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Power System Stability Enhancement via STATCOM Supplementary Control Based on Fuzzy Energy Function

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Abstract*- *Following a disturbance, the machines in a stable power system initially oscillate, and then settle at the stable equilibrium point where the transient energy is zero. This paper aims at producing additional damping by means of by a fuzzy logic based static synchronous compensator (STATCOM) in coordination with a PSS. The stability of the system is evaluated by calculating the dissipation rate of the transient energy in post fault period. The control strategy of the STATCOM is selected very carefully to increase the rate of dissipation of the transient energy. The STATCOM's supplementary controller is a fuzzy controller whose inputs are energy function and its derivative. The proposed approach is then successfully verified on Kundur's four-machine two-area system.

Index terms*: *Power System Stability, FACTS, STATCOM ,Fuzzy Energy function

I. INTRODUCTION

Reactive power compensation is an important issue in electrical power systems, and shunt flexible AC transmission system (FACTS) devices play an important role in controlling the reactive power flow to the power network and, hence, the system voltage fluctuations and stability. Static synchronous compensator (STATCOM) is a well-known member of FACTS family, which is connected in shunt with the system and resembles, in many respects, a rotating synchronous condenser used for voltage control and reactive power compensation. It replaces the bulky reactive elements of conventional static var compensator (SVC) by a solid-state synchronous voltage source. From the power system dynamic stability viewpoint, the STATCOM provides better damping characteristics than the SVC as it is able to transiently exchange active power with the system [1]-[4].

While the primary purpose of STATCOM is to support the bus voltage by injecting (or absorbing) reactive power, it is also capable to improve the power system stability [2].

While the shunt FACTS device is operated to control the bus voltage, it may not be able to significantly improve the system damping or, in some cases, may even provide negative damping [5], [6]. However, a significant improvement of system damping can be achieved when the FACTS device is controlled by some auxiliary signals superimposed over its normal voltage control loop [5]–[7].

To improve the overall system performance, many researches were made on the coordination between PSSs and FACTS [1]power oscillation damping controllers [8]–[11].On the other hand, the energy function method is a powerful tool of assessing stability of a power system [4], [13]-[14]. During the fault period, the electrical output power of the machines reduces drastically while the input mechanical power (or prime mover power) remains more or less constant. When the fault is cleared, the conversion between KE and PE takes place and thus the machines angles oscillate. For a stable situation, the machines ultimately settle down at a stable equilibrium point (SEP) where the transient energy is zero. Thus the transient energy gained in fault period is completely dissipated during the energy conversion process (KE into PE and vice versa) in the post fault period. This happens only if the system has adequate damping. However, in the absence of sufficient damping of any form, the transient energy is not dissipated during the energy conversion process and remains constant in post fault period. For such a case, the machine angle has undamped oscillations [4].

Thus the rate of dissipation of transient energy in post fault period can be considered as a measure of system damping.

In recent decade, fuzzy logic based control has received more attention. The advantages of applying fuzzy control in power systems are apparent. Modern power systems are large, complex, geographically widely distributed and highly nonlinear systems. It is not trivial to derive detailed global system model. Moreover, power system operation conditions and topologies are time varying and the disturbances are unforeseeable. These uncertainties make it very difficult to effectively deal with power system stability problems through conventional controller that is based on linearized model and single operation condition. Therefore the fuzzy logic control approach, as one area of artificial intelligence, has been emerging in recent years as a complement to the conventional approaches.

This paper investigates the additional damping provided by a static synchronous compensator (STATCOM) in coordination with a PSS controlled by a fuzzy controller based on a new concept. The system's damping is evaluated by examining the rate of dissipation of transient energy in post fault period. The control strategy of the STATCOM is selected very carefully to increase the rate of dissipation of transient energy. To verify the control approach proposed ,we evaluated transient energy function (TEF) for Kundur's four-machine two-area system in post fault period. Then designed a supplementary controller for the STATCOM, this controller is a fuzzy controller whose inputs are energy function and its derivative.

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II. POWER SYSTEM MODEL

The system under study is Kundur's four machine tow area system. The diagram of this system is shown in Fig.1.

