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Power System Stability Enhancement using Adaptive Neuro-Fuzzy Tuned Static Synchronous Series Compensator (SSSC)

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Abstract – This paper investigates the enhancement of voltage stability using Static Synchronous Series Compensator (SSSC). The continuous demand in electric power system network has caused the system to be heavily loaded leading to voltage instability. Under heavy loaded conditions there may be insufficient reactive power causing the voltages to drop. This drop may lead to drops in voltage at various buses. The result would be the occurrence of voltage collapse which leads to total blackout of the whole system. Flexible AC transmission systems (FACTS) controllers have been mainly used for solving various power system stability control problems. In this study, a static synchronous series compensator (SSSC) is used to investigate the effect of this device in controlling active and reactive powers as well as damping power system oscillations in transient mode. The Adaptive neuro fuzzy logic controller is used to tune the circuit and to provide the zero signal error. Results are compared with conventional PI controller. The dynamic performance of SSSC is presented by real time voltage and current waveforms using MATLAB software for IEEE 4 bus system.

Keywords – Static Synchronous Series Compensator (SSSC), Proportional-Integral Controller, Adaptive Neuro Fuzzy logic Controller, Real and Reactive Power Flow, Voltage Stability.

I. INTRODUCTION

In recent years, greater demands have been placed on the transmission network and the increase in demands will rise because of the increasing number of nonutility generators and heightened competition among utilities themselves. Increasing demands, lack of long-term planning, and the need to provide open access electricity market for Generating Companies and utility customers, all of them have created tendencies toward less security and reduced quality of supply. The power systems of today, by and large, are mechanically controlled. There is a widespread use of microelectronics, computers and high-speed communications for control and protection of present transmission systems; however, when operating signals are sent to the power circuits, where the final power control action is taken, the switching devices are mechanical and there is little high-speed control.

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Another problem with mechanical devices is that control cannot be initiated frequently, because these mechanical devices tend to wear out very quickly compared to static devices. In effect, from the point of view of both dynamic and steady-state operation, the system is really uncontrolled. Power system planners, operators, and engineers have learned to live with this limitation by using a variety of ingenious techniques to make the system work effectively, but at a price of providing greater operating margins and redundancies. These represent an asset that can be effectively utilized with prudent use of FACTS technology on a selective, as needed basis. The FACTS devices (Flexible AC Transmission Systems) could be a means to carry out this function without the drawbacks of the electromechanical devices such as slowness and wear. FACTS can improve the stability of network, such as the transient and the small signal stability, and can reduce the flow of heavily loaded lines and support voltages by controlling their parameters including series impedance, shunt impedance, current, voltage and phase angle. Controlling the power flows in the network leads to reduce the flow of heavily loaded lines, increased system loadability, less system loss and improved security of the system. The static synchronous series compensator (SSSC) FACTS controller is used to prove its performance in terms of stability improvement. A Static Synchronous Series Compensator (SSSC) is a member of FACTS family which is connected in series with a power system. It consists of a solid state voltage source converter (VSC) which generates a controllable alternating current voltage at fundamental frequency. When the injected voltage is kept in quadrature with the line current, it can emulate as inductive or capacitive reactance so as to influence the power flow through the transmission line. While the primary purpose of a SSSC is to control power flow in steady state, it can also improve transient stability of a power system. Here Adaptive Neuro-Fuzzy controller is used to control the parameters of the power system.

II. BASIC OPERATION PRINCIPLE OF SSSC

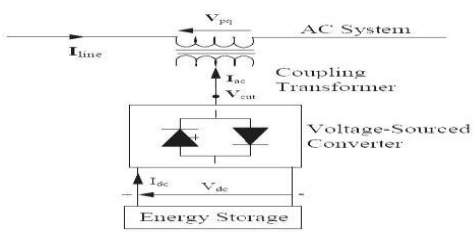

Fig (1): Functional Model of SSSC

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The Fig.1 Shows a functional model of the SSSC [4] where the dc capacitor has been replaced by an energy storage device such as a high energy battery installation to allow active as well as reactive power exchanges with the ac system. The SSSC's output voltage magnitude and phase angle can be varied in a controlled manner to influence power flows in a transmission line. The phase displacement of the inserted voltage Vpq, with respect to the transmission line current line I, determines the exchange of real and reactive power with the ac system.

