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Using Fuzzy Logic and Static VAR Compensator to Reactive Power Compensation and Power Factor Correction

Hossein Morshedi, Siamak Masoudi, Amir Ghorbani

Islamic Azad University, Abhar Branch, Iran

Abstract: In this paper Static Var Compensator (SVC) is proposed for reactive power compensation and power factor correction. The TCR is operated automatically by a Fuzzy Logic Controller (FLC). The ability of the TSK (Takagi-Sugeno-Kang) and mamdani, two typical types of fuzzy controllers, for thyristors firing control in SVC is compared. Input signals for the FLC are chosen as load reactive power and initial firing angle of thyristors. The control signal is calculated using fuzzy membership functions. MATLAB/Simulink based simulation is utilized to demonstrate the comparison two types of controllers in SVC

Key word: Fuzzy logic, Static Var Compensator, Reactive Power, Power Factor

INTRODUCTION

Advances in power electronic technology have led to the development of flexible AC transmission systems (FACTS). The main advantages of FACTS devices are their fast responses to changes in power system conditions and their ability to continuously control transmission line parameters (Lo *et al*, 2003). Industrial static var compensators (SVCs) are typically applied at or near the load center to mitigate voltage fluctuations, flicker, phase unbalance, or other load-related disturbances (Juanjuan Wang *et al*, 2008). Most FACTS devices have been designed by using linear control methods based on small signal analyses and eigenvalue techniques. In this regard, lead-lag controllers and PID controllers are the most interesting methods, which are based on eigenvalue techniques such as pole placement or eigenvalue sensitivity. Since power systems are inherently non-linear systems this kind of linear controller cannot perform well in power system stability restoration. Therefore, research into the area of non-linear control is required. Fuzzy logic control is one of the best and most successful techniques among expert control strategies, and is well known as an important tool to control non-linear, complex, vague, and ill-defined systems (Lo *et al*, 2003). The application of control algorithms based on fuzzy sets theory, proposed by Zadeh (Ronan Marcelo Martins *et al*, 1995), has grown in recent years (Suiton *et al*, 1965) (Graham *et al*, 1989). Some related works are as follow (Mustafa *et al*, 2009): in Ref. (Kazemi *et al*, 2006) have suggested a hybrid fuzzy controller for FACTS devices which have been tested on two area four machines, eleven bus system (Kundur) with TCSC, UPFC and SVC installed in the study system. In Ref. (Schoder *et al*, 2000), the authors have proposed a Fuzzy PI design method, to design the fuzzy controller for UPFC. The usefulness of their proposed controller has been tested on a four machines, eleven bus systems also. Salman Hammed (Hameed *et al*, 2008) have presented a self-tuning fuzzy PI controller for TCSC. The performance of the proposed TCSC controller has been tested on the 11 bus, four machines system and 39 bus system. From the above discussion it is observed that the different fuzzy control strategies proposed in the literature have been tested on relatively small test systems or using simple method of turning.However, in recent years, static Var compensators (SVCs) employing thyristor-switched capacitors (TSCs) and thyristor-controlled reactors (TCRs) to provide or absorb the required reactive power have been developed (Dixon *et al*, 2005).

This paper presents an application of fuzzy control to determine the control signal of static var compensator (SVC) for reactive power compensation and power factor correction. Input signals for the FLC are chosen as load reactive power and initial firing angle of thyristors. The control signal is calculated using fuzzy membership functions. The effectiveness and feasibility of the TSK (Takagi-Sugeno-Kang) and mamdani type fuzzy controllers for thyristors firing control in SVC is compared. Effectiveness of the proposed technique is demonstrated by simulation studies on a single machine infinite bus system. Results obtained show improvement in the overall system characteristics using the proposed adaptive fuzzy logic SVC controller.

Shunt Compensation

Fig. 1 shows the principles and theoretical effects of shunt reactive power compensation in a basic ac

Corresponding Author: Hossein Morshedi, Islamic Azad University, Abhar Branch, Iran

system, which comprises a source, a power line, and a typical inductive load. Fig. 1(a) shows the system without compensation and its associated phasor diagram. In the phasor diagram, the phase angle of the current has been related to the load side, which means that the active current is in phase with the load voltage. Since the load is assumed inductive, it requires reactive power for proper operation and hence, the source must supply it, increasing the current from the generator and through power lines. If reactive power is supplied near the load, the line current can be reduced or minimized, reducing power losses and improving voltage regulation at the load terminals. This can be done in three ways: 1) with a capacitor; 2) with a voltage source; or 3) with a current source. In Fig. 1(b), a capacitor device is being used to compensate the reactive component of the load current.

