World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:3, No:12, 2009

Fuzzy Controller Design for TCSC to Improve Power Oscillations Damping

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***Abstract*—Series compensators have been used for many years, to increase the stability and load ability of transmission line. They compensate retarded or advanced volt drop of transmission lines by placing advanced or retarded voltage in series with them to compensate the effective reactance, which cause to increase load ability of transmission lines. In this paper, two method of fuzzy controller, based on power reference tracking and impedance reference tracking have been developed on TCSC controller in order to increase load ability and improving power oscillation damping of system. In these methods, fire angle of thyristors are determined directly through the special Rule-bases with the error and change of error as the inputs. The simulation results of two area four- machines power system show the good performance of power oscillation damping in system. Comparison of this method with classical PI controller shows the increasing speed of system response in power oscillation damping.**

***Index Terms*—TCSC, Two area network, Fuzzy controller, Power oscillation damping.**

I. INTRODUCTION

FLEXIBLE AC transmission systems refer to systems in which semi-conductors technology has been used to increase the transmission line capacity, improvement in transient, dynamic or voltage stability and increase the system efficiency. Applying these equipment was begun in 1975, that SVCs (static var compensator) were applied to increase the voltage and transfer power capacity [1]. The main objectives of using FACTS devices are increasing power transfer capacity in transmission lines. If the system stability is maintained or enhanced by FACTS controllers following the faults, the power transfer may be increased up to thermal limit. Of course, reaching to thermal limit should be avoided, due to increasing the loss in transmission lines. TCSC is one of the major FACTS devices that may be used to compensate the reactive impedance of transmission line. This powerful device may also be used to compensate a wide range of impedance continuously, and so acts as power oscillation damping in power system [2].
TCSC consists of two inti-parallel thyristors which are series

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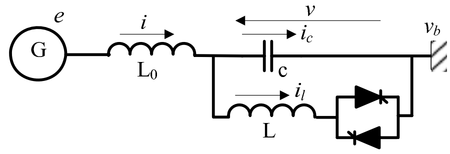

Fig. 1. Schematic diagram of one TCSC connected to infinite bus and generator

with a reactive impedance, and the whole set is parallel with a capacitor fig.1.

Power oscillations damping, avoiding voltage collapse, reliability enhancement of power system, improving dynamic and transient stability of system are the several advantages of TCSC, if a suitable controller are applied to this devices. TAKAAKI KAI examined and showed two models of current and voltage source for TCSCs. In the steady state, current source model is more adequate and in case of dynamic state with oscillation of power angle, voltage source model is more adequate [3]. YUNQIANG LU used a state estimator for verifying system's performance depends on network model and parameters [4]. General method of TCSC controller design based on linear methods cannot be adequate in large disturbances and this method is only responsible for small changes in error zone. In other words, when this system faces with large disturbances, linear model doesn't act accurately, due to large changes in the state of system. For this reason, nonlinear controller is used for damping of power oscillations [5]. ANDRE M.D, improved the system stability margins and damped the oscillations, using self-tuning linear quadratic Gaussian control. PSS is used to damp the low frequency oscillations. PSS provides a feedback to AVR, to make the system dynamically stable [6] and [7]. SALMAN HAMEED improved the system stability by using fuzzy PI controller in TCSC [8]. In this paper, fuzzy control is used to control the TCSC thyristor's firing angle. In this design, two following cases are considered to determine the error:

$$e(t) = z - z_{ref} \tag{1}$$

$$e(t) = p - p_{ref} \tag{2}$$

Where z is impedance and p is active power of transmission line.
In both of above states, firing angles of TCSC thyristors is the controller's output.

II. FUZZY CONTROLLER DESIGNING

Fig.2 shows the block diagram of fuzzy controller for TCSC which is designed in this section. In this block diagram, error

is in form of $e(t) = y(t) - R(t)$, where $y(t)$ and $R(t)$ are system's output and reference input respectively.
At first, error $(e(t))$ and change of error $(\Delta e(t))$ values will be convert to fuzzy variables. After this fuzzification, fuzzy inputs enter to inference mechanism level and with considering membership function and rules outputs are sent to defuzzification, to calculate the final outputs. Each rule of fuzzy control is as follows: "If $e(t)$ is E and $\Delta e(t)$ is ΔE, then Δu is Δu".

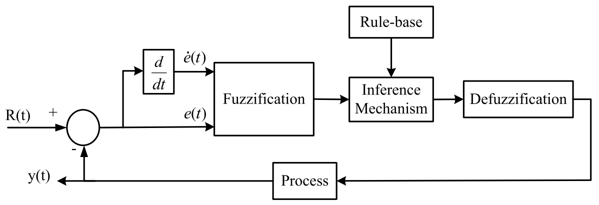

Fig. 2. Fuzzy controller block diagram

In this work for both the inputs ($e(t)$ and $\Delta e(t)$) and the output Δu, seven fuzzy subsets have been used. These are: PB (positive big), PM (positive medium), PS (positive small), ZE (zero), NS (negative small), NM (negative medium) and NB (negative big).
We use Gaussian membership functions, for each of above sub-sets.
49 control rules yield by these fuzzy sub-sets which are shown in table.I.

