Desgin of Static Var Compensator Fuzzy Controller for Damping Power System Oscillations

Mohammadzaman Zamani[1],Ghazanfar Shahgholian[2], Abbas Arab Dardori[3]
1. Department of Electrical Engineering, Islamic Azad University , Najafabad Branch, Najafabad, Iran
Email: Zamani_Mohammadzaman@yahoo.com
2. Department of Electrical Engineering, Islamic Azad University , Najafabad Branch, Najafabad, Iran
Email: shahgholian@iaun.ac.ir
3. Department of Electrical Engineering, Islamic Azad University , Najafabad Branch, Najafabad, Iran
Email: Abbas_arab88@yahoo.com

Received: January 2014 Revised: February 2014 Accepted: May 2014

ABSTRACT
Static var compensator (SVC) as the shunt reactive power compensator plays a major role in enhancing the transient stability, minimizing low frequency oscillations, etc . The present paper investigate and improves the damping of oscillations of a single machine connected to infinite bus by the presence of SVC in line. By simulating the suggested system with using simulink Matlab and applying an fault to the system ,First, we are going to examine the simulated power system by using proportional , integral and derivative (PID) controllers, then instead of PID, fuzzy logic controller (FLC) is used which is designed for SVC ,and consequently the results of computer simulation will extract. The study of results is observed that the fuzzy controller has a better performance on improving the oscillations damping than PID controller.

KEYWORDS: Damping Power System Oscillations, Fuzzy Controller, PID, SVC

1. INTRODUCTION

power system Stability is the ability of an electric power system for a given initial operating condition to regain a state of operating equilibrium after being subjected to a physical disturbance. Power Systems Transient Stability analysis is considered with Large disturbances like sudden changes in load, generation or transmission system form or due to fault or switching [1]. Dynamic voltage fortification and reactive power compensation are an important measure for improving transient stability of the system. Flexible AC Transmission Systems (FACTS) devices with a Suitable controllers are designed to increase the stability of the system [2, 3]. Movement of shunt FACTS devices play an important role in reactive power flow in power network. In large power system, low frequency electrical oscillations often follow electrical disturbances. Generally, power system stabilizer (PSS) constantly is used with automatic voltage regulator (AVR) to damp out the oscillations. However, during the operating conditions, in some cases, these devices do not produce appropriate damping and effective Changes in increasing stabilizer of power system (PSS), which is needed [4]. In other words, to achieve oscillations damping, shunt FACTS devices to Static var compensator (SVC) which are designed with auxiliary controllers are used [5]. So SVC is more effective when it is adjusted by complemented controller, and by adjusting equivalent shunt capacitance, SVC can damp out the oscillations and improve the general stability of the system [6,7]. Various methods for the design of the SVC supplementary controllers are available. In [8] a Proportional – integral – Derivative (PID) was used in SVC. It was the genies of the improvement of the system damping which is acquired by PID on the basis of SVC. Although PID controllers are easy to design, but their efficiency in system operating conditions when most of the time oscillations and disturbances occur frequently is worse. Fuzzy logic control approach is a tool for solving complex behavioral system problems which has complex external existence. An interesting feature of fuzzy logic control is its power in switching the operating conditions and parameters of the system. Fuzzy logic controllers are capable of uncertain and wrong things to bear a larger space [9]. this paper presents, a method based on Fuzzy logic controller for SVC controller that damp out the oscillations at a faster rate. input signals such as machine speed (ω) and electric power (P_e) are fuzzy controller inputs. Simulation results for a single machine connected to infinite bus system are presented and discussed. At the end, comparisons were done between PID and Fuzzy Logic controller.

2. MODELING AND CONTROL OF SVC

Static Var Compensator is basically a shunt connected of variable reactive generator that its output is set based on the capacitive changes and the inductive current system. One of the frequently used form of SVC is FC-TCR type in a way that a fixed capacitor is connected in parallel with Thyristor controlled reactor (TCR). Admittance magnitude of inductive SVC ($B_L(\alpha)$) is the Function of firing angle α, and it is as follows:

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

For $\pi/2 \le \alpha \le \pi$ where $X_s = \frac{V_s^2}{Q_L}$, V_s is bus voltage of SVC and Q_L is MVA rating of reactor. When SVC uses fixed capacitor and variable reactor combination (FC-TCR) then its efficient shunt admittance is:

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

Here X_c is the capacitor reactance.

