A FUZZY STATCOM CONTROL FOR POWER SYSTEM DAMPING ENHANCEMENT

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Abstract

Static synchronous compensators (STATCOM) are used in power systems to improve voltage and reactive power flow in the system. Properly controlled STATCOMs can also provide damping to power system oscillations. This article presents a fuzzy logic STATCOM controller design with generator speed deviation and acceleration as the input. Simulation results show that the fuzzy logic controller provides excellent damping to the power system for a good range of power system operation. The fuzzy controller was evaluated by comparing its performance with the classical PI control. The fuzzy STATCOM controller was observed to be much superior in damping enhancement.

1. INTRODUCTION

Static synchronous compensator (STATCOM) is a shunt-connected converter, which can affect rapid control of reactive flow in the transmission line by controlling the generated AC voltage. Besides providing voltage support, a STATCOM is known to improve the dynamic and transient performance of the power system [1]. The static synchronous compensator (STATCOM) provides shunt compensation in a way similar to the static var compensators (SVC), but utilizes a voltage source converter rather than shunt capacitors and reactors [2, 3]. STATCOM is an active device, which can control voltage magnitude and, to a small extent, the phase angle in a very short time and, therefore, has the ability to improve the system damping as well as voltage profiles of the system. It has been reported that STATCOM can offer a number of performance advantages for reactive power control applications over the conventional SVC because of its greater reactive current output at depressed voltage, faster response, better control stability, lower harmonics and smaller size, etc. [4]. That STATCOM's can provide damping to a power system has been reported in several recent articles [5-9].

This article presents a fuzzy logic STATCOM controller design for power system damping control. A single-machine infinite bus system was simulated with generator speed variation and acceleration as inputs to the fuzzy controller. The transient response obtained by the fuzzy controller has been observed to provide excellent damping characteristics over a range of operating points compared with normal PI designs.

2. SYSTEM MODEL

A single machine infinite bus system with a STATCOM installed at the mid-point of the transmission line is considered for this study. The STATCOM consists of a step down transformer, a three phase GTO–based voltage source converter, and a DC capacitor. The STATCOM is modeled as a voltage sourced converter (VSC) behind a step down transformer. Depending on the magnitude the VSC voltage, the STATCOM current can be made to lead or lag the bus voltage. Generally, the STATCOM voltage is in phase with the bus voltage. However, some active power control may be possible through a limited control of phase angle. This would necessitate a power source behind the capacitor voltage.

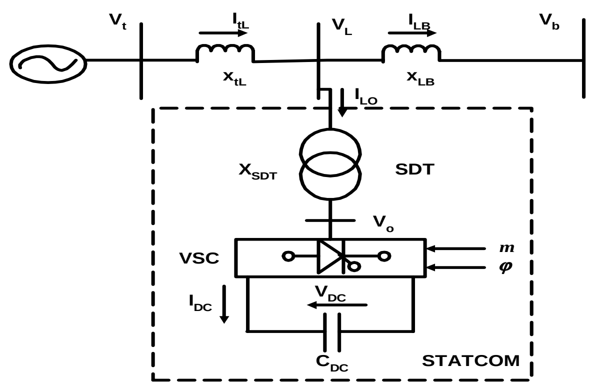

Fig.1 Power system configuration with STATCOM

The dynamics of the generator including the excitation system and the STATCOM are expressed through a 5th order model. Here, the synchronous generator-exciter system equations are,

$$\dot{\delta} = \omega_o \Delta\omega$$

$$\dot{\omega} = -\frac{1}{M}[P_m - P_e - D\Delta\omega]$$

$$\dot{e}'_q = \frac{1}{T'_{do}}[E_{fd} - e'_q - (x_d - x'_d)I_{tLd}] \qquad (1)$$

$$\dot{E}_{fd} = -\frac{1}{T_A}(E_{fd} - E_{fdo}) + \frac{K_A}{T_A}(V_{to} - V_t)$$

The STATCOM capacitor voltage equation is,

$$\frac{dV_{DC}}{dt} = \frac{I_{DC}}{C_{DC}} = \frac{m}{C_{DC}}\left(I_{Lod}\cos\psi + I_{Loq}\sin\psi\right) \quad (2)$$

Combining (1) and (2), the dynamic equations of a synchronous generator installed with STATCOM can be expressed as,

$$\dot{x} = f(x, u) \quad (3)$$

The state and the control vectors are given as, $[\delta\ \ \omega\ \ \Delta e_q'\ \ E_{fd}\ V_{DC}]^T$ and $[m\ \ \psi]^T$, respectively.

