STATCOM Stabilizer based on Fuzzy Logic
Control for Damping Power Oscillation

Prechanon Kumkratug
Department of Electrical Engineering, Faculty of Engineering at Si Racha,
Kasetsart University, 199 M.6, Tungsukhla, Si Racha, Chonburi, 20230, Thailand

Abstract: Problem statement: In power systems, there exists a continuous challenge to improve
dynamic performance of power system. Approach: Static Synchronous Compensator (STATCOM) is
a power electronic based device that has the capability of controlling the power flow through a line.
This study applies the Static Synchronous Compensator (STATCOM) to control the power flow during
dynamic period. To verify the effect of the STATCOM on dynamic performance, the mathematical
model and control strategy of a STATCOM was needed to be presented. The converters of STATCOM
were represented by variable voltage source with associate transformer leakage reactance and the
voltage source and the reactance were transformed into current injection. The current injection model
of STATCOM was modeled into power flow equation and thus it was used to determine control
strategy. This study applies the fuzzy logic control to determine the control strategy of STATCOM.
The swing curves of the three phase faulted power system without and with a STATCOM was tested
and compared in various cases. Results: The swing curve of the system with STATCOM based fuzzy
logic control had the less amplitude during the dynamic period. Conclusion: STATCOM can improve
the dynamic performance of the system after disturbance.

Key words: Power system, fuzzy logic control, static synchronous compensator, FACTS devices,
current injection, power flow, transient stability, voltage source

INTRODUCTION

Power system oscillation is one of the important
aspects in modern power system. Currently, power
engineers are much more concerned about stability
problem due to blackout in Northeast United States,
Scandinavia, England and Italy (Kumkratug, 2010;
Padma and Rajaram, 2011; Osuwa and Igwiro, 2010;
Kumkratug, 2011a). They have proposed many
methods to improve stability of power system such as
load shedding, Flexible AC Transmission System
(FACTS), (Al-Husban, 2009; Kumkratug, 2011b;
Magaji and Mustafa, 2009; Mustafa and Magaji, 2009;
Zarate-Minano et al., 2010).

A Static Synchronous Compensator (STATCOM)
is a member of the FACTS family that is connected in
shunt with system. The STATCOM consists of a solid
state voltage source converter with GTO thyristor
switches or other high performance of semi-conductor
and transformer. The STATCOM can electrically
mimic reactor and capacitor by injecting a shunt current
in quadrature with the line voltage. The reactive power
(or current) of the STATCOM can be adjusted by
controlling the magnitude and phase angle of the output
voltage of the shunt converter (Al-Husban, 2009;
Mustafa and Magaji, 2009).

This study presents the fuzzy logic control law of
STATCOM. The mathematical model of power system
with a STATCOM is systematically derived. The
nonlinear control of fuzzy logic control is applied to
determine the control strategy. The simulation results
are tested on a sample system.

MATERIALS AND METHODS

Mathematical model: Figure 1a shows the single line
diagram of Single Machine Infinite Bus (SMIB) system
without a STATCOM and the corresponding equivalent
circuit is shown in Fig. 1b.

Here $X_1$ is the equivalent reactance between the
machine internal bus and the bus $m$ and $X_2$ is the
equivalent reactance between bus $m$ and the infinite bus.
The generator is represented by a constant voltage source
($E'$) behind transient reactance ($X'_{d}$).
The active power balance at bus m is given by:

\[ P_R = P_S \]  \hspace{1cm} (1)

Here:

\[ P_k = \frac{E V}{X_1} \sin(\delta - \theta_m) \]  \hspace{1cm} (2)

And:

\[ P_S = \frac{V_m V_b}{X_2} \sin(\theta_m) \]  \hspace{1cm} (3)

After some mathematical manipulations of Eq. 1-3, the voltage angle at bus m is Eq. 4:

\[ \theta_m = \tan^{-1} \left( \frac{E X_1 \sin \delta}{E X_2} \right) \]  \hspace{1cm} (4)

The reactive power balance at bus m is given by:

\[ Q_R = Q_S \]  \hspace{1cm} (5)

Here:

\[ Q_k = \frac{E V}{X_1} \cos(\delta - \theta_m) - \frac{V_m^2}{X_1} \]  \hspace{1cm} (6)

And:

\[ Q_S = \frac{V_m V}{X_2} + \frac{V_m V_b}{X_2} \cos \theta_m \]  \hspace{1cm} (7)

After some mathematical manipulations of Eq. 5-7, the voltage magnitude at bus m is Eq. 8:

\[ V_m = \frac{E X_1 \cos(\delta - \theta_m) + X_1 V_m \cos \theta_m}{X_1 + X_2} \]  \hspace{1cm} (8)

It can be observed from the Fig. 1b and Fig. 2c that the STATCOM doesn’t affect on the active power balance and then the voltage angle equation at bus doesn’t change. However, the STATCOM affects on reactive power balance given by:

\[ Q_R = Q_S + Q_{inj} \]  \hspace{1cm} (9)

Here:

\[ Q_{inj} = -V_m I_q \]  \hspace{1cm} (10)
After some mathematical manipulations of Eq. 9-10, the voltage magnitude at bus m of the system with a STACOM is given by Eq. 11:

$$V_m = \frac{E X_q \cos(\delta - \theta_m) + X_t V_m \cos \theta_m + V_m I_q}{X_t + X_q}$$  \hspace{1cm} (11)

It can be seen from Eq. 4, 8 and 11 that the parameter of STATCOM doesn’t affect on line voltage angle but it affects on line voltage magnitude.

