STATCOM WITH FLC FOR DAMPING OF OSCILLATIONS OF MULTI MACHINE POWER SYSTEM

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ABSTRACT

This paper describes the damping of power system oscillations of multi machine power system using Static synchronous compensator (STATCOM) with combined Fuzzy Logic Controlled (FLC) voltage regulator and FLC Bang-Bang controller. The proposed controller used to damp the power system oscillations and regulate the Bus voltage at which the STATCOM is connected. The performance of the proposed controller has been compared with combined conventional PI voltage regulator along with Bang-Bang controller and is tested on Western System Coordinating Council (WSCC)– 9-bus system through simulation by using SIMULINK

Keywords: *FACTS, STATCOM, FLC, and SIMULINK.*

1. INTRODUCTION

Power systems are complex, nonlinear and often exhibit low-frequency power oscillations due to inadequate system damping. Satisfactory damping of power system oscillations is an important issue addressed when dealing with rotor angle stability of power systems. This phenomenon is well known and observable especially when fault occurs. STATCOM is a shunt FACTS device and it has been employed to control the reactive power in power system. In addition to voltage control, which is the main task of the STATCOM, it may also be employed for additional tasks such as damping of power system oscillations, which results an improvement of the transmission capability. Damping of power system oscillations is an important issue not only in improving the transmission capacity but also for improvement of power system stability. The STATCOM is generally used for voltage control, but in some cases it is not in a position to effectively damp the power system oscillations. In some critical cases the voltage control can even amplify oscillations [1].

In this paper damping power system oscillations by using STATCOM on the basis of locally measured variables is described. To attain this objective it is necessary to improve the STATCOM control strategy by introducing locally measurable signals obtained from constant resistive load located near the STATCOM, which reflect power system oscillations at any point in the power system.

2. ESTIMATION OF POWER CHANGE IN THE CONSTANT RESISTIVE LOAD CONNECTED AT STATCOM USING LOCALLY MEASURED VARIABLES AND EMPLOYING CONTROL CONCEPT

If the STATCOM is considered at any node k in a power system, the voltage across the constant resistive load is V_k.

Power across the resistive load:

$$P \propto V_k^2 \quad (1)$$

Change in power across the load:

$$\Delta P \propto V_{ref}^2 - V_k^2 \quad (2)$$

The ability of STATCOM for damping oscillations is restricted by the maximum rating of the STATCOM. Maximum damping is thus obtained by introducing Bang-Bang control with correct phase angle of the signal thus utilizing the maximum STATCOM rating [1]. Fig. 3 describes a STATCOM control employing a damping signal. Additional filters are required in order to filter out interference signals from the relevant frequency range of oscillation from 0.3 to approximately 2 Hz**.** The transfer function (3) [1] to filter out harmonic content in the estimated change in power signal from (2) was employed for bang-bang controller

$$G(s) = \frac{(b_1 s + 1)}{(a_1 s^2 + a_2 s + 1)} \frac{(T_W s)}{(T_W s + 1)} \qquad (3)$$

3. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

3.1. Configuration

STATCOM is one of the important shunt connected Flexible AC Transmission Systems (FACTS) controllers to control power flow and make better transient stability [2][6]. The basic structure of STATCOM in schematic diagram is shown in Figure 1. It regulates voltage at its terminal by changing the amount of reactive power in or out from the power system. When system voltage is low, the STATCOM inject reactive power. When system voltage is high, it absorbs reactive power.

The change of reactive power is accomplished means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The power electronics based VSC generates 3–phase voltage with power system frequency V_2 from a DC voltage source furnished by the charged capacitor.

Operating Principle of the STATCOM

The operating principle of STATCOM is explained in the figure.1 showing the active and reactive power transfer between a power system and a VSC. In this figure, V_1 denotes the power system voltage to be controlled and V_2 is the voltage produced by the VSC.