3. FUZZY LOGIC CONTROL

The fuzzy logic control (FLC) system, shown in Fig.2, contains four main components – the knowledge base (KB), the fuzzification interface (FI), the decision-making logic (DL), and the defuzzification interface (DI). The knowledge base contains knowledge about all the input and output fuzzy partitions. It will include the term set and the corresponding membership functions defining the input variables to the fuzzy 'rule-base (RB)' system and the output or decision variables to the plant. The crisp stabilizing input signals are converted to fuzzy linguistic variables in the fuzzifier. These are then composed with the fuzzy decision variables. The decision-making logic generates the fuzzified control through various composition rules. The fuzzy control is then defuzzified and is used to fire the thyristors.

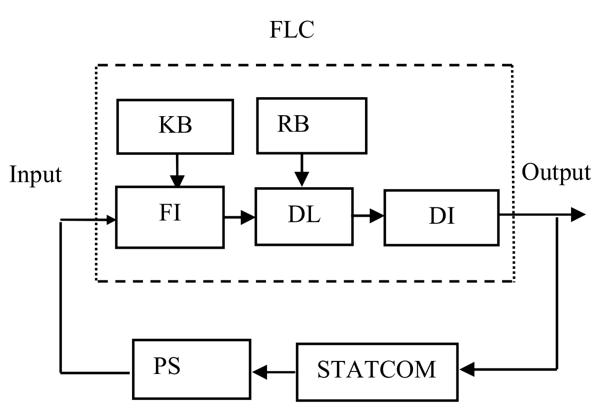

Fig.2 The fuzzy logic controller configuration

The following steps are involved in designing the fuzzy STATCOM controller [10, 11]

1. Choose the inputs to the fuzzy STATCOM controller. Only two inputs - $\Delta\omega$ and ($\Delta\alpha$=d[$\Delta\omega$]/dt have been employed in this study. The output or decision variable is the pulse modulation index 'm' of the STATCOM voltage. The symbol u has been synonymously used to represent the output. Since control of ψ is known to provide no additional damping to the system, it has not been considered any further.
2. Choose membership functions to represent the inputs in fuzzy set notation. Triangular functions are chosen in this work. For example, fuzzy representation of generator speed change ($\Delta\omega$) is shown in Fig. 3. Linguistic variables chosen are large positive (LP), medium positive (MP), small positive (SP), very small (VS), small negative (SN), medium negative (MN), and large negative (LN) at thresholds s_1, s_2, s_3, 0, s_4, s_5, s_6, respectively. Similar membership functions for the other inputs and the stabilizer output are also defined.
3. A set of decision rules relating the inputs to the output are compiled and stored in the memory in the form of a 'decision table'. The rules are of the form:

   IF $\Delta\omega$ is large positive (LN), AND $\Delta\alpha$ is large negative (LN); THEN control (u) is large negative (LN).

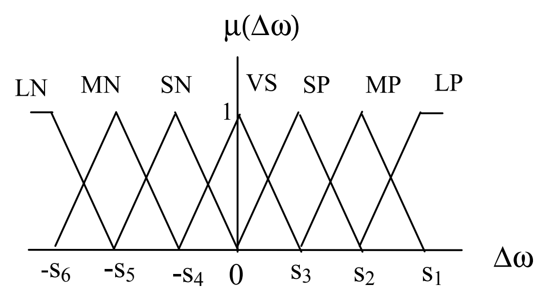

Fig.3 Fuzzy representation of speed signal

4. For N linguistic variables for each of $\Delta\omega$ and $\Delta\alpha$, there are N^2 possible combinations resulting into any of M values for the decision variable u. All the possible combinations of inputs, called states, and the resulting control are then arranged in a (N^2xM) 'fuzzy relationship matrix' (FRM).
5. The membership values for the condition part of each rule is calculated from the composition rule as follows:

   $\mu(x_i) = \mu(\Delta\omega$ is LP, and $\Delta\alpha$ is LN)

   $= \min [\mu\ (\Delta\omega$ is LP), $\mu\ (\Delta\alpha$ is LN)]; i =1,2, … N^2 (4)

   Here, x_i is the i-th value of the N^2 possible states (input-combinations) in the FRM.
6. The membership values for the output characterized by the M linguistic variables are then obtained from the intersection of the N^2 values of membership function $\mu(x)$ with the corresponding values of each of the decision variables in the FRM. For example, for the decision LN $\subset$ M and for state x_i , we obtain,

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$$\mu_u(x_i, LN)=\min[\mu(x_i, LN), \mu(x_i)];\ i=1,2, \ldots N^2. \quad (5)$$

The final value of the stabilizer output 'LN' can be evaluated as the union of all the outputs in equation (5) given by the relationship

$$\mu_u(LN)= \max\{\mu_{u_s}(x_i, LN)\},\ \text{for all } x_i \quad (6)$$

The membership values for the other M-1 linguistic variables are generated in a similar manner.

