is calculated using Fuzzy membership. Fuzzy logic control approach is an emerging tool for solving complex problems whose system behavior is complex in nature. An attractive feature of fuzzy logic control is its robustness in system parameters and operating conditions changes [9]. Fuzzy logic controllers are capable of tolerating uncertainty and imprecision to a greater extent [9]. This paper presents a method based on fuzzy logic control for SVC controller which damp out the oscillations at a faster rate. Simulation results for a Single Machine Infinite Bus System (SMIB) and a Multi machine system (WSCC system) are presented and discussed.

2. SVC MODELING

Explaining 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 magnitude of the SVC is inductive admittance B (α) is a function of the firing angle α and is given by;

$$B_L(\sigma) = \frac{\sigma - \sin\sigma}{\pi x_L} \tag{1}$$

$$B = B_L - B_C \tag{2}$$

An SVC with firing control system can be represented, for the sake of simplicity by a first order model characterized by a gain KSVC and time constants T1 and T_2 as shown in Figure 1 The controller send firing control signals to the thyristor switching unit to modify the equivalent capacitance of the SVC. The fuzzy controller provides an auxiliary control, which is in addition to the voltage feedback loop.

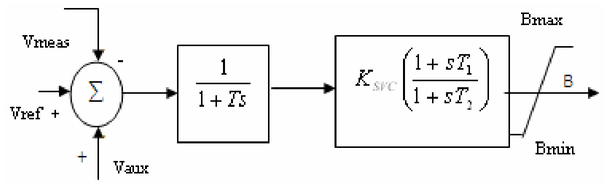

Figure 1. Block representation of SVC control

3. REVIEW OF FUZZY LOGIC

Fuzzy set theory provides an excellent means for representing uncertainty due to vagueness in the available data or unknown behavior of a system. It can represent the human control processes and also allows experimental knowledge in adjusting the controller parameters.

3.1 Fuzzy sets

A fuzzy set is a collection of distinct elements with a varying degree of relevance or inclusion. If X is a set of elements, then a fuzzy set A in X is defined to be a set of ordered pairs

$$A = \{(x, \mu_A(x)\} \qquad x \in X \tag{3}$$

Where $\mu_A(x)$ is called the membership function of x in A. This membership function can take where denotes the degree to which x belongs to A and is normally implies that it is very likely for x to be in A limite to values between 0 and 1.A high value of $\mu_A(x)$ implies that it is very likely for x to be in A.

3.2 Fuzzy Inference system

With cause effect relationship expressed as a collection of fuzzy if–then rules in which the preconditions uses linguistic variables and the consequent have class labels, qualitative reasoning is performed to infer the results. In our model Mamdani inference system with product t-norm and max t-co norm is used. Here, the set of sensor input is matched against if part of each if–then rule, and the response of each rule is obtained through fuzzy implication operation. The response of each rule is weighted according to the extent to which each rule fires. The response of all the fuzzy rules for a particular output class are combined to obtain the confidence with which the sensor input is classified to that fault class.

3.3 Defuzzification

The output of a fuzzy rule based system is generally imprecise and fuzzy. As a fuzzy set cannot directly be used to take the decisions, the fuzzy conclusions of rule based systems have to be converted in to precise quantity. This is called Defuzzification. There are various methods like centroid method, weighted average method and max-membership method etc for this purpose.

3.4 FLC based damping controller design

Figure 2 shows the schematic diagram of a SVC along with fuzzy logic based damping controller. Generator speed deviation (Δω) and (ΔP) are taken as the input signals of the fuzzy controller. The number of membership functions for each variable determines the quality of control which can be achieved using fuzzy logic controllers. In the present investigation, five membership functions are defined for the input and output variables.