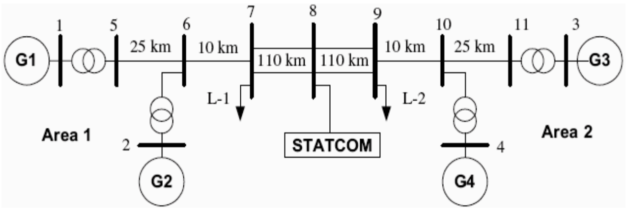

Fig. 1. Kundur four machine two area system with STATCOM

Here, the classical model for the machines is used and. The dynamics of system for the m machine system under study are governed by the following differential equations:

$$\frac{d\delta_i}{dt}=\omega_i-\omega_s \tag{1}$$

$$\frac{2H_i}{\omega_s}\frac{d\omega_i}{dt}=T_{Mi}-P_{ei}, i=1,\dots,m \tag{2}$$

Where

$$P_{ei}=E_i^2G_{ii}+\sum_{\substack{j=1\\ \neq i}}^{m}\left(C_{ij}\cos\delta_{ij}+D_{ij}\sin\delta_{ij}\right) \tag{3}$$

$$C_{ij}=E_iE_jB_{ij}, D_{ij}=E_iE_jG_{ij} \tag{4}$$

$$P_{mi}=T_{mi}, P_i=P_{mi}-E_i^2G_{ii}, \frac{2H_i}{\omega_s}=M_i \tag{5}$$

And with simplifications we have:

$$\dot\delta_i=\omega_i-\omega_s \tag{6}$$

$$\dot\omega_i=\frac{1}{M_i}\left(P_i-P_{ei}(\delta_1,\dots,\delta_m)-D_i(\omega_i-\omega_s)\right) \tag{7}$$

$$i=1,\dots,m$$

Here, δ, ω, M, Pm and D are the angle, speed, moment of inertia, input mechanical power and damping coefficient of the machines respectively .Note that most of the works on the TEF method are based on the simplified machine model. The method may not be used when very sophisticated machine models and all associated controls are considered.

Using energy function is presented in reference [15] for multi machine system we have:

$$V(\theta,\tilde\omega)=\frac{1}{2}\sum_{i=1}^{m}M_i\tilde\omega_i^2-\sum_{i=1}^{m}P_i\left(\theta_i-\theta_i^s\right)-\sum_{i=1}^{m-1}\sum_{j=i+1}^{m}\left[C_{ij}\left(\cos\theta_{ij}-\cos\theta_{ij}^s\right)-\int_{\theta_i^s+\theta_j^s}^{\theta_i+\theta_j}D_{ij}\cos\theta_{ij}d\left(\theta_i+\theta_j\right)\right]=V_{KE}(\tilde\omega)+V_{PE}(\theta) \tag{8}$$

III. STATCOM MODEL

The SPSs toolbox is used for all simulations and STATCOM-based controller design. SPS is a MATLAB-based modern design tool that allows scientists and engineers to rapidly and easily build models to simulate power systems using Simulink environment. The SPS's main library, powerlib, contains models of typical power equipment such as machines, governors, excitation systems, transformers, lines and FACTS devices. The FACTS library provides phasor models of power-electronics based flexible AC transmission systems such as the Static Synchronous Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC), the Static Var Compensator (SVC), and the Unified Power Flow Controller (UPFC). In this study we use STATCOM model in this toolbox. This STATCOM consists of a three-level 48-pulse inverter and two series-connected 3000 µF capacitors which act as a variable DC voltage source. The variable amplitude 60 Hz voltage produced by the inverter is synthesized from the variable DC voltage, which varies around 19.3 kV. It has been proved that the centre midpoint of a transmission line is the optimal location for shunt FACTS devices or reactive power support [2].

IV.STATCOM SUPPLEMENTARY CONTROLLER

The STATCOM SC is designed for damping power oscillation on the tie line and improving dynamic behavior of the interconnected power systems. Fig. 2 is a schematic diagram for SC, where the transient energy of the system in post fault period and its derivative is taken as SC input signals. The output signal of supplementary controller is taken as the voltage modulation signal connected to the main controller.