In Figure 1, SVC is shown with the fire control system, Due to the simplicity by a first order model characterized by a gain K_{SVC} and t_1‘ t_2 are considered as time constants. Controller sends the fire control signal to the thyristor switching to improve the equal capacitance in SVC. The Fuzzy controller provides a auxiliary controller, that addition with the voltage feedback loop. In order to improve the overall dynamic system, in SVC auxiliary control loop, the stabilizing signal, such as speed, frequency, the phase angle differences, etc are used.

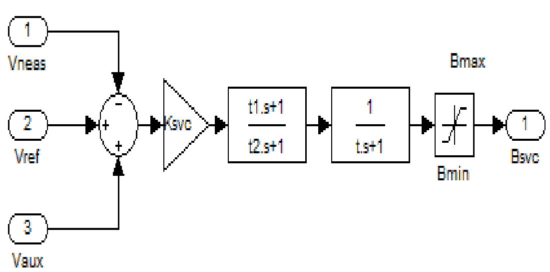

Fig .1: Construction of a SVC Control

3. OVERVIEW OF FUZZY LOGIC

Fuzzy set theory provides a precise ability to express uncertainty in the estimation error of the available data or unknown behaviour of the system. It can express human control methods and experimental knowledge to adjusting the parameters of the controller.

3.1. Fuzzy set

A fuzzy set is a set of elements with a certain degree of relationships and the capacity. If we consider X as a set of x elements, Then the A fuzzy set is defined in X as ordered pairs:

$$A = \{(x, \mu_A(x)) \vdots x \varepsilon X \quad (3)$$

μ_A (x) is called as a membership function of X in A. This membership function maps each member of X belongs to A with a degree of membership which is a value between 0 and 1. A large amount of μ_A (x) indicates that it is likely that X is in A.

3.2. Fuzzy if-then rules

In Fuzzy models that reflect one's knowledge, Input feature and Output row by fuzzy If– Then rules are like below:

$$R_j = if\ X\ is\ A\ then\ Y\ is\ B \quad (4)$$

A and B values are defined by fuzzy sets on the sets Y and X. "X is A " is often known as the primary or assumption and "Y is B" as the result. Fuzzy rules can be created by a skilled person, expert, engineer or designer or nonlinear Simulation.

3.3. Fuzzy Inference System

Fuzzy Inference System is a process, in which the mapping from inputs to outputs will be legitimized from inputs to outputs by using Fuzzy Logic, and the concept consists of three parts. The first part is rules, which are the selection of fuzzy rules. The second part is the database. The membership functions used in the fuzzy rules are defined in this part. The third part is related to inference mechanism thereby inference procedure is done by inference rules and facts to achieve a reasonable output.

3.4. Defuzzification

The output of each system based on fuzzy rules is often imprecise and fuzzy. This fuzzy result is converted to a numeric value. This method is called Defuzzification . There are several methods such as Centroid method, the maximum mean, the smallest maximum, etc which are used for this purpose.

4. FUZZY CONTROLLER

The Fuzzy Controller which is considered in this paper is the Mamdany type of the two input signals and one output signal which can be seen in the block diagram in Figure 2.

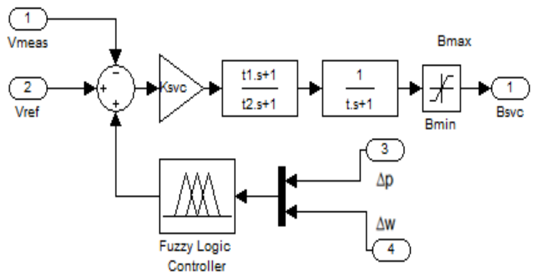

Fig. 2. Block diagram of a fuzzy logic controller

For Fuzzy controller design, in the first phase, the input signals must be fuzzed to Fuzzy controller, which contains the generator speed deviation (Δω) and electric power changes (Δp). Fuzzy modelling is taking the actual value to a fuzzy value, but before entering this phase the input signals must have been measured by the multiplied factors. Then these two measured signals are going to be fuzzed to the two fuzzy variables that are known as linguistic terms.

