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MODERN CONTROL OF STATIC VAR COMPENSATOR FOR POWER SYSTEM STABILITY ENHANCEMENT

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ABSTRACT

The effects of shunt compensation on power system transmission stability and modern approach of the reactive power control scheme have been investigated in this paper. Reactive power compensation is realized in shunt connection with two components: thyristor controlled reactor (TCR) and thyristor switched capacitor (TSC). A special attention has been given in the following paragraphs to a modern control approach for power system stability enhancement which uses fuzzy logic. In the final part of the paper the modern control block scheme of static VAR compensator for reactive power in transmission systems is presented.

Keywords: FACTS, fuzzy control, reactive power control, static VAR compensator, power system transmission

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.

Below different types of FACTS devices are presented in [7]:

- Static Var Compensators (SVC) 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.

- 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). Connecting a STATCOM with a series compensator in the transmission line via its DC circuit results a UPFC. 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.

One of these FACTS devices, SVC, is considered in the present paper. A SVC is practically considered to be a "static var generator or absorber whose output is varied so as to maintain or control specific parameters of the electric power system". The main advantages that SVC offers are: effective and fast voltage control, larger power transmission capability, dynamic and transient stability. The conventional SVC is composed by means of physical circuit elements such as capacitors or inductors, which can provide reactive power. The switching elements in this device are thyristors. It is well known that thyristors may be turned on when they have a forward biased voltage, but turn off only at a natural current zero crossing.

The next chapters describe how work a Static Var Compensator and how to design a fuzzy controller for this device.

2. SVC operation principles

The particular SVC modeled in this chapter consists of two thyristor switched capacitor (TSC) stages to provide the leading vars, and a thyristor controlled reactor (TCR) stage to provide the lagging 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 supply to the system [4].

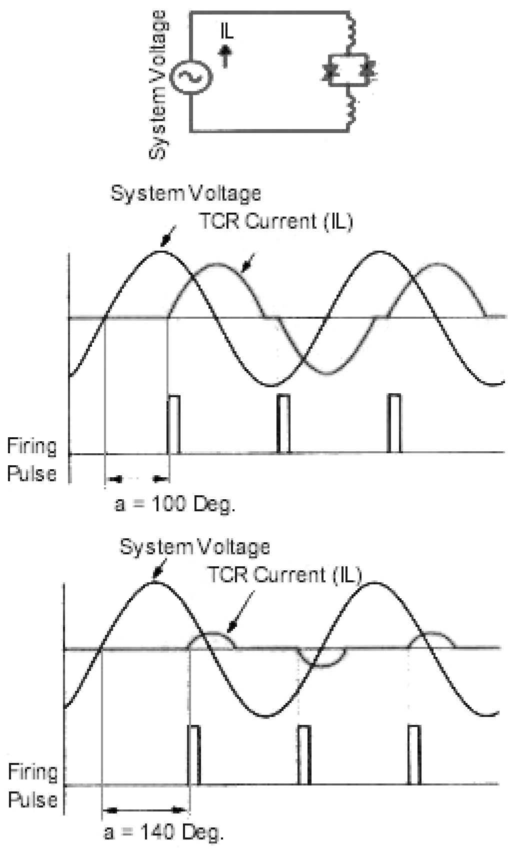

Fig. 1 – TCR control

The leading vars (capacitive reactive power) are provided by a different number of capacitor bank units (only one bank is shown in the diagram) which are switched on or off in steps. The capacitor switching operation is completed within one cycle of the fundamental frequency and the TSC provides a faster and more reliable solution to capacitor switching than conventional mechanical switching devices [4].

An alternative current filter is usually used to reduce and absorb the harmonic current components generated by TCR. Thus, the leading vars are switched in steps, the lagging vars can be varied smoothly. By combining the two operations, switching capacitor in steps and controlling continuously reactor, a smooth variation in reactive power over the entire range can be achieved and the sum of the reactive power becomes linear.