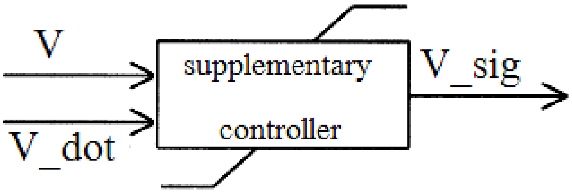

Fig. 2. Simplified supplementary controller

V.FUZZY CONTROLLER

In order to design the fuzzy controller, first we design a conventional controller based on the system's linearized model and at a dominant operation point, because the linear control theory is mature. Then, we add disturbances on the original nonlinear system with the conventional controller. Through time simulation we can collect a large number of controller input–output pairs, which serve as the training data for the designing the fuzzy controller. The overall structure is quite similar to the one used in [3], while here we use some more powerful membership functions shown in Figs 3-4. The well-known Mamdani Fuzzy inference machine is used and training is done based on the energy function introduced by (8). In other words, in this paper, the controller is already trained to produce supplementary signal causing minimum energy for the power system during fault. The rule base is the well-known rule base is used for many traditional Fuzzy Controllers. Table 1 shows the rule base used where the symbols are well-known in the literature.

The four fuzzy sets or linguistic variables are defined for each SC input, that is four sets for energy function and four sets for derivative of energy function as shown in Fig. 3 and Fig. 4, respectively.

Table 1 : Rule Base

V V_dot	n	z	p	vp
n	N5	N3	P2	P3
z	N3	Z	p 3	P4
p	N2	P1	P4	P4
vp	Z	P2	P5	P6

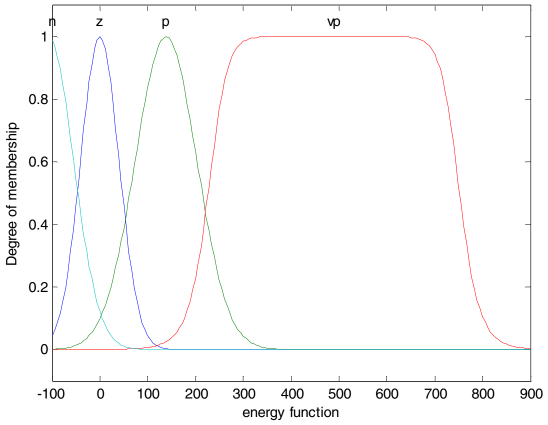

Fig .3. Membership functions of energy function

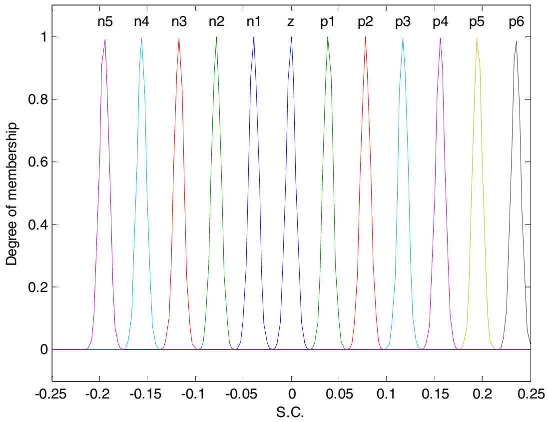

Fig .4. Membership functions of SC output

VI.SIMULATION RESULTS

The proposed technique of investigating the additional damping provided by a STATCOM is tested on Kundur's four- machine two- area system. The diagram of the Kundur's four machine two area system is shown in Fig. 1 and the data of the system is presented in reference. First the system is studied with Delta Pa PSS and without STATCOM and Fig. 5 shows the variation of transient energy *V* for a three-phase fault of 100 ms duration at the middle of transmission line, in comparison with Delta Pa PSS in coordination with STATCOM placed at the middle of the line and controlled by a supplementary controller in its DC voltage control loop. It can be observed in Fig. 3 that without the STATCOM, the system transient energy has undamped oscillation.