7. The fuzzy outputs μ_u (LN), μ_u (LP), etc. are then defuzzified to obtain crisp u. The popular methods of defuzzification are the centroid and the weighted average methods. Using the weighted average method, the output of the FLC is then written as

$$u = \sum_{i=1}^{M} \frac{\mu_u(A_i) \text{ x threshold values of } A_i}{\sum \mu_u(A_i)} \quad (7)$$

The decision table is provided in Table 1.

Δω \ Δα	LN	MN	SN	VS	SP	MP	LP
LN	LN	LN	LN	LN	MN	SN	VS
MN	LN	LN	MN	MN	SN	VS	SP
SN	LN	MN	SN	VS	SP	MP	MP
VS	MN	MN	SN	VS	SP	MP	MP
SP	MN	SN	VS	SP	SP	MP	LP
MP	SN	VS	SP	MP	MP	LP	LP
LP	VS	SP	MP	LP	LP	LP	LP

Table 1 The decision table

The expert knowledge employed in the general fuzzy STATCOM design is that if the states are far from the origin, exertion of large control is required to bring the states to the origin; polarity of the control being decided roughly by the quadrants. Since a Δω - Δα based control is generally known to damp transients, given enough time to iterate, this type of strategy will eventually converge. The fuzzy relationship matrix for all the 49 states and the corresponding membership values of control are tabulated in Table 2.

FLC Input		FLC Output						
x_i	**(Δω, Δα)**	**LN**	**MN**	**SN**	**VS**	**SP**	**MP**	**LP**
		Membership values						
		$\mu(x_1,LN)$	MN	SN	VS	SP	MP	LP
x_1	**(LN,LN)**	1	0.5	0	0	0	0	0
x_2	**(LN,MN)**	1	0.5	0	0	0	0	0
..	..	..	..	..	..	..	..	..
x_{24}	**(VS,SN)**	0	0.5	1	0.5	0	0	0
..	..	..	..	..	..	..	..	..
x_{48}	**(LP,MP)**	0	0	0	0	0	0.5	1
x_{49}	**(LP,LP)**	0	0	0	0	0	0.5	1

Table 2 Part of the fuzzy relationship matrix

4. SIMULATION RESULTS

The single-machine infinite bus system considered in Fig.1 was tested with the fuzzy logic STATCOM control for a number of disturbances and for various operating conditions. Fig. 4 shows the rotor angle variation of the generator for a nominal load of 0.9 pu at 0.95 pf lagging with and without fuzzy logic control. Without control the system is very oscillatory (a), while the fuzzy controller provides excellent damping (b).

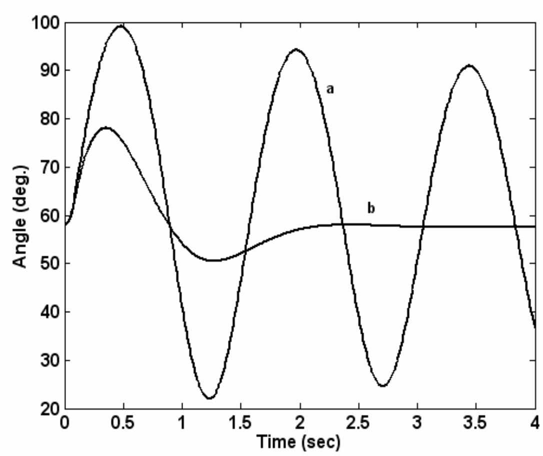

Fig. 4 The generator rotor angle variation for a 50% torque pulse for 0.1 sec, (a) no control, (b) with the proposed fuzzy STATCOM control

The generator rotor angle variations for a number of loading conditions for a 50% torque pulse disturbance are shown in Fig.5, while the corresponding variations of the DC capacitor voltage is given in Fig.6. The loading conditions are, a) 1.1 pu power output at 0.9 pf lagging, b) 1 pu power at 0.95 pf lag, c) 0.9 pu power at 0.95 pf lag, and d) 0.6pu power at 0.85pf lagging. The rotor angle variations and DC capacitor voltages for a more severe three-phase fault of 0.2s duration on the remote bus are shown in Figs. 7 and 8, respectively. As can be observed the fuzzy control scheme gives very good damping profile over a range of operating conditions even for severe fault conditions.