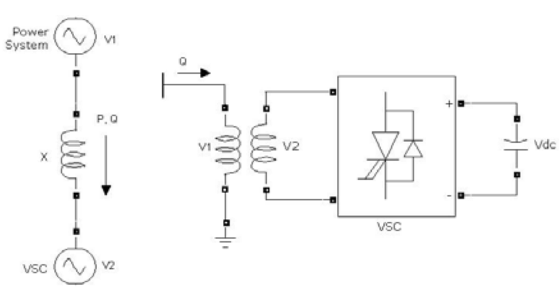


Figure 1. Schematic representation of STATCOM

During steady state working condition, the voltage V_2 produced by the VSC is in phase with V_1 (i.e δ=0), so that only reactive power is flowing (Active power P=0). If the magnitude of voltage V_2 produced by VSC is less than the magnitude of power system voltage V_1, reactive power Q is flowing from power system to VSC (STATCOM is absorbing reactive power mode). If V_2 is greater than V_1, Q is flowing from VSC to power system (STATCOM is producing reactive power mode). If V2 is equal to V1 the reactive power exchange is zero. The amount of reactive power is given by

$$Q = \frac{V_1 (V_1 - V_2)}{X} \qquad (4)$$

3.2. STATCOM V-I characteristic

Modes of the STATCOM operation:
1) Voltage regulation mode
2) VAR control mode

When the STATCOM is worked in voltage regulation mode, it implements the V-I characteristic as shown in Fig. 2. The V-I characteristic is depicted by the following equation:

$V = V_{ref} + X_S.I$

Where

V = Positive sequence voltage (pu)
I = Reactive current (pu/P_{nom})
(I > 0 indicates an inductive current and I< 0 indicates capacitive current)
X_S=Slope (pu/P_{nom}: usually between 1% and 5%)
P_{nom}=Converter rating in MVA

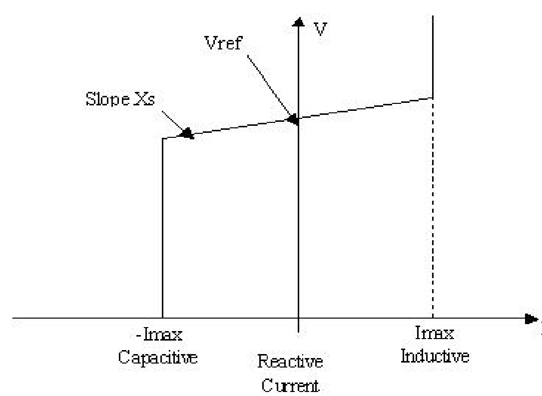


Figure 2. V-I characteristics of STATCOM

4. MODELING OF STATCOM

4.1. Using combined conventional PI Voltage Regulator with Bang-Bang controller

The STATCOM control block diagram is shown in Figure 3. The voltage regulator is of proportional plus integral type and the slope Xs, realized through current feedback.

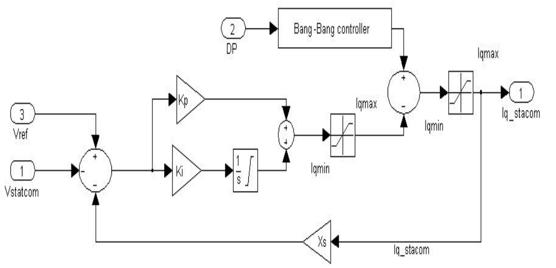


Figure 3: STATCOM model with Combined conventional PI – Voltage Regulator and Bang-Bang Controller block diagram

4.2. Using Combined FLC Voltage Regulator with FLC Bang-Bang controller

FLC voltage regulator is fed by one input that is voltage error (Ve) and FLC Bang-Bang controller is fed by one input that is change in power (DP). These give the appropriate Reactive current (IQ), which is required to the system. It is shown in Figure .4

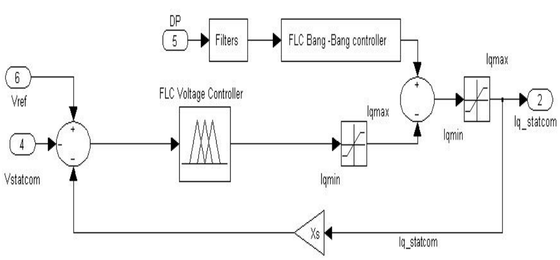


Figure 4: STATCOM model with Combined FLC Voltage Regulator and FLC Bang-Bang controller block diagram