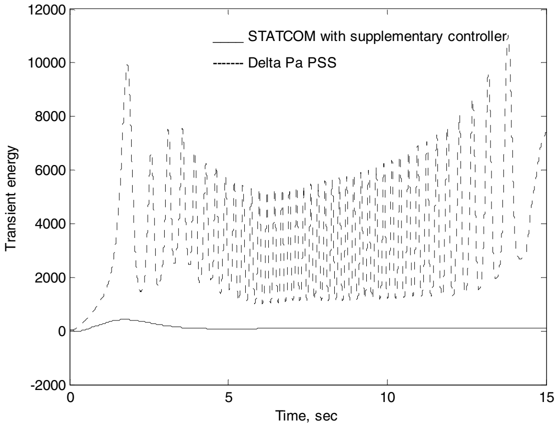

Fig. 5.variation of system transient energy

When a single STATCOM is added, the damping of the system is improved, but not so much. However, with adding a supplementary controller, damping of the system can improve significantly and the transient energy decreases very rapidly. Fig. 6, shows the variation of transient energy for system controlled by STATCOM.

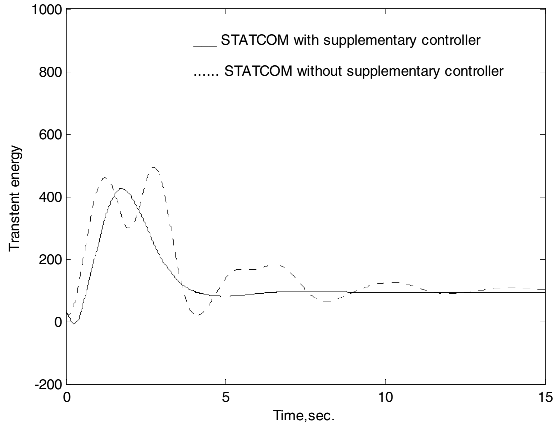

Fig. 6. Variation of transient energy

Fig. 7 shows the swing curves of the machines. It can be noticed in Fig. 7 that the machine angles have undamped oscillations in the absence of STATCOM.

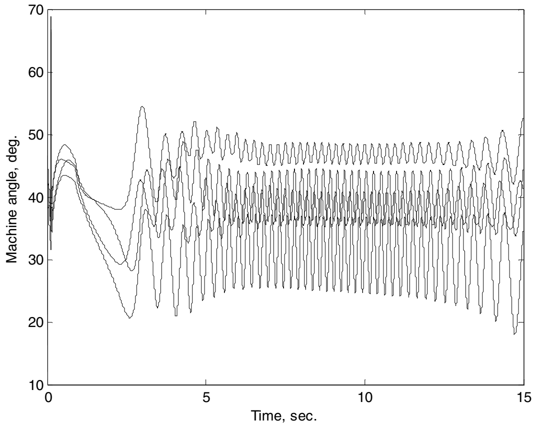

Fig. 7. Swing curve of machines in the absence of STATCOM

Fig. 8 shows the swing curves of the machines in presence of STATCOM compensator. As can be seen the machine angle oscillations are damped very rapidly.

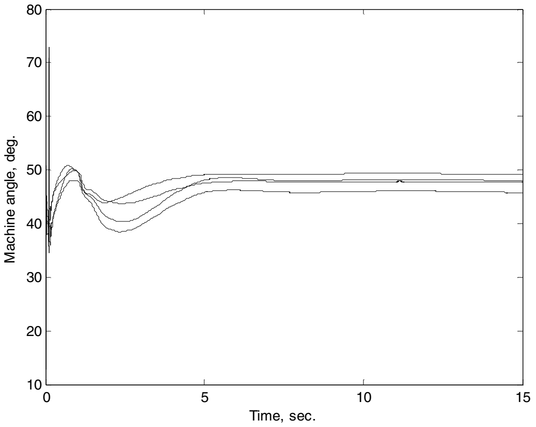

Fig. 8. Swing curve of machines in the presence of STATCOM

Fig. 9 indicates the speed deviations for Pa PSS as well as Pa PSS in coordination with STATCOM controlled by supplementary controller