For each of the input variables we have defined 5 linguistic terms which are: NB (large negative) NS (Small negative) Z(zero) PB(Large positive) and PS (small positive), which are shown in Figures 3 and 4. In second phase we should obtain a set of fuzzy relations based on these linguistic terms have been used for fuzzy rules. These rules are designed based on personal knowledge and experience. In this paper, two inputs, 5 linguistic terms, 25 rules are explained and shown in Table1. If we want to explain the first law based on table 1:

R1) if Δω is NB and Δp is NB then B_{svc} NB

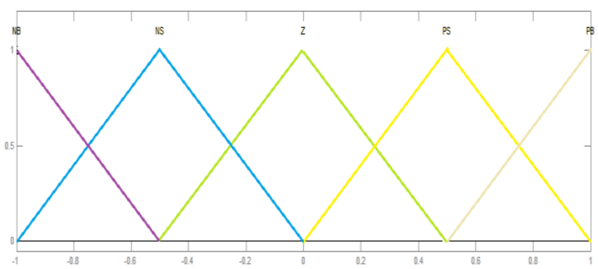

Fig .3. Membership functions of inputs

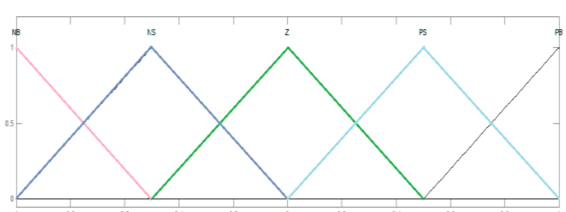

Fig .4. Output membership functions

Table 1: Fuzzy rules

O/P Signal		ΔW				
		NB	NS	ZE	PS	PB
ΔP	NB	NB	NS	NB	NS	ZE
	NS	NS	NB	ZE	ZE	PS
	ZE	NS	ZE	ZE	PS	PS
	PS	ZE	ZE	PS	PS	PS
	PB	ZE	PS	PS	PS	PB

In third phase, all rules are compared with the input and determined which rule should be applied to the current situation. Just after processing, the desired conditions are selected. However, the output of the fuzzy controller is in the number form in the system, the output is fuzzy and unclear for the system. So it should be defuzzification. In this paper the centroid method is used, and Output is calculated according to the equation (5). Here bi is the centre of membership functions and μi is of the fuzzy system.

$$O/P = \frac{\sum_{i=1}^{5} b_i \int \mu_i}{\sum_{i=1}^{5} \int \mu_i} \tag{5}$$

5. STUDY OF PRESENT POWER SYSTEM

Figure 5, shows a single machine connected to infinite bus with intended SVC in the present paper. Synchronous generator deliver and transfers power to an infinite bus using two transmission lines, which are located parallel to each other. In Figure 5 V_t and E_b, bus terminal and infinite bus voltage, and X_t, X_1 and X_2 are reactance transformer and transmission line, respectively.

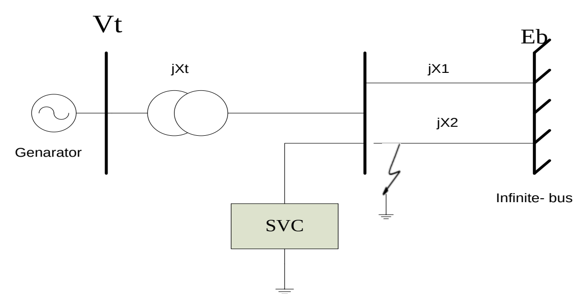

Fig .5. A single machine connected to infinite bus power system with SVC

5.1. Modelling synchronous generator connected to infinite bus power system

Synchronous generators presented in this paper are the model (1.1). A field is placed on the axis q with the Field circuit, and then machine equations are as follows [10]. And all the relationships abbreviations which are presented in this paper listed in Appendix B.

