MODELING AND SIMULATION OF STATIC VAR COMPENSATOR FUZZY CONTROL FOR POWER SYSTEM STABILITY ENHANCEMENT

Stelian-Emilian OLTEAN#1, Mircea DULĂU#2, Adrian-Vasile DUKA #3

# Electrical Engineering and Computer Science Department, Petru Maior University of Tîrgu Mureș
Nicolae Iorga str., no. 1, Tîrgu Mureș, Romania
1stelian.oltean@ing.upm.ro
2mircea.dulau@ing.upm.ro
3adrian.duka@ing.upm.ro

ABSTRACT

The static var compensators SVC are FACTS devices in shunt connection which can be used for power system enhancement. The paper investigates a modern approach for SVC control using fuzzy logic based controller. The simulations and effects of shunt compensation on power system transmission stability are also presented. The SVC modeled in the paper is a TCR-FC type with two components: the thyristor controlled reactor (TCR) and the fixed capacitor (FC). The performances of fuzzy based control of the SVC are compared with a conventional compensation and the advantages of modern control to offer significant damping to the system oscillations are highlighted. Matlab Simulink environment was used for system modeling and simulations.

Keywords: static VAR compensator, fuzzy logic control, FACTS devices, power system stability

1. Introduction

The need of more efficient electricity systems management has given rise to innovative technologies in power generation and transmission. Flexible AC transmission systems, FACTS as they are generally known, are new devices that improve transmission systems. Flexible AC Transmission System (FACTS) means alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability [1].

Although PID controllers, lead/lag networks and other conventional controls are simple and easy to design, their performances deteriorate when the system operating conditions vary widely and large disturbances occur. In power system large differences occur every time and the dynamic and steady state stability is endangered. Fuzzy logic control approach is an emerging tool for solving complex problems whose system behavior is complex in nature [8], [9].

In [1]-[7], [13] different types of FACTS devices and their controls are modeled, conventional, adaptive or intelligent methods are studied:
- Static Var Compensators (SVC), which are the most important FACTS devices. They have been used for a number of years to improve transmission line economics and system losses by resolving dynamic voltage problems and reactive power control.
- Thyristor controlled series compensators (TCSC) are an extension of conventional series capacitors through adding a thyristor-controlled reactor. TCSC increase energy transfer, dampening of subsynchronous resonances, and control of line power flow [17].
- STATCOM are GTO (gate turn-off thyristor) based SVC’s [2]. They don’t require as large inductive and capacitive components as SVC’s to provide inductive or capacitive reactive power to high voltage transmission.

- Unified Power Flow Controller (UPFC). Actually an UPFC is the result of connecting a STATCOM with TCSC in the transmission line. This device combines the benefits of a STATCOM and a TCSC [3].

FACTS devices are normally connected in three modes: shunt connection like the Static Var Compensator SVC, in series connection to a line like Thyristor Controlled Series Compensator TCSC or in combined shunt and series connection like the Universal Power Flow Controller UPFC [18].

A TCR-FC compensator is the main device considered in the present paper for power system
enhancement. The control of the total admittance provided by the TCR-FC is made based on fuzzy logic.

The next chapters describe how work a Static Var Compensator, the modeling of the TCR-FC and the design of the fuzzy controller for power system enhancement. In the final section the simulations and comparison of the experimental results are also presented.

2. The SVC operation, power system configuration and modeling

The particular SVC modeled in this chapter consists of a thyristor controlled reactor (TCR) stage to provide the lagging vars and a fixed capacitor FC which offers the leading vars.

The lagging reactive power (inductive reactive power) and TCR current amplitude can be controlled continuously by varying the thyristor firing angle between 90 and 180. The TCR firing angle can be fully changed within one cycle of the fundamental frequency, thus providing smooth and fast control of reactive power supplied to the system [4, 18].

The leading vars (capacitive reactive power) are usually provided by a different number of capacitor bank units. By combining these two components, fixed capacitor and continuously controlled reactor, a smooth variation in reactive power over the entire range can be achieved and the sum of the reactive power becomes linear.