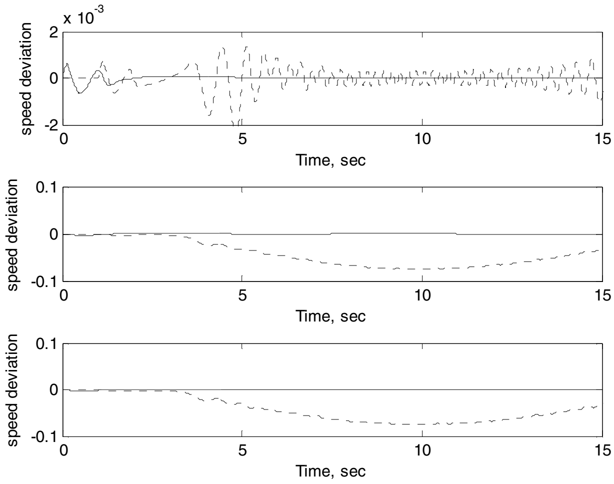

Fig. 9. Speed deviations

For a comparison we compare the above results with MB-PSS that has a proved good performance for system stability improvement. The swing curve of machines for this PSS is presented in Fig. 10. As can be seen, in comparison with this PSS, the results obtained above indicate better performance.

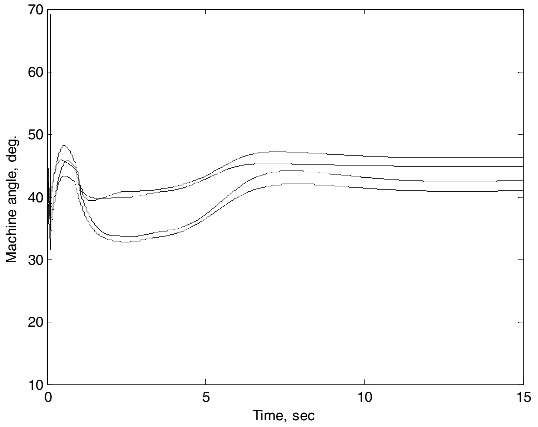

Fig. 10. Swing curves for MB-PSS

Fig. 11-13, indicates comparison between speed deviations for these two procedures, as can be seen STATCOM in coordination with Pa PSS has better damping characteristics than MB-PSS.

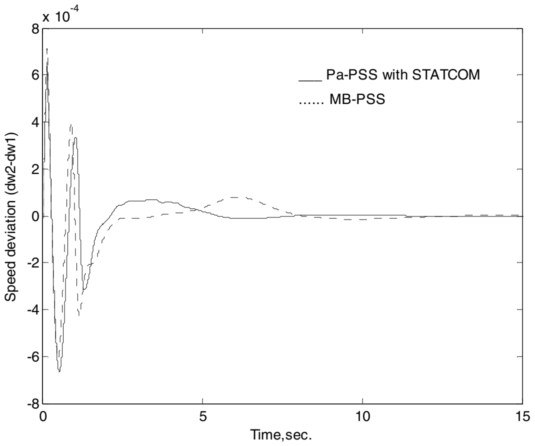

Fig. 11. Speed deviation (dω2-dω1)

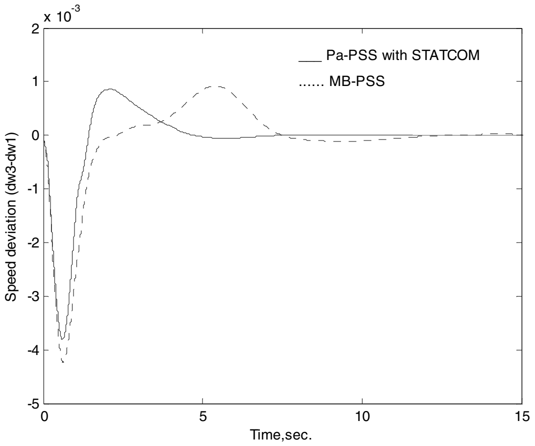

Fig.12. Speed deviation (dω3-dω1)

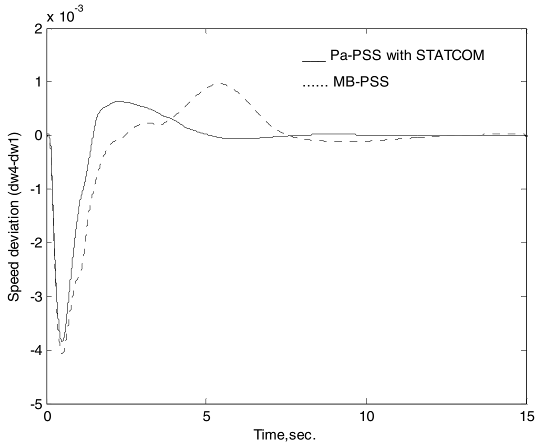

Fig. 13. Speed deviation (dω4-dω1)

Fig. 14 Indicate the output of fuzzy controller or the output of supplementary controller which remains inside the standard limits.