III. CONTROL SYSTEM OF SSSC

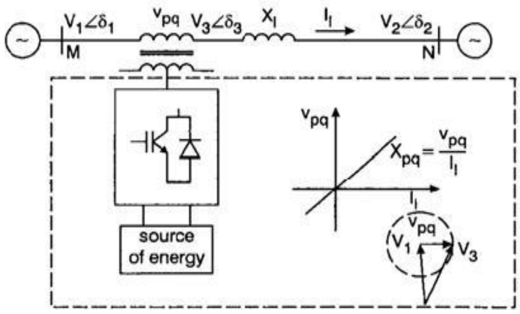

Fig (2): Single Line Diagram of Simple Transmission Line

Fig. 2 shows a single line diagram of a simple transmission line with an inductive reactance, XL, connecting a sending-end voltage source, VS, and a receiving-end voltage source, V_r respectively [8].

The real and reactive power (P and Q) flow at the receiving-end voltage source are given by the expressions

$$P = \frac{Vs\,Vr}{X_L}\sin(\delta_s - \delta_r) = \frac{V^2}{X_L}\sin\delta \qquad (1)$$

$$Q = \frac{Vs\,Vr}{X_L}\left(1 - \cos(\delta_s - \delta_r)\right)$$

$$= \frac{V^2}{X_L}(1 - \cos\delta) \qquad (2)$$

Where VS and V_r are the magnitudes and δS and δr are the phase angles of the voltage sources VS and V_r respectively. For simplicity, the voltage magnitudes are chosen such those VS = V_r = V and the difference between the phase angles is:

$$\delta = \delta s - \delta_r \qquad (3)$$

An SSSC, limited by its voltage and current ratings, is capable of emulating a compensating reactance X_q (both inductive and capacitive) in series with the transmission line inductive reactance X_L, Therefore, the expressions for power flow given in equation (1& 2) becomes

$$P_q = \frac{V^2}{X_{eff}}\sin\delta = \frac{V^2}{X_L(1 - X_q/X_L)}\sin\delta \qquad (4)$$

$$Q_q = \frac{V^2}{X_{eff}}(1 - \cos\delta)$$

$$= \frac{V^2}{X_L(1 - X_q/X_L)}(1 - \cos\delta) \qquad (5)$$

Where X_{eff} is the effective reactance of the transmission line between its two ends, including the emulated variable reactance inserted by the injected voltage source of the Static Synchronous Series Compensator (SSSC). The compensating reactance X_q is defined to be negative when the SSSC is operated in an inductive mode and positive when the SSSC is operated in a capacitive mode.

IV. TWO MACHINE POWER SYSTEM MODELLING

The dynamic performance of SSSC is presented by real time voltage and current waveforms. Using MATLAB software the system shown in Fig. 3, has been obtained [1]. In the simulation one SSSC has been utilized to control the power flow in the 500 KV transmission systems. This system which has been made in ring mode consisting of 4 buses (B1 to B4) connected to each other through three phase transmission lines L1, L2-1, L2-2 and L3 with the length of 280, 150, 150 and 5 km respectively. System has been supplied by two power plants with the phase-to-phase voltage equal to 13.8 Kv.

Active and reactive powers injected by power plants 1 and 2 to the power system are presented in per unit by using base parameters S_b=100MVA and V_b=500KV, which active and reactive powers of power plants 1 and 2 are (24-j3.8) and (15.6-j0.5) in per unit, respectively.

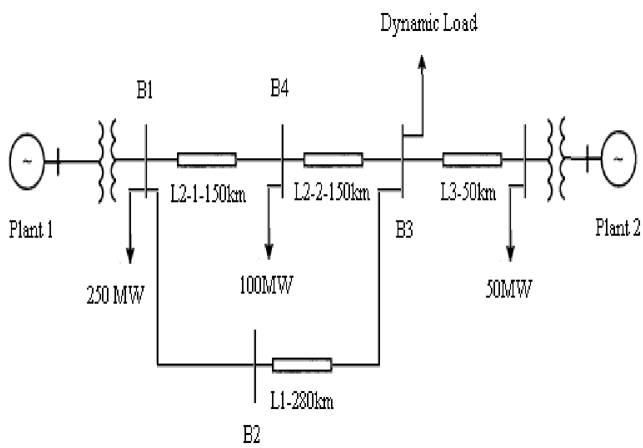

Fig (3): Two Machine System

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V. BUS TWO PARAMETER WITH PI TUNED SSSC

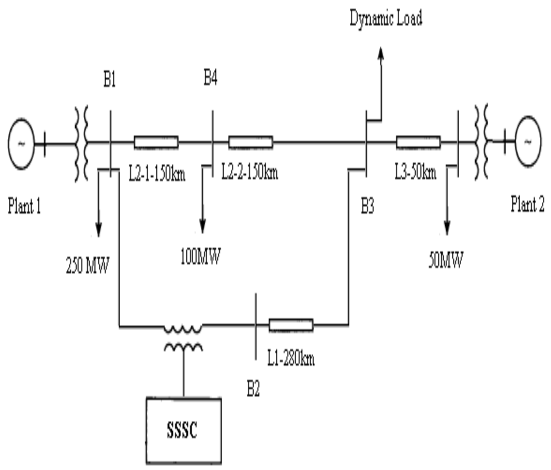

Fig (4): Two Machine System with SSSC

As shown in Fig. 4. SSSC has been placed between bus-1 and bus-2 [1]. The main role of SSSC is controlling the active and reactive powers; beside these SSSC could fairly improve the transient oscillations of system.