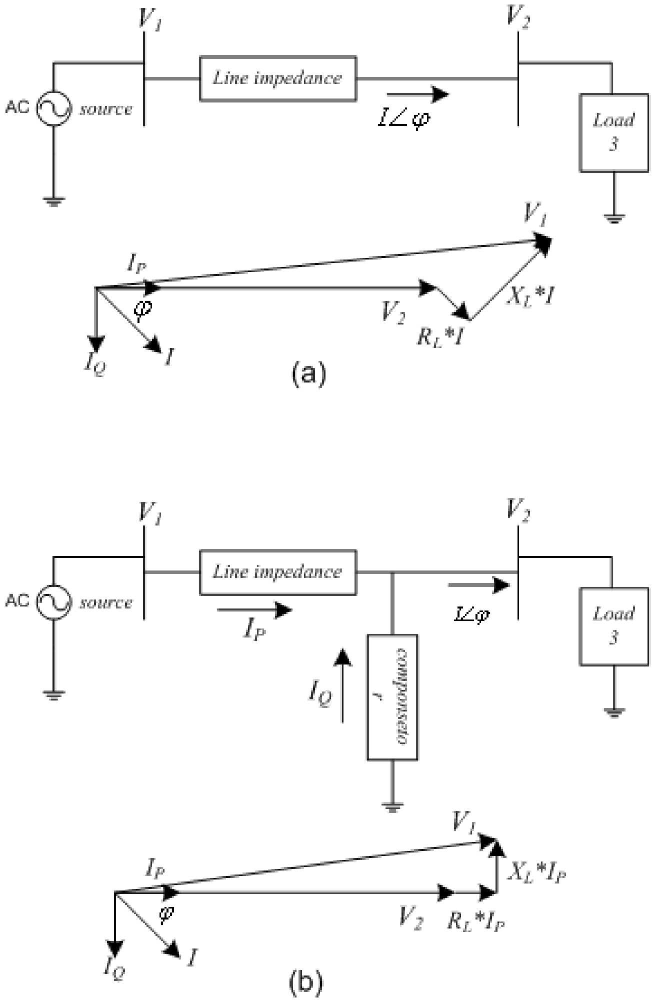

Fig. 1: Principles of shunt compensation in a radial ac system,(a) without reactive compensation. (b) With shunt compensation.

As a result, the system voltage regulation is improved and the reactive current component from the source is reduced or almost eliminated. If the load needs leading compensation, then an inductor would be required. Also, a current source or a voltage source can be used for inductive shunt compensation. The main advantage of using voltage- or current-source Var generators (instead of inductors or capacitors) is that the reactive power generated is independent of the voltage at the point of connection.

TCR (Thyristor Controlled Reactor) Branch:

The TCR branch makes use of the TSC overcompensation to fine-tune the SVC VARs supplied to the load. This fine- tuning is completed by varying the firing delay angle of the thyristors. The firing delay angle is the time delay from the start of each half-cycle that the TCR is turned on. Firing angles of TCR will be in the range of (p/2)<a<p for each half-cycle. Eq. (1) derived from the conduction angle equation in (Dixon

et al, 2005), illustrates the relationship between the firing angle and the TCR reactance (X_{TCR}).

$$X_{TCR} = [2(\pi - \alpha) - \sin(2(\pi - \alpha))/(\pi \times X_L)]^{-1} \tag{1}$$

Fig. 2 shows the relationship between the firing angle and the TCR reactance. Fig. 3 shows the relationship between the firing angle and the SVC impedance. This figure illustrate that the SVC impedance is so sensitive in small firing angles.