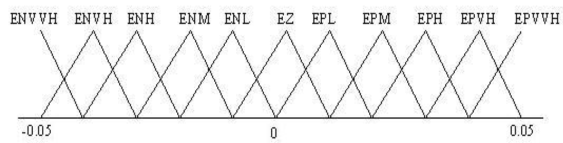
The rules for the proposed FLC voltage controller are:

i) If 'Ve' is 'ENVVH' Then 'IQ' is 'IQNVVH'
ii) If 'Ve' is 'ENVH' Then 'IQ' is 'IQNVH'
iii) If 'Ve' is 'ENH' Then 'IQ' is 'IQNH'
iv) If 'Ve' is 'ENM' Then 'IQ' is 'IQNM'
v) If 'Ve' is 'ENL' Then 'IQ' is 'IQNL'
vi) If 'Ve' is 'EZ' Then 'IQ' is 'IQZ'
vii) If 'Ve' is 'EPL' Then 'IQ' is 'IQPL'
viii) If 'Ve' is 'EPM' Then 'IQ' is 'IQPM'
ix) If 'Ve' is 'EPH' Then 'IQ' is 'IQPH'
x) If 'Ve' is 'EPVH' Then 'IQ' is 'IQPVH'
xi) If 'Ve' is 'EPVVH' Then 'IQ' is 'IQPVVH'

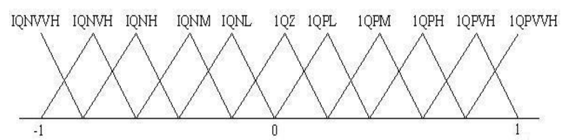
The rules for the proposed FLC bang-bang controller are:

i) If 'DP' is 'DPN' Then 'IQ' is 'IQN'
ii) If 'DP' is 'DPZ' Then 'IQ' is 'IQZ'
iii) If 'DP' is 'DPP' Then 'IQ' is 'IQP'

The membership functions for input and output to FLC Voltage regulator, Voltage error (Ve) and Reactive current (IQ) are given in Figure 5(a and b). The membership functions for input and output to FLC Bang –Bang controller, Change in power (DP) and Reactive current (IQ) are given in Figure 6(a and b).

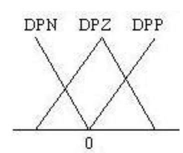


5(a)

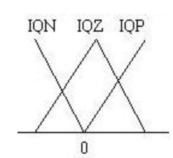


5(b)

Figure 5: (a) Input membership function (Ve) and (b) Output membership function (IQ) for FLC Voltage regulator



6(a)



6(b)

Figure 6: (a) Input membership function (DP) and (b) Output membership function (IQ) for FLC bang-bang controller

5. POWER SYSTEM MODEL

Consider Three Machine Nine bus system (WSCC 9 – Bus) [7] with loads assumed to be represented by constant impedance model and all the three machines are operate with constant mechanical power input and with constant excitation as shown in Figure 7. STATCOM is placed at Bus – 5 by the Extended Voltage Phasors Approach (EVPA) [4].