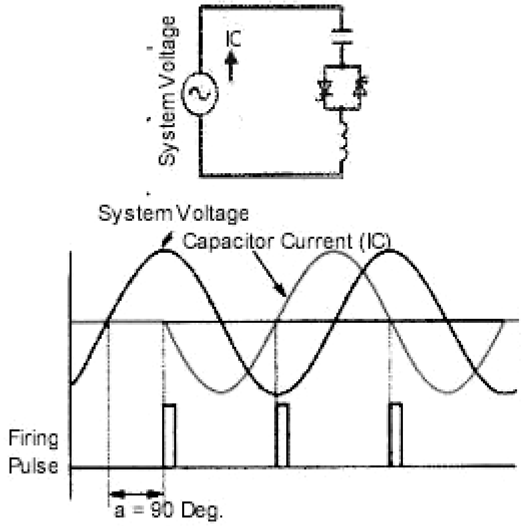

Fig. 2 – TSC control

Applications with only TSC's are also available, providing stepwise control of capacitive reactive power. Improved performances can be obtained by using a fixed capacitor (FC) connected in parallel with thyristor controlled reactor (TCR), resulting a FC-TCR configuration like in [4]-[6].

In conclusion, the FC-TCR 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 bus is given by:

$$\begin{aligned} Q_{SVC} &= -B_{SVC} \cdot V^2 \\ B_{SVC} &= B_C - B_L \end{aligned} \tag{1}$$

In (1) Q_{SVC} is the reactive power injection of the SVC (FC-TCR type), B_{SVC} the susceptance of the SVC, B_C the constant susceptance of the fixed capacitor and B_L the variable susceptance of the thyristor controlled reactor.

For a FC-TCR compensator the susceptance depends on firing angle α [7].

$$\begin{aligned} B_{SVC} &= \frac{1}{X_C} - B_L \\ B_L(\alpha) &= \frac{2\pi - 2\alpha + \sin(2\alpha)}{\pi X_L} \end{aligned} \tag{2}$$

The inductive reactance and capacitive reactance are X_L and X_C.

3. Fuzzy control basics

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].

Figure 3 shows the fuzzy control structure.

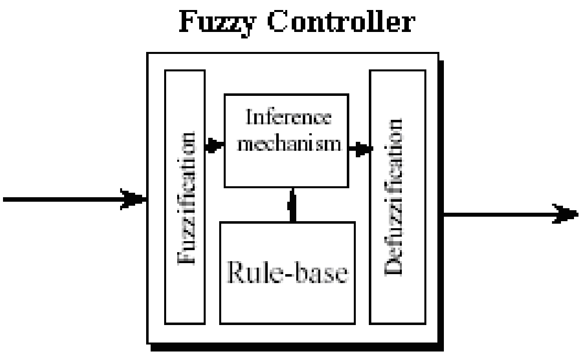

Fig. 3 – Fuzzy controller

Usually, the inputs and the output of the fuzzy system are:

- the error *e*;
- change in error (error derivative) *ce*;
- the output variable *u*.

The fuzzy logic controllers designed for power system stability enhancement uses important parameters such as rotor speed, frequency, reactive or active power, voltage, phase angle difference.

The universe of discourse of the variables (that is, their domain) is normalized using scaling gains (*ge, gc, gu*) to cover a range of [-1, 1]. A standard choice for the membership functions is used with five membership functions for the three fuzzy variables (meaning 25 = 5^2 rules in the rule base) and symmetric, 50% overlapping triangular shaped membership functions, meaning that only 4 =2^2 rules at most can be active at any given time.

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* is positive big NB.