**Fuzzy logic control:** The dynamic equation of power system as shown in Fig. 2a can be expressed by following Eq. 12 and 13:

\[
\delta = \omega \\
\omega = \frac{1}{M} \left[P_m - P_e\right]  \hspace{1cm} (12, 13)
\]

Here, \(\delta, \omega, P_m, M\) and \(P_e\) are the rotor angle, speed, mechanical input power and moment of inertia electrical output power, respectively of machine.

Figure 3 shows the machine speed of system after disturbance by using Eq. 12-13. Figure 4 shows the input and the output fuzzy membership function based on fuzzy logic control, respectively. The machine speed at pre-fault is considered as reference at zero value (\(\omega = 0\)). This study uses the rules based on human reasoning of Mamdani inference engine. Rules are defined as follows:

- If \(\omega\) is positive big then \(I_q\) is positive big
- If \(\omega\) positive then \(I_q\) is positive
- If \(\omega\) zero then \(I_q\) is zero
- If \(\omega\) negative then \(I_q\) is negative
- If \(\omega\) negative big then \(I_q\) is negative big

**RESULTS**

The proposed control method is tested on sample system equipped with a STATCOM based fuzzy logic control strategy. The single line diagram of sample system is shown in Fig. 2a. The system parameters are:

\(H=5, X_t = 0.1 \text{ pu}, X_{d} = 0.3 \text{ pu}, X_{L1} = 0.4 \text{ pu}, X_{L2} = 0.4 \text{ pu}, X_{L3} = 0.4 \text{ pu}, X_{L4} = 0.4 \text{ pu}, P_m = 1.0 \text{ pu}, E_q = 1.23 \text{ pu}\)

It is considered that 3 phase fault appears at line 1 near bus m for 130 ms and then it is cleared by opening both circuit breakers. Figure 5 shows the machine speed of sample system without FACTS devices for generating the fuzzy membership of input \(\omega\) and output \(I_q\) as shown in Fig. 6a-b, respectively. Figure 7 shows the swing curve of the system without and with a STATCOM.
DISCUSSION

It can be observed from the simulation results that the STATCOM based fuzzy logic control can improve dynamic performance of the system. The maximum and minimum machine rotor angles are around 98.74 and 9.28, respectively.

CONCLUSION

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

REFERENCES

Al-Husban, A.N., 2009. An eigenstructure assignment for a static synchronous compensator. Am. J. Eng. Applied Sci., 2: 812-816. DOI: 10.3844/ajeassp.2009.812.816

Kumkratug, P., 2010. Application of interline power flow controller to increase transient stability of power system. J. Comput. Sci., 6: 1490-1493. DOI: 10.3844/jcssp.2010.1484.1487

Kumkratug, P., 2011a. Nonlinear control design of shunt flexible AC transmission system devices for damping power system oscillation. J. Comput. Sci., 7: 854-858. DOI: 10.3844/jcssp.2011.854.858

Kumkratug, P., 2011b. Optimal control design of static synchronous series compensator for damping power system oscillation. J. Comput. Sci., 7: 844-848. DOI: 10.3844/jcssp.2011.844.848

Magaji, M. and M.W. Mustafa, 2009. Optimal thyristor control series capacitor neuro-controller for damping oscillations. J. Comput. Sci., 5: 980-987. DOI: 10.3844/jcssp.2009.980.987

Mustafa, M.W. and N. Magaji, 2009. Optimal location of static var compensator device for damping oscillations. Am. J. Eng. Applied Sci., 2: 353-359. DOI: 10.3844/ajeassp.2009.353.359

Osuwa, J.C. and E.C. Igwiro, 2010. Uninterruptible power supply using solar rechargeable battery. Physics. Int., 1: 77-82. DOI: 10.3844/pisp.2010.77.82.

Padma, S. and M. Rajaram, 2011. Fuzzy logic controller for static synchronous series compensator with energy storage system for transient stability analysis. J. Computer Sci., 7: 859-864. DOI: 10.3844/jcssp.2011.859.864

Zarate-Minano, R., T. Van Custem, F., Milano and A.J. Conejo, 2010. Securing transient stability using time domain simulations within an optimal power flow. IEEE Trans. Power Syst., 5: 243-253, DOI: 10.1109/TPWRS.2009.203069.