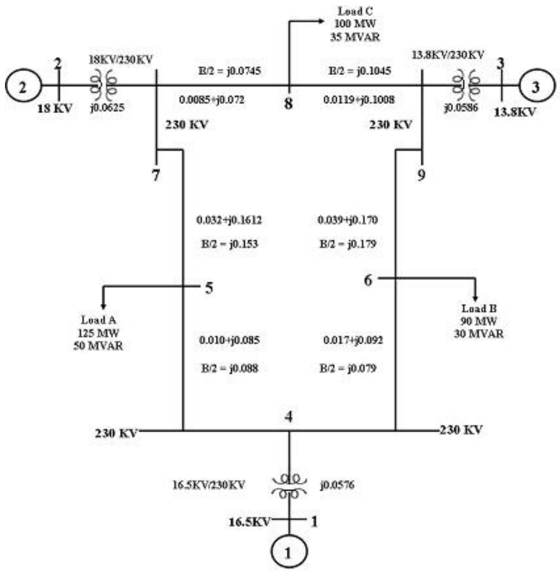
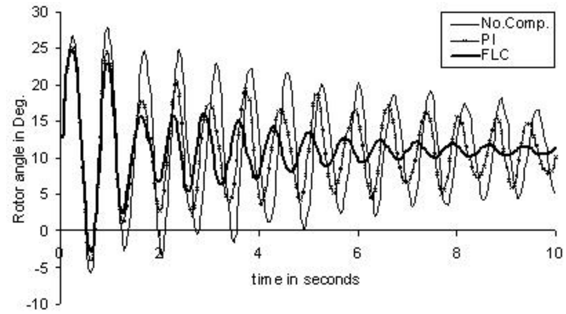


Figure 7. WSCC 9 – Bus system



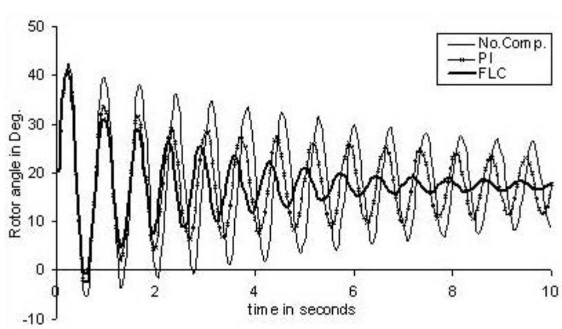
8(b)

Figure 8. Rotor angle Oscillations of (a) Generator-2, and (b) Generator-3 with respect to Generator-1 for 3-Ph Short circuit at Bus – 7

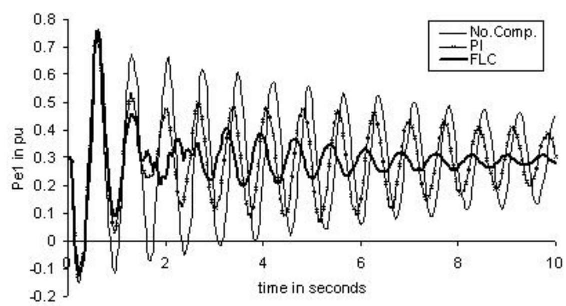
6. TEST RESULTS

The WSCC 9 –Bus system with STATCOM placed at the Bus – 5 is simulated in SIMULINK. The Figures 8 – 11 shows the plotted results pertaining to the WSCC 9 – bus system with STATCOM (equipped with proposed controller, combined conventional PI voltage regulator with Bang –Bang controller) and without STATCOM, when 3-Ph short circuit fault occurs at bus – 7 initially (at 0 sec) and fault cleared at 0.1 sec.

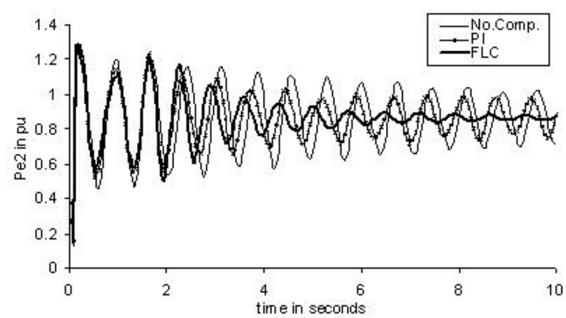
Figure 8(a and b) is the rotor angle oscillations of Generators 2 and 3 with respect to Generator 1. Figure 9(a, b and c) shows the power oscillations of three Generators. Figure 10(a, b and c) shows the speed (rad/sec) of the three generators. Figure 11 shows the Bus – 5-voltage variation. In all the above aspects STATCOM with proposed controller shows better performance.