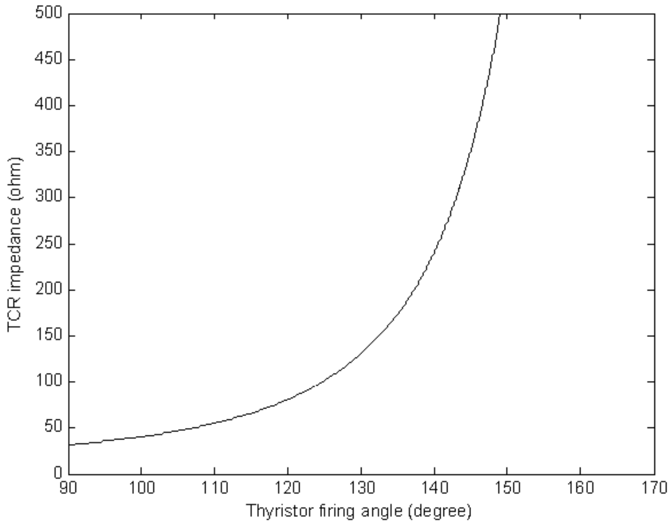

Fig. 2: TCR impedance vs. thyristor firing angle

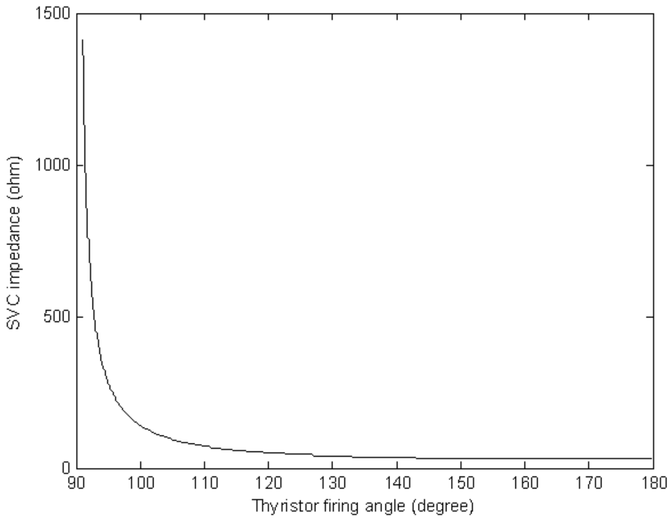

Fig. 3: SVC impedance vs. thyristor firing angle

Simulation Results:

Several simulink simulations were created to verify the feasibility of the SVC design and the TCR fuzzy controller. For the particular simulink model is shown in Fig. 4. Three reactive loads are switched in different times. Load 2 is switched on at $t_1=0.4s$ and switched off at $t_3=1.2s$ and load 3 is switched on at $t_2=0.8s$. The TSC branch and a TCR branch were modeled with their respective controllers. The TSC branch consists of a single switched capacitor while the TCR branch consists of a reactor that is fed a firing angle determined by the fuzzy controller. The fuzzy controller accepts the phase angle difference of the load and firing angle of thyristors as an input and outputs the optimum firing angle of TCR.

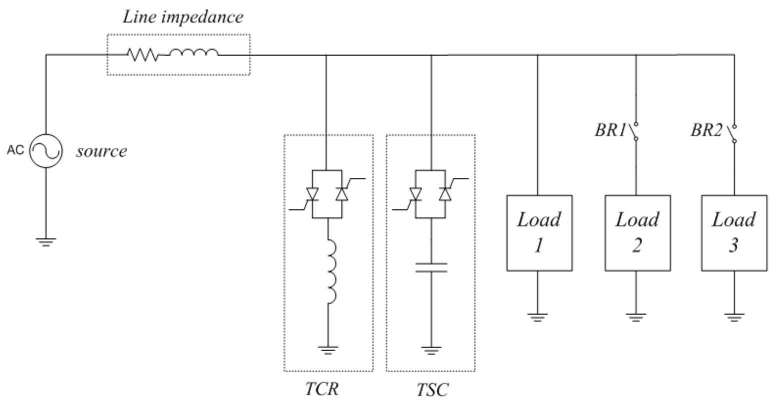

Fig. 4: Analyzed power circuit topology

Fig. 5 shows the displacement power factor (PF) of the load without the branches compensating.

Fig. 6 shows the active and reactive power at load side without compensation. As shown in this figure at t_1=*0.4s* and t_2=*0.8s*.reactive power increases and power factor (PF) decreases by inductive load increasing. Also at t_3=*1.2s* one of inductive loads retreat from power system and therefore power factor increases and reactive load decreases.