TABLE I
FUZZY CONTROL RULES IN THE STATE OF 1,2 FOR SELECTING ERROR SIGNALS

$\Delta e/e$	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NS	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PE
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PS	PM	PB	PB	PB

Fig.3 shows the single line diagram of two area four-machines power system with TCSC.

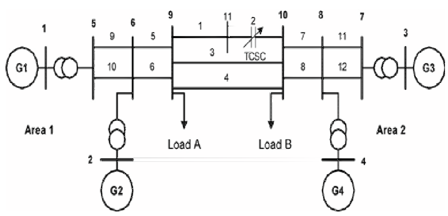

Fig. 3. Two area four machines power system with TCSC

To design the fuzzy controller for this TCSC, two states are considered to select the error signal as follows:
First, the error signal is obtained by impedance of transmission line as:

$e(t) = z - z_{ref}$

Related membership functions are shown in Figs. 4, 5 and 6.

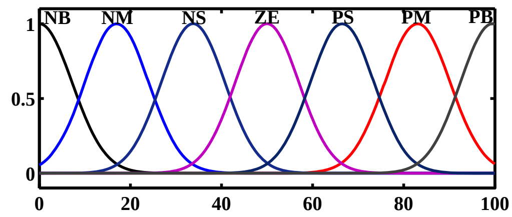

Fig. 4. Membership function of error derivative $(\dot{e}(t))$ in first state

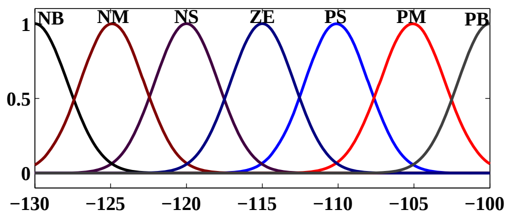

Fig. 5. Membership function of error $(e(t))$ in first state

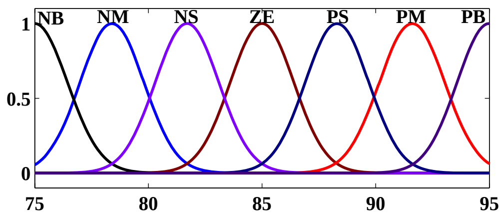

Fig. 6. Output membership function in first state

In second state, the error signal is obtained by power in transmission line as:

$p(t) = p - p_{ref}$

Related membership functions are shown in Figs. 7, 8 and 9.

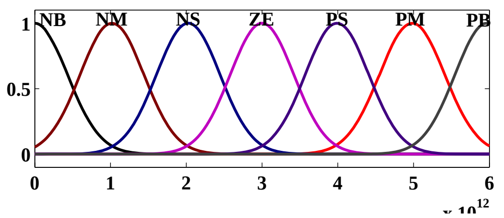

Fig. 7. Membership function of error derivative $(\dot{e}(t))$ in second state

III. SIMULATION RESULTS

In order to evaluate the performance of TCSC controller designed, the model of two-area four-machine power system shown in Fig.3, is considered. The parameter of this system can be found in [8].

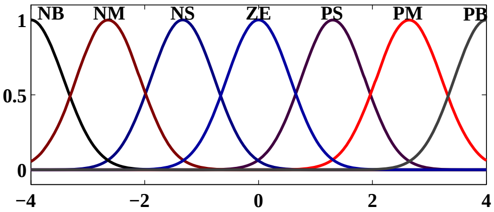

Fig. 8. Membership function of error $(e(t))$ in second state

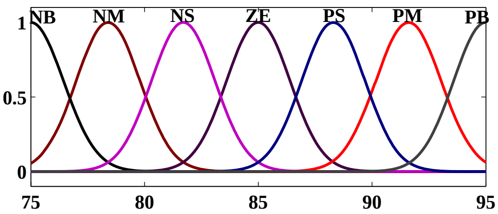

Fig. 9. Output membership function in second state

This system is studied to show power oscillation damping effect of TCSC with fuzzy controller. The model of this system is developed in MATLAB/SIMULINK.
To investigate the performance of the controller, a short circuit is inserted in bus 11 at $t = 6sec$ for $0.2sec$.
Fig.10 shows the voltage and active power with PI controller for TCSC active power. These system responses with TCSC fuzzy controller with using impedance as error signal are shown in fig.11. The same responses in second state that uses the power as the error signal are shown in fig.12.