$$\dot{\delta} = \omega_B (S_m - S_{m0}) \tag{6}$$

$$\dot{S}_m = \frac{1}{2H}\left[-D(S_m - S_{m0}) + P_m - P_e\right] \tag{7}$$

$$\dot{E}'_q = \frac{1}{T'_{d0}}\left[-E'_q + (X_d - X'_d) i_d + E_{Fd}\right] \tag{8}$$

$$\dot{E}'_d = \frac{1}{T'_{q0}}\left[-E'_d + (X_q - X'_q) i_q\right] \tag{9}$$

The electric torque is expressed as:

$$T_e = E'_d i_d + E'_q i_q + (X'_q - X_d) i_q i_d \tag{10}$$

For a network without network losses and stator algebraic equations are as follows:

$$E'_d - X'_q i_q = V_d \tag{11}$$

$$E'_q + X'_d i_d = V_q \tag{12}$$

$$V_d = X'_e i_q - E_b \sin\delta \tag{13}$$

$$V_q = E_b \cos\delta - X'_e i_d \tag{14}$$

Solving the above equation we have:

$$i_d = \frac{E_b \cos\delta - E'_q}{X_e - X'_d} \tag{15}$$

$$i_q = \frac{E_b \sin\delta - E'_q}{X_e - X'_q} \tag{16}$$

$$V_T = \left[(V_d)^2 + (V_q)^2\right]^{\frac{1}{2}} = \left[(E_b \cos\delta - X_e i_d)^2 + (X_e i_q - E_b \sin\delta)^2\right]^{\frac{1}{2}} \tag{17}$$

And excitation system can be expressed as follows:

$$\dot{E}_{fd} = \frac{1}{T_A}\left[K_A (V_{ref} - V_T) - E_{fd}\right] \tag{18}$$

6. THE SIMULATION RESULTS

According to Figure 5 which is stimulated in simulink Matlab environment and its parameter values are presented in Appendix A. First of all, a severe disturbance of the permanent cessation of a line parallel lines at time t=1s is done. And system response without svc (N.C) will be oscillatory and unstable. When SVC with PID controller (PID.S.C) is in the same state of confusion, damping is better, but still there are oscillations. With the use of fuzzy logic controller instead of PID controller in SVC, is observed that output oscillations are completely undermined and the system returns to its steady-state. The results are visible in the figures (6-12).