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

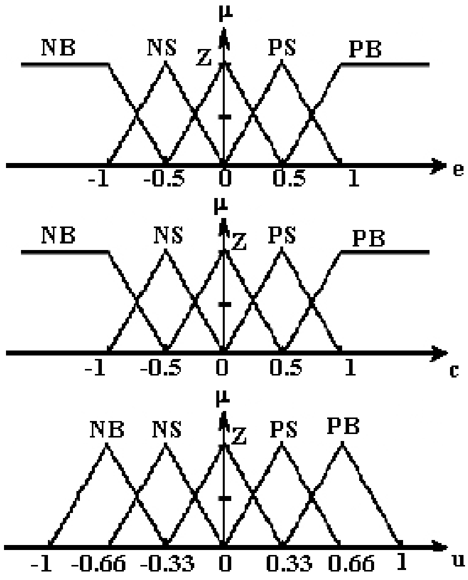

Fig. 4 – Membership functions

u		c				
		NB	NS	Z	PS	PB
e	NB	NB	NB	NB	NS	Z
	NS	NB	NB	NS	Z	PS
	Z	NB	NS	Z	PS	PB
	PS	NS	Z	PS	PB	PB
	PB	Z	PS	PB	PB	PB

Fig. 5 – Rule base for the fuzzy controller

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], [11].

4. Fuzzy control of Static VAR Compensator

In figure 6 is shown the modern control approach for power system stability enhancement which uses fuzzy logic.

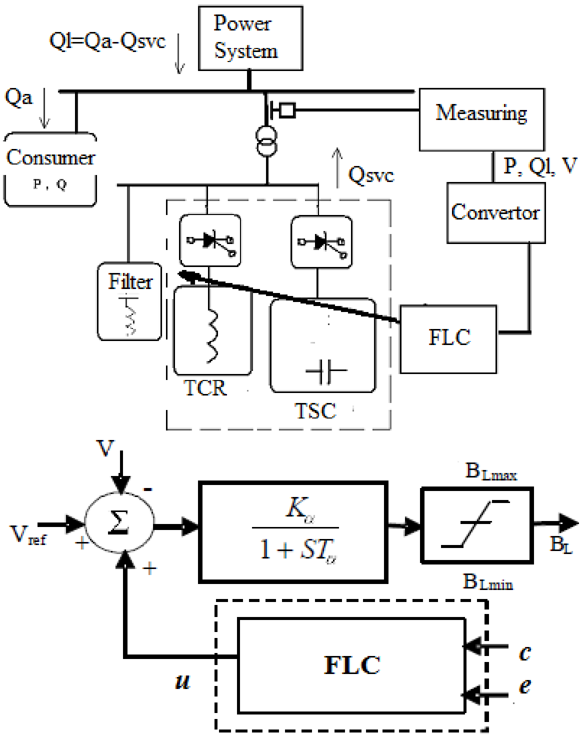

Fig. 6 – Fuzzy control block scheme of the SVC

In the first diagram from figure 6 the consumer (load) and the static VAR compensator are connected to the same bus bar. The static VAR compensation is adjusted to exchange capacitive or inductive current to the system.

For the SVC with firing control system a simplified first order model characterized by gain K and constant time T was considered. The fuzzy logic controller provides a supplementary control signal which is addition to the voltage feedback loop [15].

5. Conclusions

The paper presents a modern approach of reactive power control, using fuzzy logic and control theory. Because the lagging reactive power (TCR) is controlled continuously and the leading reactive power (TSC) is provided discontinuously, a classic control design approach cannot be used.

In this situation an intelligent control method, like fuzzy systems, can solve the problem. There is no need to model the plant or to have concrete information about it when we are using fuzzy method to control the plant. Actually, the fuzzy logic control approach is an emerging tool to deal with complex problems and uncertainties from the power system.

Also, a great advantage with fuzzy control consists of the possibility to obtain a non-linear or discontinuous plant command even in the presence of the perturbation.

A more smooth control of the reactive power is obtained by using a special type of SVC, which use a fixed capacitor with a thyristor controlled reactor FC-TCR.

The availability of semiconductor devices, such as thyristors and gate turn-off thyristors (GTO), allows rapid control of bus voltage and reactive power. Controllable reactive power sources such as Static VAR Compensators and STATCOMs with semiconductor devices are used to improve the maximum power transfer limits available on a transmission line and the transient stability of the power system.

The cost of these devices is significantly lower than the cost of synchronous compensators traditionally used for this purpose. They have also a faster response time.

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