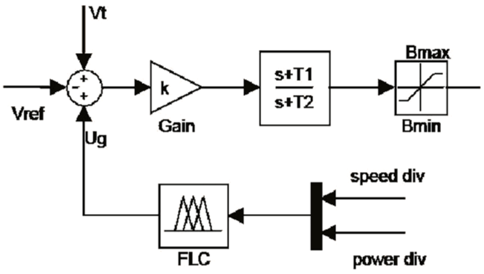

Figure 2. Block diagram of proposed Fuzzy logic controller

Figure 3 shows the membership functions defined. The mentioned membership functions are used to specify a set of rules called a rule base. The rules developed are based on the knowledge and experience. With two inputs and five linguistic terms, 25 rules were developed which is given in Table 1. In inference mechanism all the rules are compared to the inputs to determine which rules apply to the current situation. After the matching process the required rules are fired. The controlled output Bsvc is determined for the different input conditions. The defuzzification produces the final crisp output of FLC with the fuzzified input. Centroid method is employed where the output will be calculated as

$$OIP = \frac{\sum_{j=1}^{5} bi \int \mu_i(x)}{\sum_{i=1}^{5} \int \mu_i(x)} \tag{4}$$

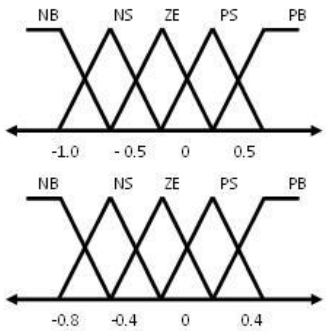

Figure 3. Membership functions of Δω, ΔP and Bsvc

Table 1 Fuzzy Inference Rules

O.P signal		Δω					
		PB	PS	ZE	NS	NB	PB
ΔP	E	NS	NB	NS	NB	NB	E
	PS	ZE	ZE	NB	NS	NS	PS
	PS	PS	ZE	ZE	NS	ZE	PS
	PS	PS	PS	ZE	ZE	PS	PS
	PB	PS	PS	PS	ZE	PB	PB

4. CASE STUDY

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 here.

4.1 SMIB System

The A single machine-infinite bus (SMIB) system is considered for the present investigations. A machine connected to a large system through a transmission line may be reduced to a SMIB system, by using Thevenin's equivalent of the transmission network external to the machine. Because of the relative size of the system to which the machine is supplying power, the dynamics associated with machine will cause virtually no change in the voltage and frequency of the Thevenin's voltage E_B (infinite bus voltage). The Thevenin equivalent impedance shall henceforth be referred to as equivalent impedance (i.e.R_e+jX_e). A SMIB system, equipped with Generator, Transmission line and SVC at the midpoint of the line is shown in Figure 4 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.

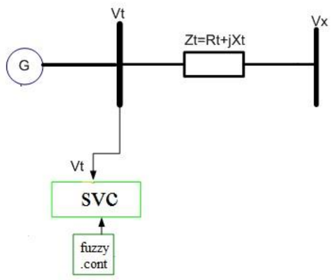

Figure 4. A single machine-infinite bus (SMIB) system

Generator equations are as fallow:

$$\frac{d\delta_j}{dt} = \omega_j - \omega_o \tag{5}$$

$$\frac{d\omega_j}{dt} = \frac{1}{M}(p_{mj} + K_d\omega_j - P_{ej}) \tag{6}$$

$$\frac{dE'qj}{dt} = \frac{1}{T'_{do}}(E_{fj} - E'_{qj} + (x_{dj} - x'_{dj})i_{dj}) \tag{7}$$

$$\frac{dE'dj}{dt} = \frac{1}{T'q_0}(-E_{dj} + (x'_{qj} - x_{qj})i_{qj}) \tag{8}$$

$$\frac{dE''_{dj}}{dt} = \frac{1}{T'_{qo}}(E'_{dj} - (x'_{qj} - x''_{qj})i_{qj} - E''_{dj}) \tag{9}$$

$$\frac{dE''_{qj}}{dt} = \frac{1}{T''^{0}_{d0}}(E'_{qj} + (x'_{dj} - x''_{dj})i_{dj} - E''_{qj}) \tag{10}$$