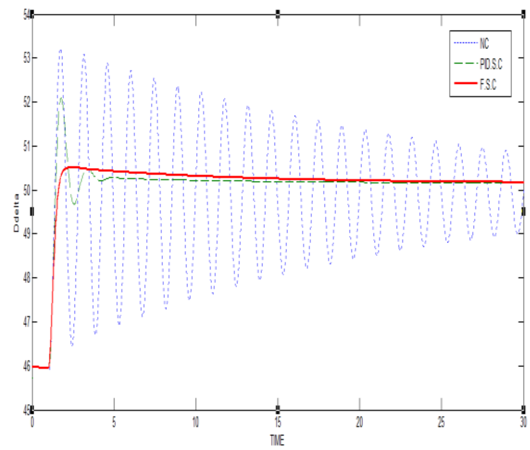

Fig .6. The power angle in the case of a line outage

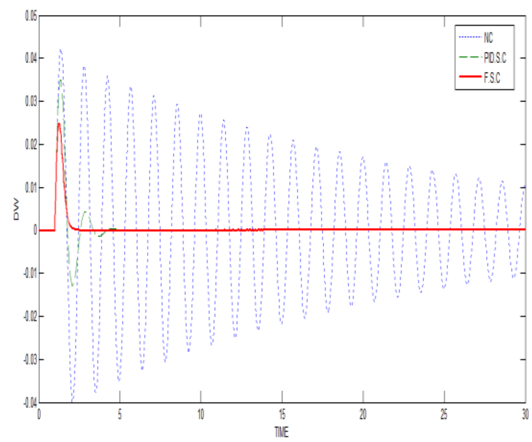

Fig 7. The Variation of speed deviation in the case of a line outage

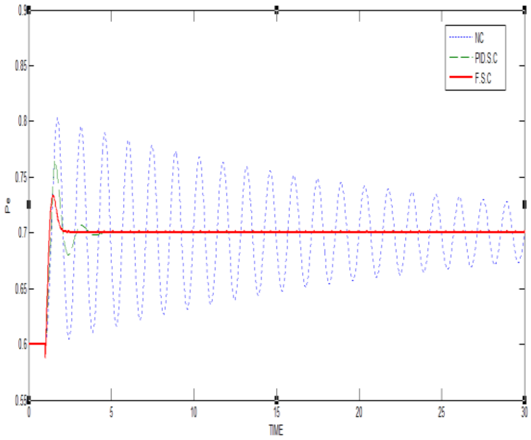

Fig .8. Variation of electrical powe in the case of a line outage

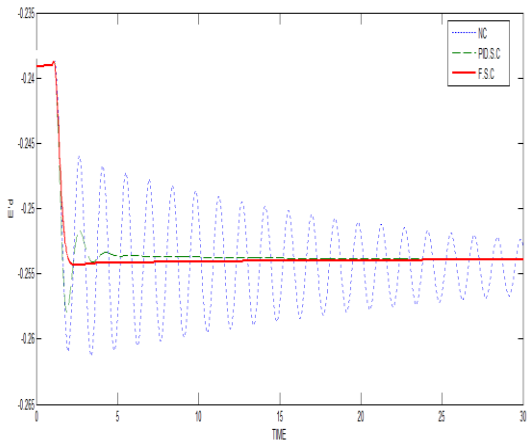

Fig. 9. Variation of voltage E'd in the case of a line outage

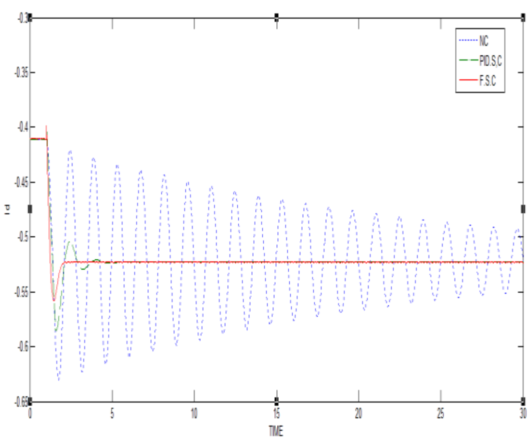

Fig . 10. Variation of current I_d f in the case of a line outage

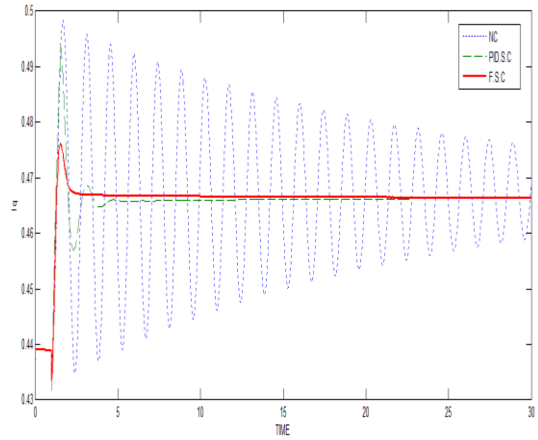

Fig. 11. Variation of current I_q in the case of a line outage

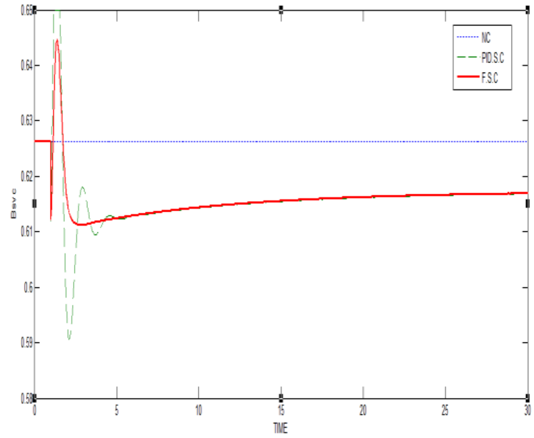

Fig. 12.Variation of B_{svc} in the case of a line outage

7. CONCLUSION

Since FACTS devices with controllers have a significant effect on damping of power system oscillations. So in this paper SVC based on the damping mechanism controller FLC has been proposed for oscillation damping oscillations in the single-machine power system with fault event, and Compared with PID controller performance. The presented Simulation results stabilize the performance of the proposed controller. This indicates that the damping control improves power system.

REFERENCES

[1] P., Kundur, **"Power System Stability and Control"**, *Mc Graw Hill, New york*, 1994.

[2] T., Athay, R., Podmore and S., Virmani,**" A Robust control strategy for shunt and series reactive compensators to damp electromechanical oscillations"** *IEEE Transactions on Power Delivery*,Vol.16, No .4 , pp.812- 817,Oct,2001.

[3] M.A., Abido, "**Analysis and assessment of STATCOM based damping stabilizers for Power system stability enhancement**", *Electric Power System Research,73*, pp. 177- 185,2005.

[4] E., Lerch, D., Povh, **"Advanced SVC control for damping powersystem oscillations"** *IEEE Transactions on Power Systems*, Vol.16,No.2, pp 524 – 535, May 1991.

[5] S.M., Abd-Elazim, E.S., Ali, **"Coordinated design of PSSs and SVC via bacteria foraging optimization algorithm in a multimachine power system"** *ELSEVIER* , .2013