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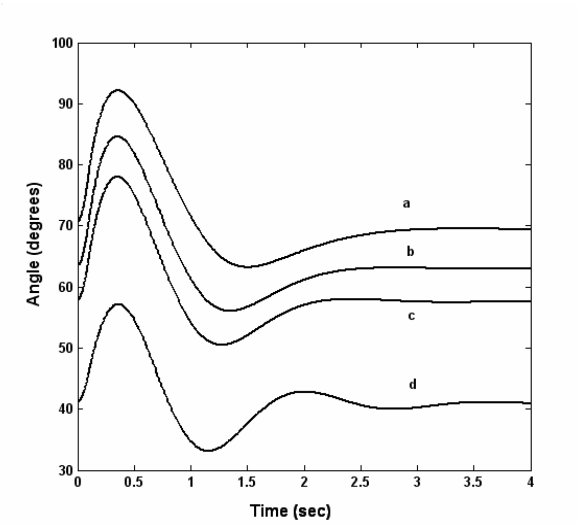

Fig.5 Generator rotor angle variations for the 4 operating conditions following a 50% torque pulse disturbance for 0.1s.

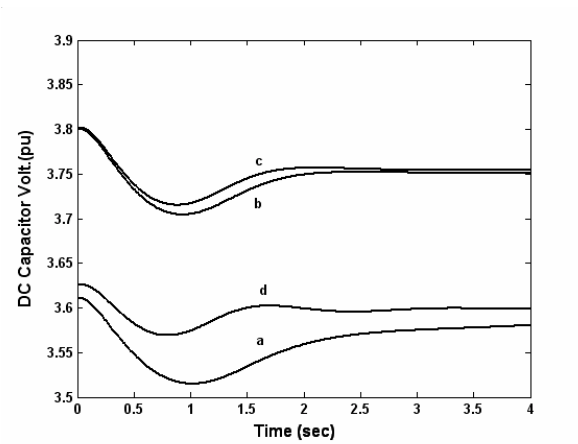

Fig.6 DC Capacitor voltage variations corresponding to Fig.5

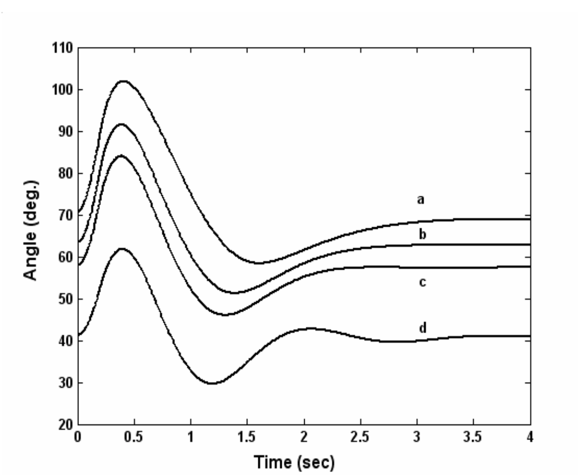

Fig.7 Generator rotor angle variations following a three-phase on the remote bus for 0.2s