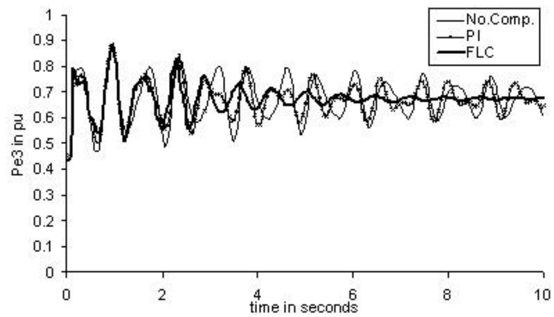
8(a)



9(a)

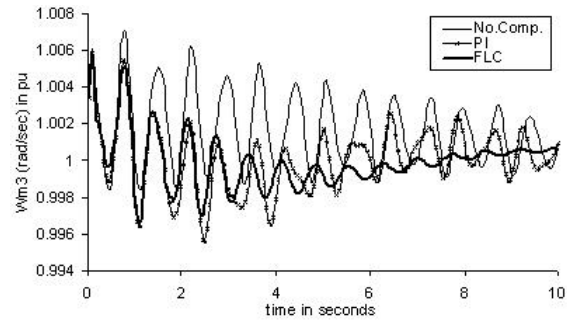


9(b)



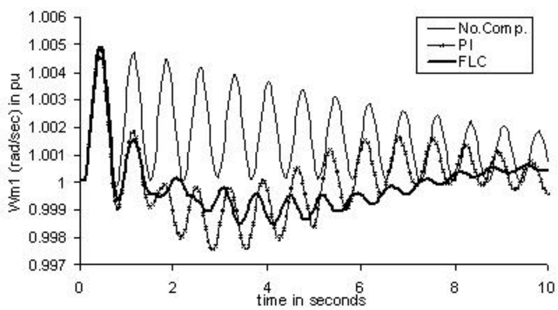
9(c)

Figure 9: Oscillations in Power output of (a) Generator – 1, (b) Generator – 2 and (c) Generator – 3 for 3-Ph Short circuit at Bus – 7

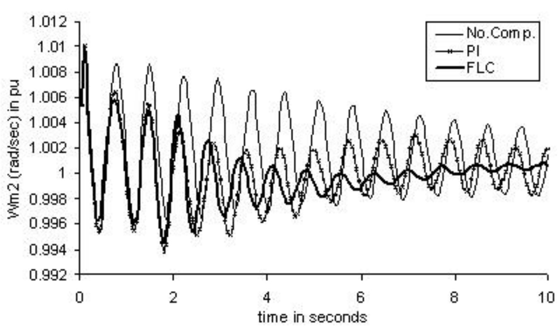


10(c)

Figure 10: Speed Variation of (a) Generator –1, (b) Generator –2 and (c) Generator – 3 for 3-Ph Short-circuit at Bus –7



10(a)



10(b)

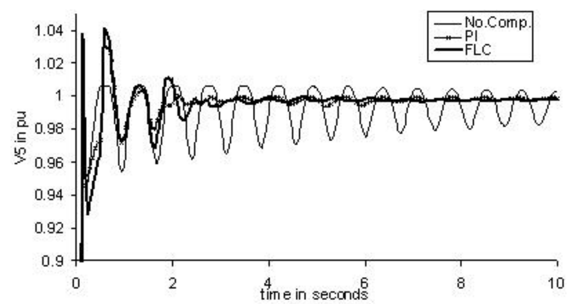


Figure 11: Voltage at Bus – 5 for 3-Ph Short-circuit at Bus – 7

7. CONCLUSIONS

A combined FLC voltage regulator with FLC Bang-Bang controller for STATCOM has been proposed instead of combined conventional PI voltage regulator with Bang-Bang controller [2]. The proposed controller shows better performance to damp the power system oscillations

8. REFERENCES:

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I. APPENDIX

PI controller parameters: Xs = 0.05, Tm = 0.005,
Kp = 0, Ki = 1000

STATCOM Rating: ±100 MVAR

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