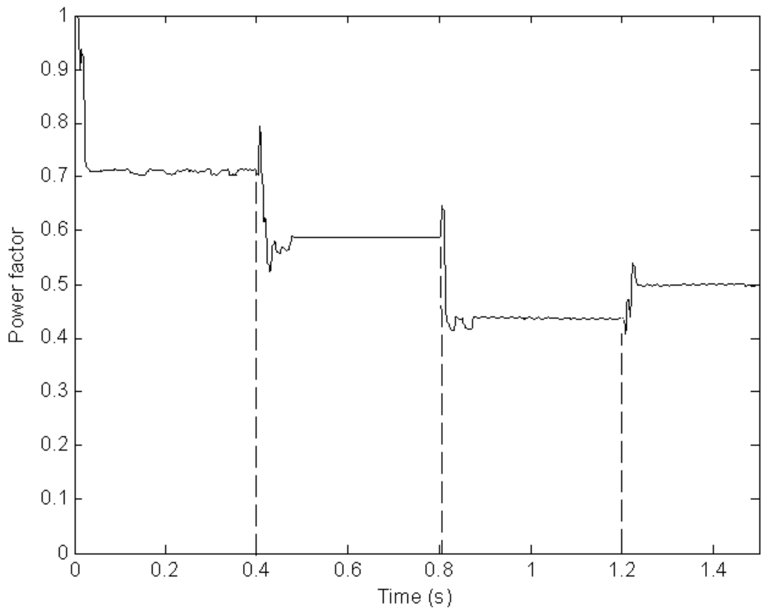

Fig. 5: Power factor (PF) of the load without the branches compensating

Mamdani Type Fuzzy Controler:

In this section a Mamdani type double input single output (DISO) Fuzzy Linguistic Controller has been designed. The rules are shown in Table I. As shown in figures 10 and 11 with using fuzzy controller we have suitable power factor and reactive power compensation.

Table 1: Fuzzy controller rules (Mamdani type fuzzy controller)

Reactive power												
		NVB	NB	NM	NS	NVS	Z	VS	S	M	B	VB
	VS	NVVB	NVB	NM	NS	NVS	Z	VS	S	M	VB	VVB
	S	NVVB	NVVB	NB	NS	NS	Z	S	S	B	VVB	VVB
α	M	NVVB	NVVB	NVVB	NM	NM	Z	M	M	VB	VVB	VVB
	B	NVVB	NVVB	NVVB	NVVB	NB	Z	B	VB	VVB	VVB	VVB
	VB	NVVB	NVVB	NVVB	NVVB	NVB	Z	VB	VVB	VVB	VVB	VVB
	VVB	NVVB	NVVB	NVVB	NVVB	NVVB	Z	VVB	VVB	VVB	VVB	VVB

Table 2: Fuzzy controller rules (Sugeno type fuzzy controller)

	Reactive power											
		NVB	NB	NM	NS	NVS	Z	VS	S	M	B	VB
	VS	NH	NVB	NB	NS	NVVVS	Z	VVVS	S	B	VB	H
	S	NH	NH	NVB	NS	NVVS	Z	VVS	S	VB	H	H
α	M	NH	NH	NVVVB	NM	NVVS	Z	VVS	M	VVVB	H	H
	B	NH	NH	NH	NVVB	NVS	Z	VS	VVB	H	H	H
	VB	NH	NH	NH	NH	NVB	Z	VB	H	H	H	H
	VVB	NH	NH	NH	NH	NH	Z	H	H	H	H	H