So, the TCR-FC can be seen as an adjustable reactance that can perform both inductive and capacitive compensation. The reactive power injection of a SVC connected to a busbar and the total shunt admittance of the SVC are given by:

\[ Q_{SVC} = -B_{SVC} \cdot V^2 \]  
\[ B_{SVC} = B_C - B_L \]  
\[ 1 \]  
\[ B_C = \frac{1}{X_C} - B_L \]  
\[ B_L(\alpha) = 2\pi - 2\alpha + \sin(2\alpha) \frac{\pi X_L}{X_C} \]  
\[ 2 \]  

The inductive reactance and capacitive reactance are \( X_C \) and \( X_L \). The block diagram from figure 1 was considered to test the power system enhancement using the fuzzy logic based control of SVC. We borrowed the single machine infinite bus theory consists of a synchronous generator connected via a transmission line, represented by reactance \( x_s \), to a large power system, represented by the infinite busbar.

The static VAR compensator will be located at the generator busbar to provide significant damping during transient conditions.

Fig. 1 – Power system configuration

The synchronous generator is described by a third-order nonlinear mathematical model, represented by Park's equations [15].

\[ \begin{align*} 
\dot{\delta} &= \omega - \omega_0 \\
\dot{\omega} &= \frac{1}{H} \cdot (T_m - T_{el} - T_d) \\
E_q^e &= \frac{1}{\tau_{d\phi}} \cdot \left( E_{d} - \frac{x'_1 E'_q V_b}{x_1} - E_i \right) 
\end{align*} \]  
\[ 3 \]  

Where \( T_{el}, T_d, E_l, x_1, x'_1 \) and \( x_2 \) are given by (4).

\[ \begin{align*} 
T_{el} &= E''_q V_b \sin \delta + \frac{(x_q - x'_d)V_b^2 \sin \delta}{2x_1x_2} \\
T_d &= K_d \cdot \omega \\
E_i &= \frac{1}{x_1} \left( x_g - x'_g \right) V_b \cos \delta \\
x_1 &= x'_q (1 - x_s \cdot B_q) + x_e \\
x'_1 &= x_s (1 - x_s \cdot B_L) + x_e \\
x_2 &= x'_q (1 - x_s \cdot B_q) + x_e 
\end{align*} \]  
\[ 4 \]  

Where:
- \( \delta \) is the rotor angle;
- \( \omega \) - angular speed;
- \( H \) - time constant;
- \( T_m \) - constant mechanical torque;
- \( T_{el} \) - electrical torque;
- \( T_d \) - damping torque;
- \( E'_q \) - \( q \) axis transient voltage;
- \( \tau_{d\phi} \) - \( d \) axis open circuit transient time constant;
- \( E_{d\phi} \) - field voltage;
- \( V_b \) - infinite busbar voltage;
- \( x'_d \) - \( d \) axis transient reactance;
- \( x_d \) - \( d \) axis reactance;
- \( x_q \) - \( q \) axis reactance.
The generator is also equipped with an automatic voltage regulator AVR for the field voltage $E_{fd}$, characterized by a first order model (5), time constant $T_{AVR}$ and constant $K_{AVR}$.

$$E_{fd} = \frac{K_{AVR}}{T_{AVR}}(V_{ref} - V_i) - \frac{1}{T_{AVR}}E_{fd}$$ (5)

Figure 2 contains the control block diagram of the SVC. The auxiliary control loop of the SVC uses stabilizing signals, such as speed, frequency, phase angle difference etc., to improve the dynamic performance of the integrated system.

The dynamic equation (6) describes the control loop of the SVC.

$$\dot{B}_s = \frac{K_{SVC}}{T_{SVC}}(V_{ref} - V_i) - \frac{B_s}{T_{SVC}} + \frac{K_{SVC}}{T_{SVC}}u_S$$ (6)

3. Fuzzy control design

This section discusses the basics of the fuzzy logic control design as applied to the static VAR compensator.

The design of a fuzzy controller can be resumed to choosing and processing the inputs and outputs of the controller and designing its four component elements (the rule base, the inference mechanism, the fuzzification and the defuzzification) [8]-[10], [18].

Figure 3 shows the fuzzy control structure.

The linguistic terms from the fuzzy sets presented in the figure 4 are negative big NB, negative small NS, zero Z, positive small PS and positive big PB.

The fuzzy controller implements a rule base made of a set of IF-THEN type of rules (25 rules). These rules can be determined heuristically based on the knowledge of the plant [9]. An example of IF-THEN rule is the following: IF $e$ is negative big NB and $c$ is negative big NB THEN $u_S$ is negative big NB.

The resulting rule table and IF-THEN example are shown in the figure 5.

The min-max inference engine is a good alternative, which for the premises, uses maximum for the OR operator and minimum for the AND operator. The conclusion of each rule, introduced by THEN, is also done by minimum. The final conclusion for the active rules is obtained by the maximum of the considered fuzzy sets. To obtain the crisp output, the centre of gravity (COG) defuzzification method is used.