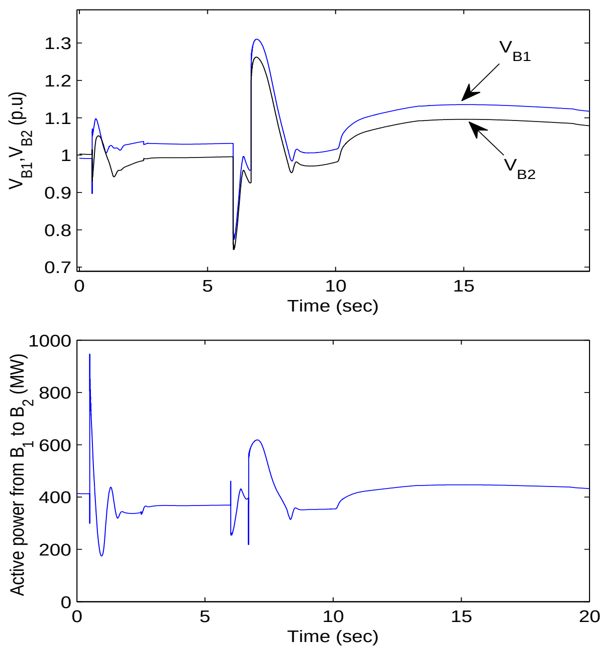

Fig. 10. System response with TCSC and PI controller

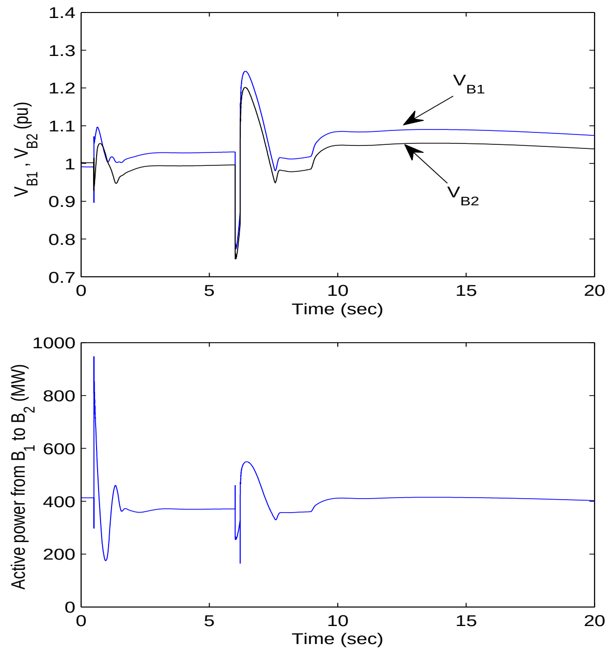

Fig. 11. System response with TCSC and fuzzy controller in first state

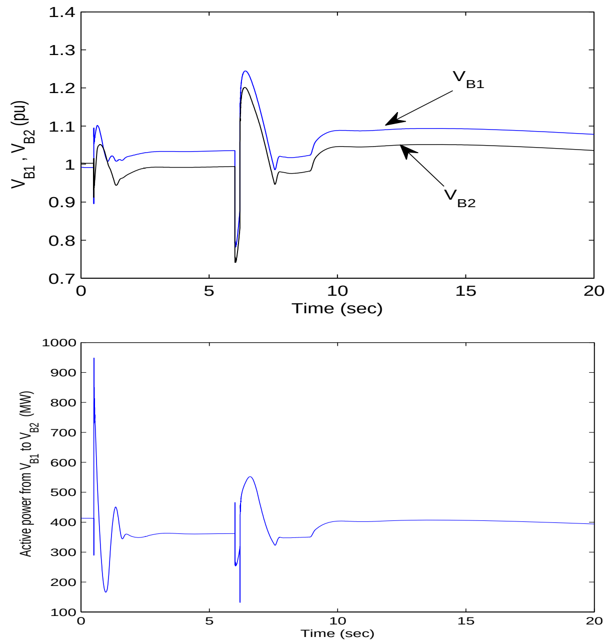

Fig. 12. System response with TCSC and fuzzy controller second state

IV. Conclusion

In this paper, fuzzy control method is used for controlling TCSC thyristors fire angle, in order to improve damping of power oscillations in two states as follow: 1. Fuzzy controller input at first state, is considered as changes of transmission line impedance in regard to base impedance. 2. Fuzzy controller input in the second state, is considered as active power changes of transmission line in regard to base power. The simulation conducted on a two area four- machines standard network, shows that in two above states, power oscillations damping is faster than the case in which PI controller is used. In fuzzy controller with selecting active power as fuzzy controller input, the response is damped faster than selecting the impedance of transmission line as fuzzy controller input.

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