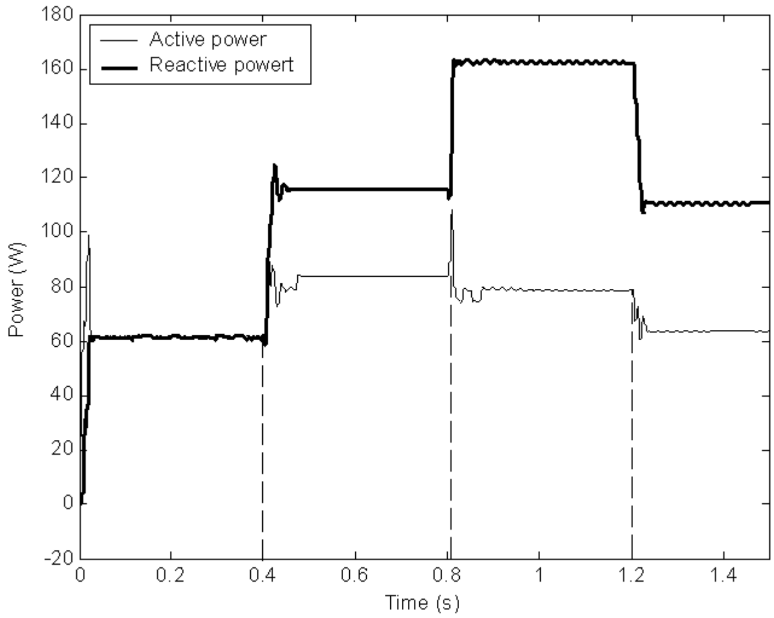

Fig. 6: Active and reactive power at load side without compensation

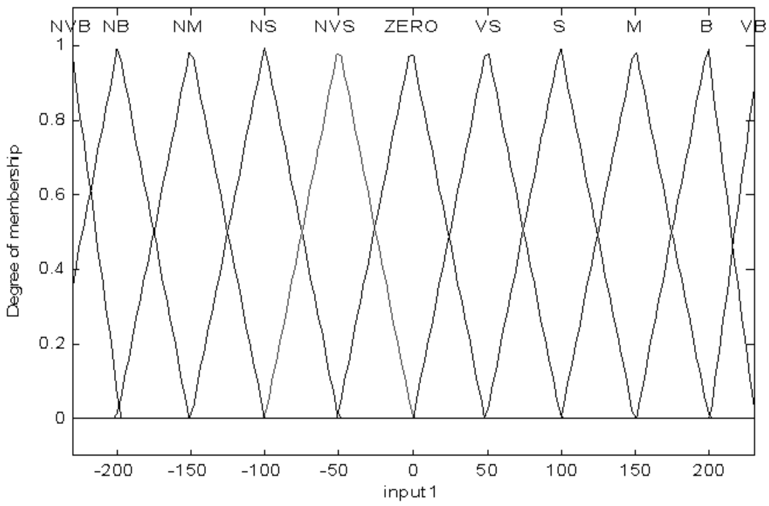

Fig. 7: The fuzzy membership function of reactive power at load side (input 1 of fuzzy controller)

Sugeno Type Fuzzy Controller:

In this section a sugeno type double input single output (DISO) Fuzzy Linguistic Controller has been designed which has same memberships at input.

The rules are shown in Table II. As shown in fig. 14 and 15 using sugeno type controller results power factor correction and reactive power compensation similar to section (a). But as shown in fig. 17 using mamdani type fuzzy controller has results better characteristics in reactive power and power factor.

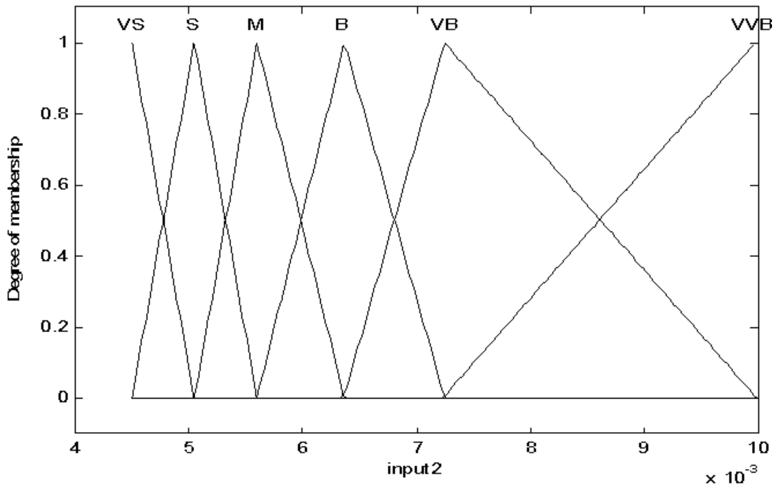

Fig. 8: The fuzzy membership function of initial thyristor firing angle (input 2 of fuzzy controller)

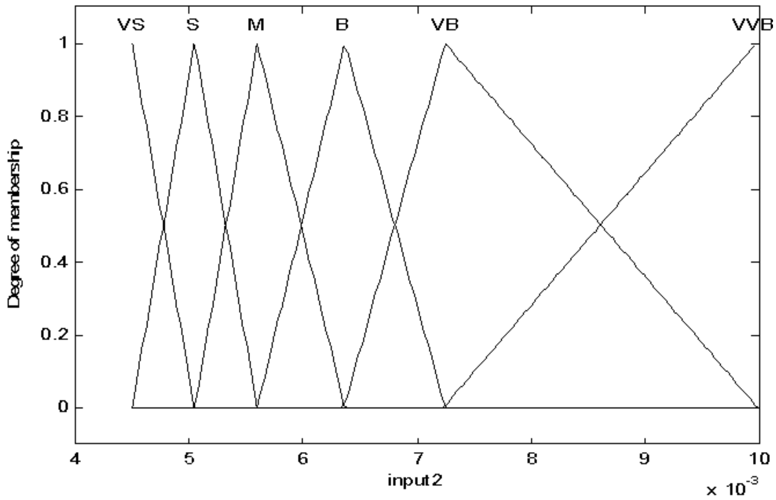

Fig. 9: The fuzzy membership function of variation of thyristor firing angle (output of fuzzy controller)