$$i_{dj} = G_{jj}E''_{dj} + B_{jj}E''_{qj} + \sum_{\substack{k=1\\k\neq j}}^{n} \left\{ \begin{array}{l} E''_{dk}(G_{jk}\cos\delta_{jk} + B_{jk}\sin\delta_{jk} \\ + \\ E''_{qk}(B_{jk}\cos\delta_{jk} - G_{jk}\sin\delta_{jk} \end{array} \right\} \quad (11)$$

$$i_{qj} = G_{jj}E''_{qj} - B_{jj}E''_{qj} + \sum_{\substack{k=1\\k\neq j}}^{n} \left\{ \begin{array}{l} E''_{qk}(G_{jv}\cos\delta_{jk} + B_{jk}\sin\delta_{jk} \\ + \\ E''_{dk}(B_{jk}\cos\delta_{jk} - G_{jk}\sin\delta_{jk} \end{array} \right\} \quad (12)$$

$$V_{dj} = E''_{dj} - r_j i_{dj} - x''_{qj} i_{qj} \quad (13)$$

$$V_{qj} = E''_{qj} - r_j i_{dj} + x''_{idg} \quad (14)$$

$$V_j = \sqrt{V^2{}_{dj} + V^2{}_{dj}} \quad (15)$$

$$P_e = E''_{dj} i_{dj} + E''_{qj} i_{qj} + (x''_{dj} - x''_{dj}) i_{dj} i_{qj} \quad (16)$$

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. When the SVC with conventional PID 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 5 and 6 show the dynamic response of the speed deviation $\Delta\omega$ and the power angle δ, under fault conditions with FLC-SVC.

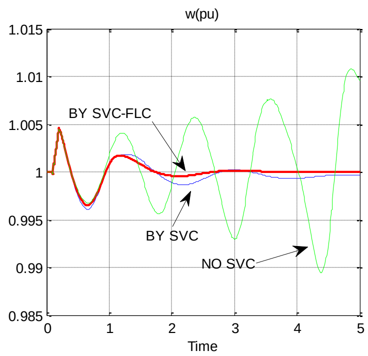

Figure 5. Speed deviation for FLC- SVC

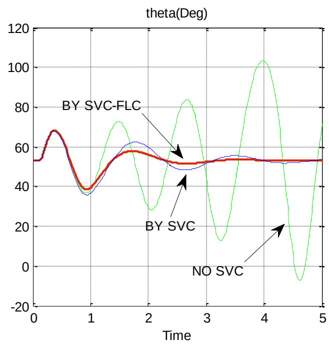

Figure 6. Angle response for FLC- SVC

Figures 7 and 8 show the dynamic response of the voltage deviation and the line power, under fault conditions with FLC-SVC.

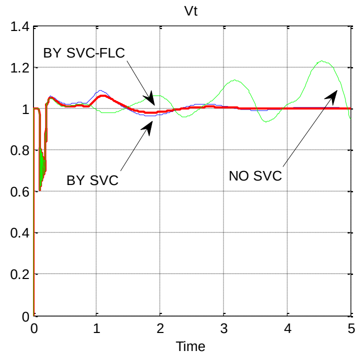

Figure 7. Terminal voltage for FLC- SVC

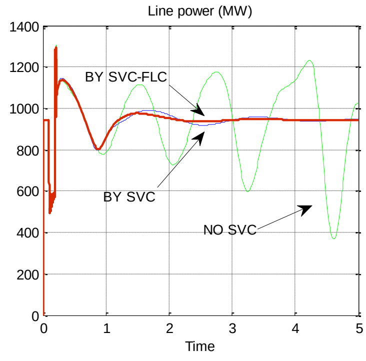

Figure 8. Line power for FLC- SVC

4.2 Multi machine system

The same SVC controller with FLC is implemented in two area 4 machine system (WSCC system). The one line diagram of WSCC system is given Figure 9. Power system data is given in [8].