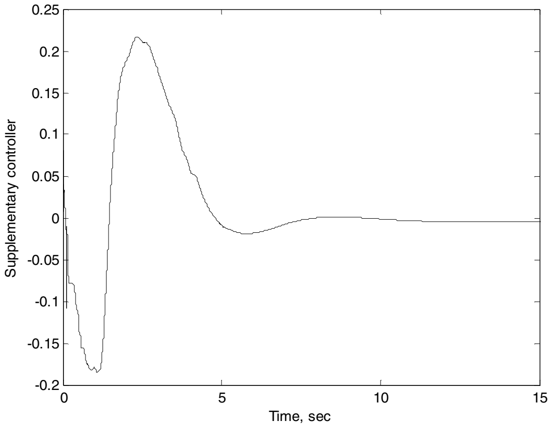

Fig. 14. Output of supplementary controller

Fig. 15 Indicate dissipation of transient energy for MB-PSS in comparison with system controlled by Delta Pa PSS in coordination with STATCOM controlled by supplementary controller.

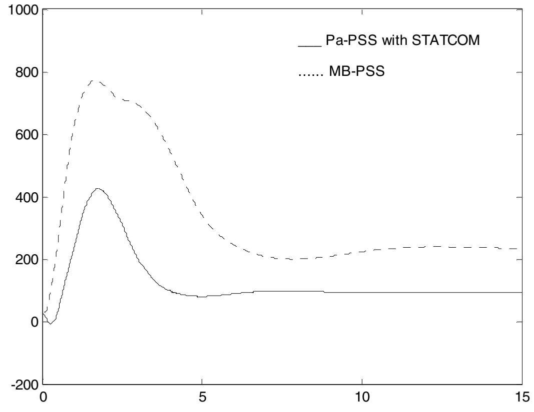

Fig. 15. Dissipation of transient energy

Also, Fig. 16 Indicate tie line power for system controlled with MB-PSS in coordination with STATCOM

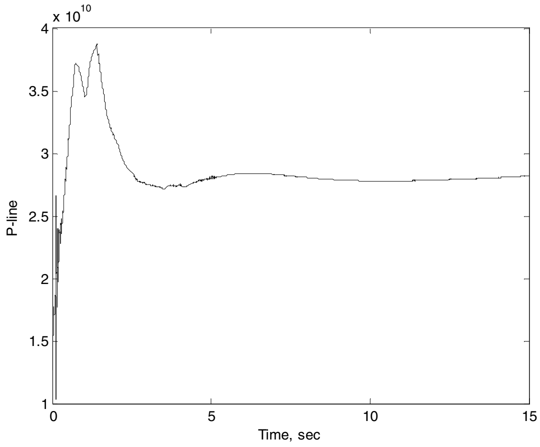

Fig. 16. Tie line power

VII. CONCLUSION

A new technique for determining additional damping for power system by a fuzzy controlled STATCOM is presented in this paper and the system stability is evaluated by observing the rate of dissipation of the transient energy in post fault period. The control strategy of the STATCOM is selected very carefully to increase the rate of dissipation of transient energy so that the system can reach the stable equilibrium point (SEP) quickly. The above control strategy is then applied to the Kundur's four- machine two- area system. Simulation results proved that, in the absence of damping STATCOM, the transient energy of the system remains constant in post fault period resulting in undamped oscillations ,whereas in the case of using a STATCOM, the transient energy dissipates in post fault period, which is an essential criterion for settling down the system at the stable equilibrium point. Simulation results in obtained in MATLAB / SIMULINK environment prove that the STATCOM system with proper control is interestingly capable of enhancing system transient stability. The system dynamic behavior can also be improved by SC.

VIII. REFERENCES

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