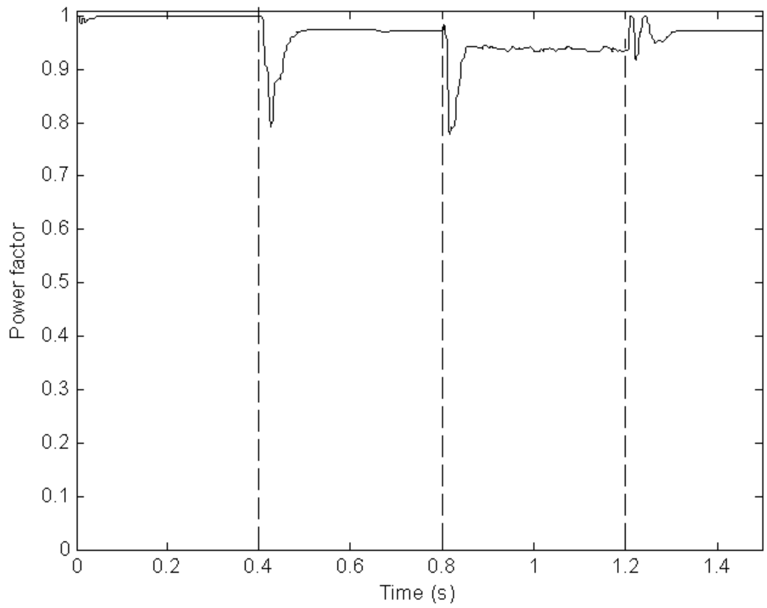

Fig. 10: Power factor (PF) of the load with the branches compensating (Mamdani type fuzzy controller)

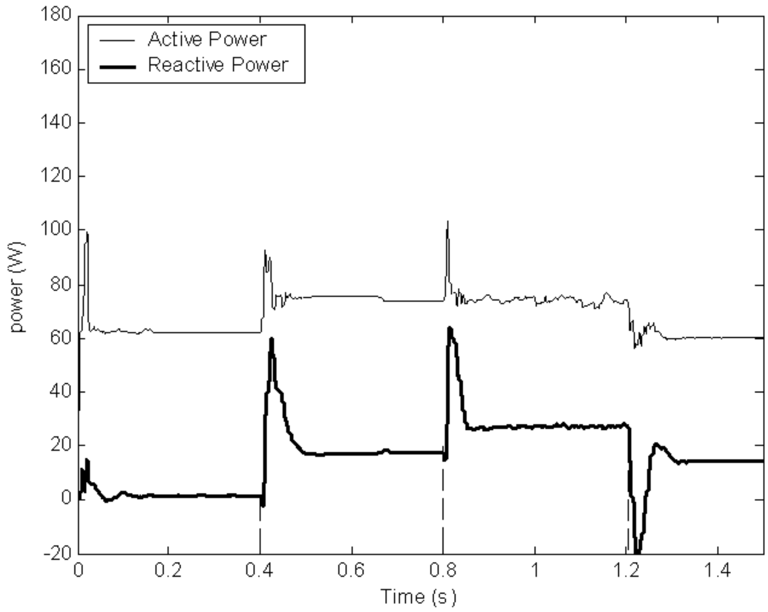

Fig. 11: Active and reactive power at load side with compensation (Mamdani type fuzzy controller)

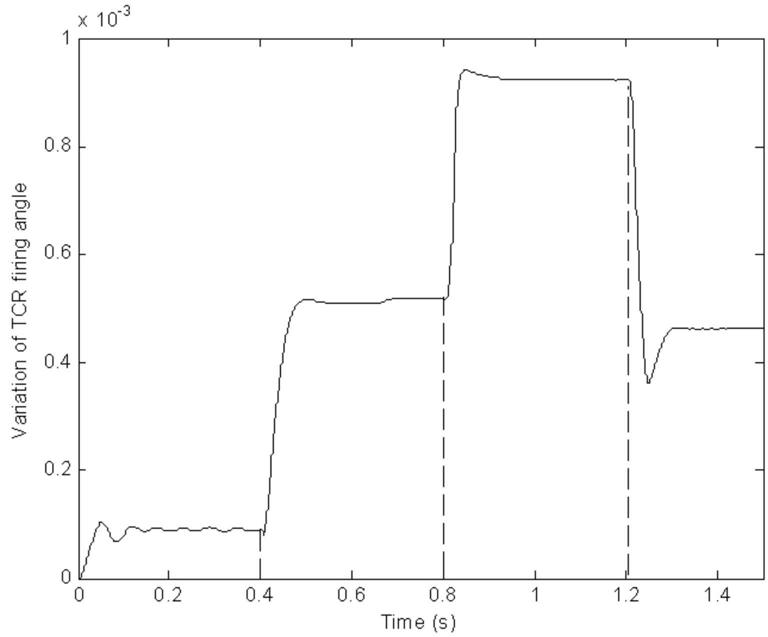

Fig. 12: Variation of TCR firing angle (Mamdani type fuzzy controller)