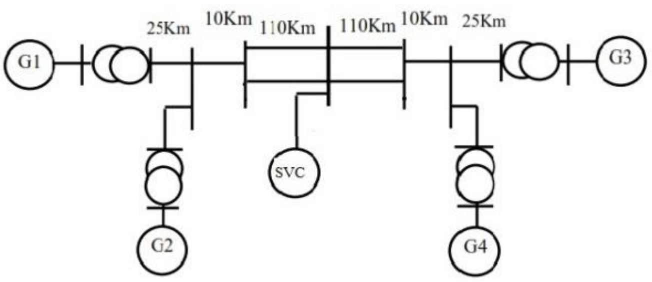

Figure 9. Two area 4 machine system

The FLC based SVC is installed at bus7 of the transmission line. With the initial power flow conditions, a three phase to ground short circuit was simulated near bus 7. In this study case, fault condition at 0.3 seconds, existing for the period of 0.1 second and cleared at 0.4 seconds. From Figures 10-13 it is clear that the rotor angle damping using fuzzy controller is suitable under fault conditions with FLC-SVC.

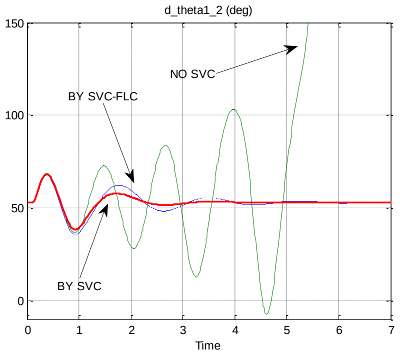

Figure 10. Angle response for FLC- SVC between G1-G2

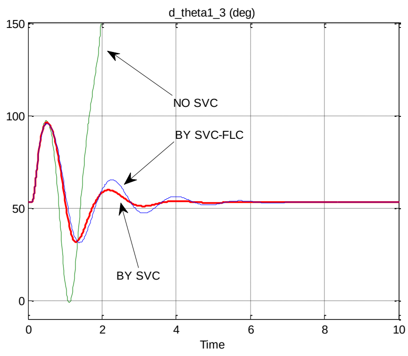

Figure 11. Angle response for FLC- SVC between G1-G3

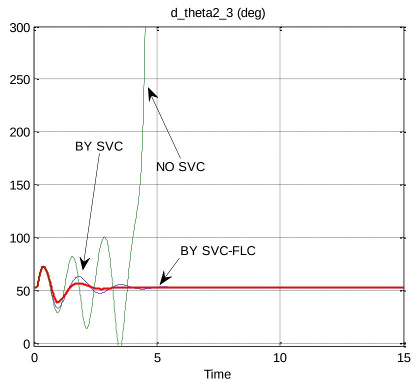

Figure 12. Angle response for FLC- SVC between G2-G3

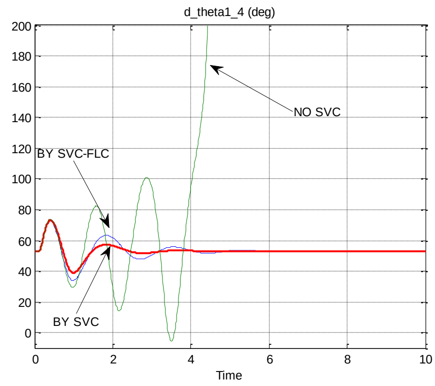

Figure 13. Angle response for FLC- SVC between G1-G4

5. CONCLUSION

This paper presents the application of a fuzzy logic based auxiliary control for an SVC to achieve transient stability enhancement. 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 controller is inspected based on non linear simulation results. The performance of the proposed controller is found to be better damp out the system oscillations at faster rate. It was also observed that for both SMIB system and multi machine system, SVC controller works accurately. Digital computer simulations were performed using MATLAB/ SIMULINK software.

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