[6] S., Kyanzadeh, M.M., Farsangi, and H., Nezamabadi-pour**,"Damping of Low-Frequency Oscillations by Designing the Supplementary Controller of AVR and SVC Using Immune Algorithm**", *Iranian journal of electrical and computer engineering*, Vol. 8, No. 2, summer-fall 2009.

[7] A., Banga1 , S.S., Kaushik**,"Modling and simulation of svc controller for enhancement of power system stability"**, *International Journal of Advances in Engineering & Technology*, July 2011.

[8] Q., Gu , A., Pandey and Sh.K., Starrett, **"Fuzzy logic control schemes for static VAR compensator to control system damping using global signal"** *Electric Power Systems Research* ,67, 115-122, 2003.

[9] J., Lu, M.H., Nehrir and D.A., Pierre**," A fuzzylogic – based adaptive damping controller for static VAR compensator"** ,*Electric Power Systems Research* ,68, pp.113 - 18,2004.

[10] D.Z., Fang, Y.X., dong, T.S., Chung and K.P., Wong**, "Adaptive fuzzy-logic SVC damping controller using strategy of oscillation energy descent,"** *IEEE Trans. on Power Systems*, Vol.19(3), pp.1414–1421, Aug. 2004.

[11] K.R., Padiyar, **"Power System Dynamics Stability Control"**, *BS Publications, Second Edition*, Hyderabad,India, 2002.

A: values and system parameters

Synchronous Generator:

:H=3.542, K_d =0, Xd=1.7572, X_q=1.584 , X'_d=.4245, x'_q=1.04, T'd0=6.66,T'_{q0}=.44 , F=60

Exciter data:

Ka=400, Ta=.025

Transmission lines and transformers:

$X_{l1}=X_{l2=}$.40625, X_t=13.64 R=0,

Svc controller:

K_{SVC}=100، T_1 =0.01، T_2 = 0.05، B_{SVC}= ±1.5

B: List of Symbols and Abbreviations

δ - synchronous generator rotor.

ω – rotor speed.

S_m – Slip generator

S_{m0}- primary slip

H- Inertia constant.

D- damping coefficient.

P_m- mechanical power

P_e- electrical power.

E_{fd} - excited voltage

X_d and X_q- d axis and q-axis synchronous reactance

V_d and V_q- d axis and q-axis voltages

X'_d and X'_q- d axis and q-axis an transient reactance