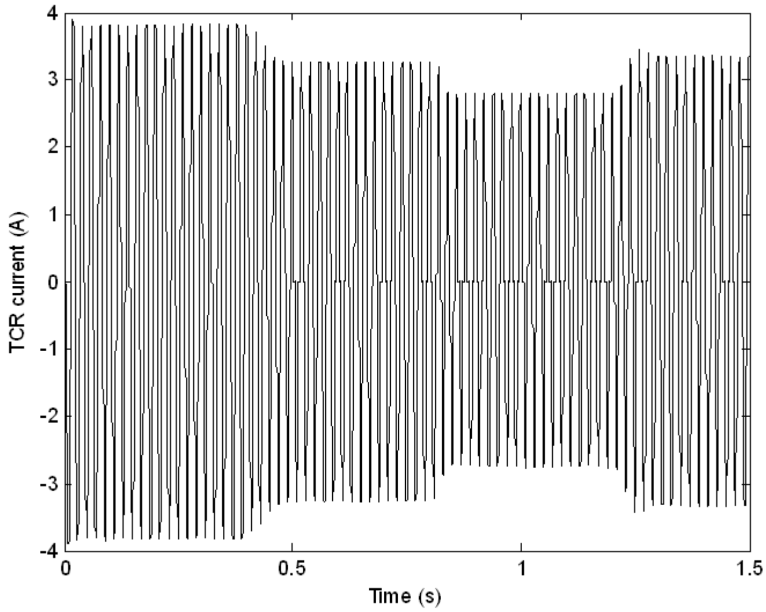

Fig. 13: TCR current at different time

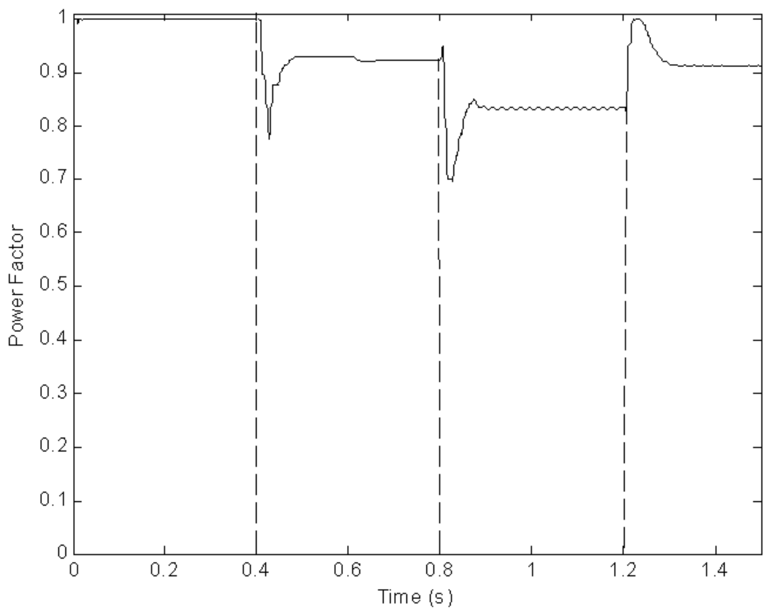

Fig. 14: Power factor (PF) of the load with the branches compensating (Sugeno type fuzzy controller)