The crisp value is the resulting controller output which will be the supplementary voltage (control signal) for the firing control of the SVC. The goal is to control the reactive power, damp the rotor angle oscillation and to improve the transient stability of the power system [3], [15], [18].
4. SVC control scheme and experimental results

In figure 6 is shown the SVC fuzzy control diagram for power system stability enhancement used for simulations.

In the diagram the SMIB block contains the model of the generator connected through a transmission line to an infinite busbar. This block has as inputs the field voltage $E_{fd}$, the mechanical torque $T_m$, the infinite busbar voltage $V_b$, where we will simulate the fault and the SVC admittance $B_s$, modified by the SVC control loop. In the SMIB model, the generator and the static VAR compensator are connected to the same busbar, characterized by voltage $V_t$.

The static VAR compensation is adjusted to exchange capacitive or inductive current to the system and to damp the rotor angle and speed oscillations.

The following parameters were used for the simulation (p.u.):

Transmission line

- $x_e = 0.2$

Generator

- $x_d = 2$; $x_q = 2$; $t_{gd} = 5$; $H = 3$; $x_d' = 0.3$; $T_m = 0.5$; $K_d = 2$

AVR

- $K_{AVR} = 100$; $T_{AVR} = 0.1$

SVC

- $B_{smin} = 0.3$; $B_{smax} = 0.3$; $B_{s0} = 0.1$; $u_{smin} = -0.2$; $u_{smax} = 0.2$; $K_{svc} = 50$; $T_{sdc} = 0.1$

Fuzzy controller

- $g_e = 0.01$; $g_c = 0.04$; $g_u = 1$

First case that we have studied was the behavior of the power system after a 0.5 second fault (3-phase short-circuit) near the infinite busbar without the auxiliary signal provided by the fuzzy logic controller.

The figure 7 shows the evolutions of the rotor angle and the speed deviation after the fault. The SVC conventional loop tries to damp the oscillation of the signals, but the performances are not so good, because the settling time is about 25 seconds.
The figure 8 shows the evolution of the total admittance provided by SVC (Thyristor controlled reactor combined with the fixed capacitor TCR-FC) to enhance the power stability without the auxiliary fuzzy loop.

![Fig. 8 – Total admittance of the TCR-FC](image)

In the second case in the simulations we considered the same fault (0.5 second 3 phase short-circuit), but with the auxiliary fuzzy loop for the SVC control.

Figure 9 shows the rotor angle, speed and the total admittance in presence of the auxiliary signal provided by the fuzzy logic controller.

![Fig. 9 – Rotor angle, speed and total admittance](image)

The fuzzy controller has an important role in damping the oscillation caused by the temporary fault. So, the SVC control loop including the fuzzy controller damps the oscillation in a more efficient way and the settling time is reduced to 10 seconds.

The auxiliary signal from the fuzzy logic controller is shown in figure 10.

![Fig. 10 – Auxiliary signal from the fuzzy loop](image)

5. Conclusions
The paper presents the fuzzy logic control of a static var compensator for power system enhancement. The single machine infinite busbar SMIB theory and model were used for power system configuration and the simulations and experimental results were obtained using Matlab-Simulink software.

SVC’s are FACTS devices in shunt connections used to improve transmission line economics and system losses by resolving dynamic voltage problems and reactive power control. So, a type of SVC was investigated in this paper to provide significant damping during transient conditions on power system.

The TCR-FC (thyristor controlled reactor TCR and fixed capacitor FC) was located on the generator busbar and the behavior of the power system was studied after the 3 phase short-circuit that occurs near the infinite busbar. This type of SVC can be seen as an adjustable reactance that can perform both inductive and capacitive compensation to improve the quality of the power system.

We proposed in this paper a SVC fuzzy control diagram which use a conventional SVC loop with an auxiliary signal computed by the fuzzy logic controller. The fuzzy logic controller has as inputs the speed deviation and the speed deviation rate. The output of the fuzzy controller is the supplementary voltage. The main goal of introducing the auxiliary loop is to damp the oscillations of the rotor angle after the fault.

Comparative results made after the simulations with the fuzzy logic controller auxiliary loop emphasize a shorter settling time and a better damping of the power system oscillations.

Other functional signals (rotor angle, frequency, power, busbar voltage) and controllers can be used in the auxiliary loop and will be tested in future works.
References