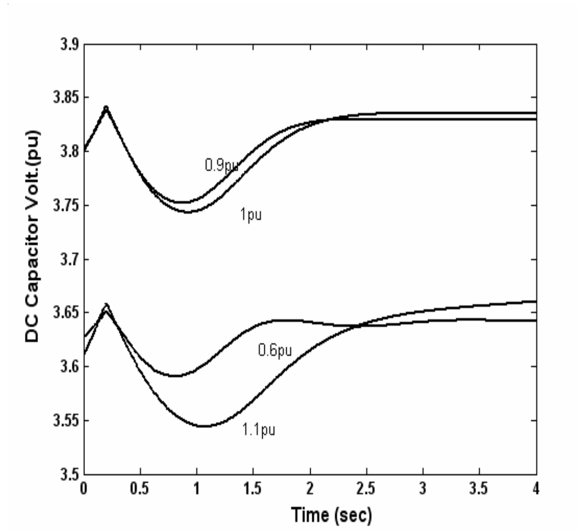

Fig.8 DC capacitor voltage variation corresponding to Fig.7

5. EVALUATION OF THE FUZZY CONTROLLER

The damping properties of the fuzzy logic controller were compared with a conventional PI controller. The PI controller is installed in the feedback path. An additional washout is included to eliminate any additional signal in steady state. The dominant eigenvalues of the closed loop system are selected so as give a damping ratio of approximately 0.3. In Fig.10, a comparison of the responses with the PI control and the fuzzy logic control are given for three operating conditions, (a) at 1.1 pu, (b) 0.9 pu and (c) 0.6 pu power outputs. The solid lines are with fuzzy control, while the dashed ones are with PI control. PI gains are calculated for the nominal loading of 0.9pu. Fig.11 shows the corresponding variations of the DC capacitor voltage with the fuzzy and PI controls. The PI controller generally gives reasonable response for the designed nominal case but the response worsens for operation away from nominal, and can even give rise to unstable situations as in (a).

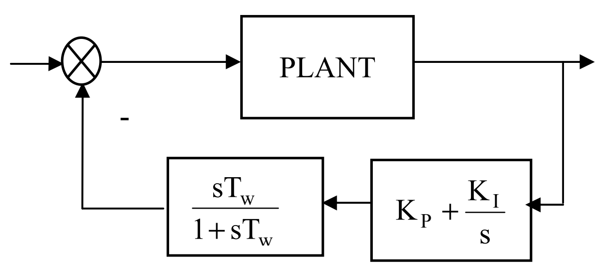

Fig.9 PI controller with washout

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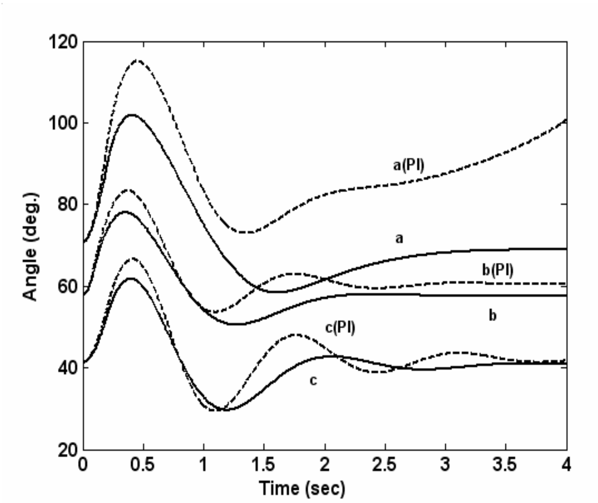

Fig10. The rotor angle response for three loading conditions (a) 1.1 pu, (b) 0.9 pu, and (c) 0.6 pu following three phase fault conditions for 0.2 sec.

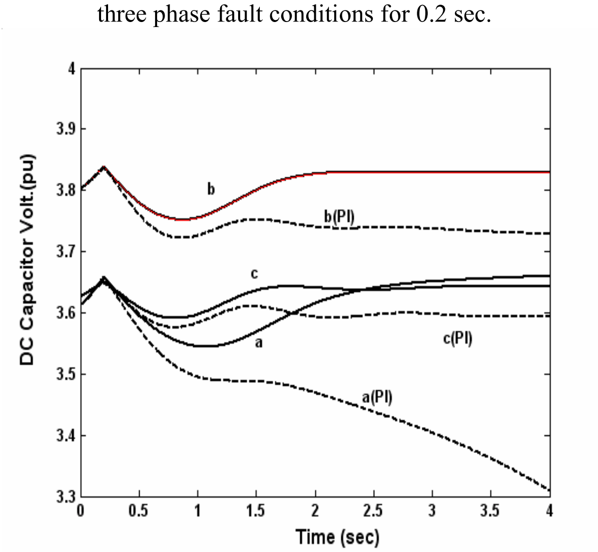

Fig.11 The DC capacitor voltage corresponding to Fig.10

6. CONCLUSIONS

A fuzzy logic STATCOM controller has been designed for stabilization of power systems. The control has been tested on a single machine infinite bus system. The transient response of the power system with the proposed fuzzy controller has been compared with a conventional PI control design. The optimum gains of the PI controller have been obtained through an 'optimized' pole-placement technique. It has been observed that the fuzzy controller designed provides excellent damping compared with the PI controller. Contrary to the PI design, the fuzzy controller design is independent of operating conditions and hence is 'robust'.

7. ACKNOWLEDGEMENT

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