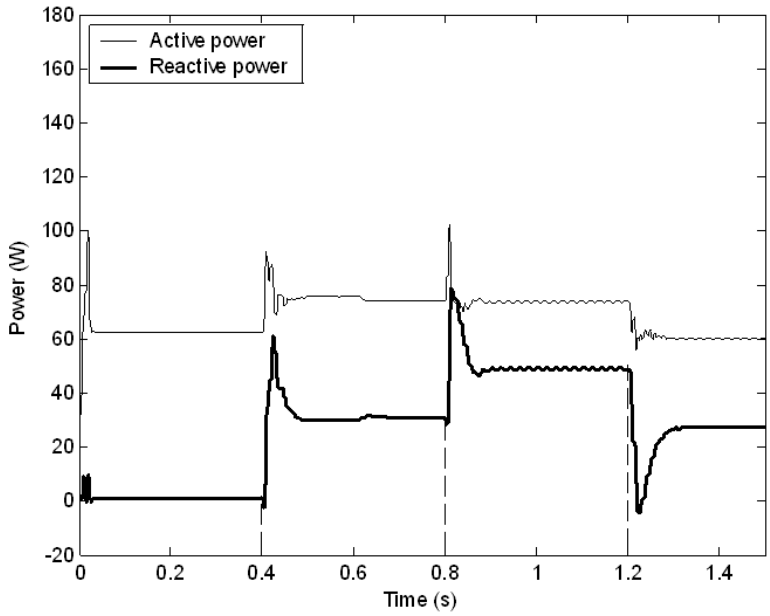

Fig. 15: Active and reactive power at load side with compensation (Sugeno type fuzzy controller)

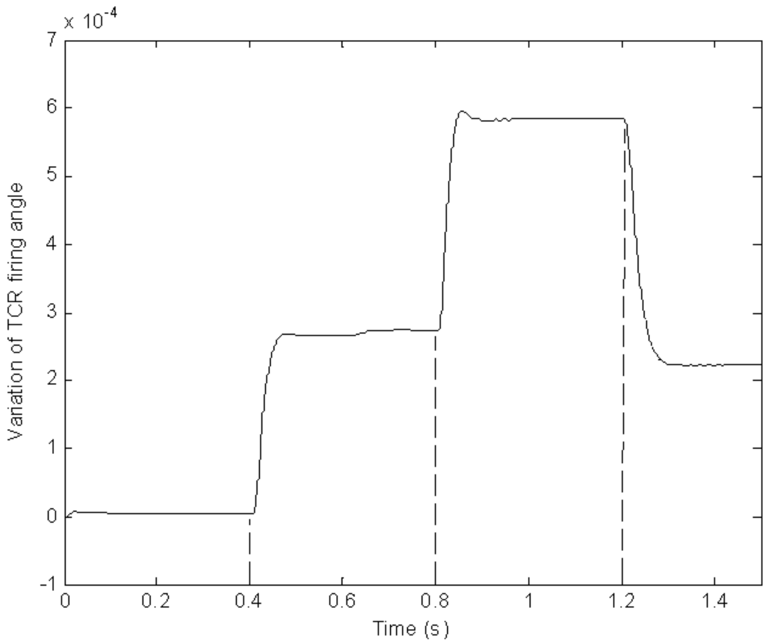

Fig. 16: Variation of TCR firing angle (Sugeno type fuzzy controller)

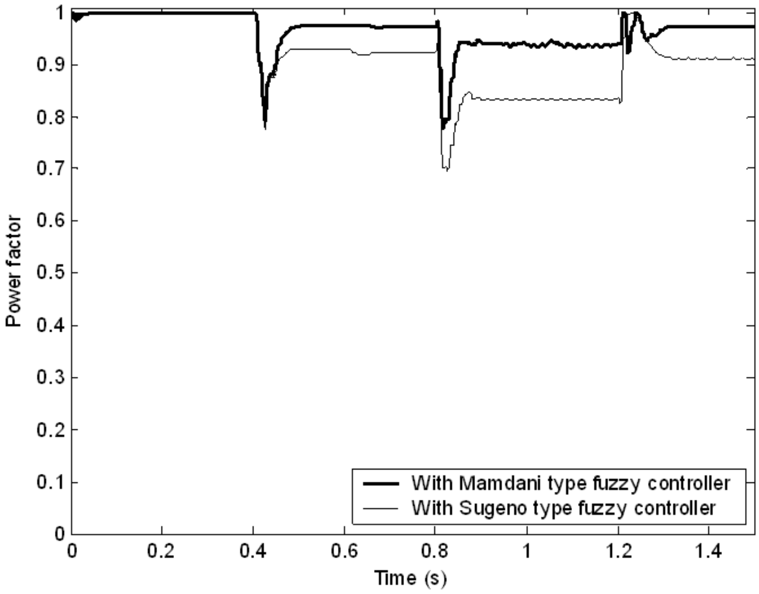

Fig. 17: Comparison of "Mamdani" and "Sugeno" type fuzzy controller for power factor correction

Conclusion:

The fuzzy logic control strategy of SVC is researched in the paper. The effectiveness and feasibility of the TSK (Takagi-Sugeno-Kang) and mamdani type fuzzy controllers for thyristors firing control in SVC is shown and compared clearly. Simulation results show good performance of fuzzy controller in power factor correction and reactive power compensation. Also in this paper demonstrated that using mamdani type fuzzy controller has results better characteristics in reactive power and power factor.

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