After the installation of SSSC, besides controlling the power flow in bus-2 we want to keep constant the voltage value in 1 per unit, hence the power flow is done in the presence of SSSC and the simulation results are as follows. According to the Fig. 11, by installing the SSSC, active power damping time will be less than the mode without SSSC and it will be damped faster. Also as shown in Fig. 12, reactive power damping time will be decreased and system will follow the references value with acceptable error.

VI. MATLAB/SIMULINK RESULTS FOR BUS-2 WITH CONVENTIONAL CONTROLLER (PI)

Power system with two machines and four buses after incorporating SSSC has been simulated in MATLAB environment, and then powers and voltages in all buses have been obtained.

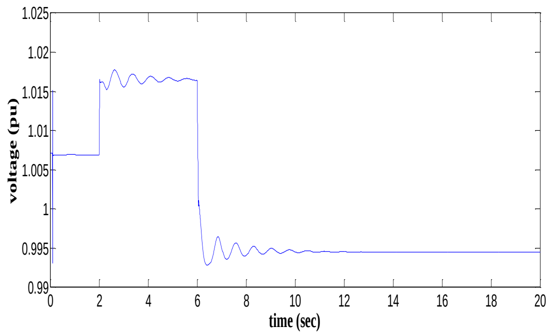

Fig (5): voltage at bus-2 with PI

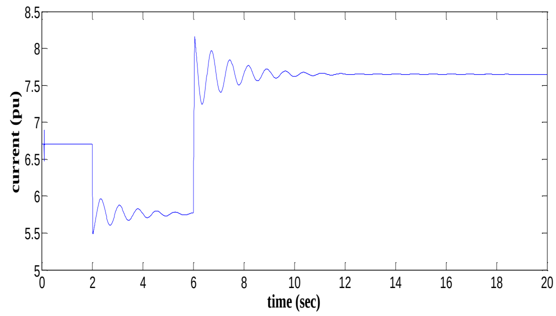

Fig (6): current at bus-2 with PI

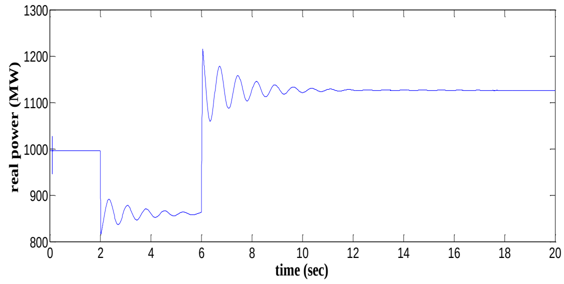

Fig (7): Real Power of bus-2 with PI

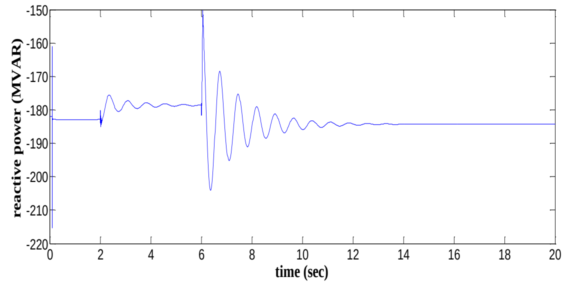

Fig (8): Reactive Power of bus-2 with PI

Obtained results of bus-2 had proven that the stability of power system parameters has been fairly increased.

VII. MODELING OF ADAPTIVE NEURO FUZZY TUNED SSSC:

Adaptive Neuro-Fuzzy Inference System (ANFIS) method based on the Artificial Neural Network (ANN) is applied to design a Static Synchronous Series Compensator (SSSC) based controller for improvement of transient stability. The proposed ANFIS controller combines the advantages of fuzzy controller and quick response and adaptability nature of ANN. The ANFIS structures were trained using the generated database by fuzzy controller of SSSC. It is observed that the proposed SSSC controller improves greatly the voltage profile of the system under severe disturbances. The results prove that the proposed SSSC-based ANFIS controller is found to be robust to fault location and change in operating conditions.

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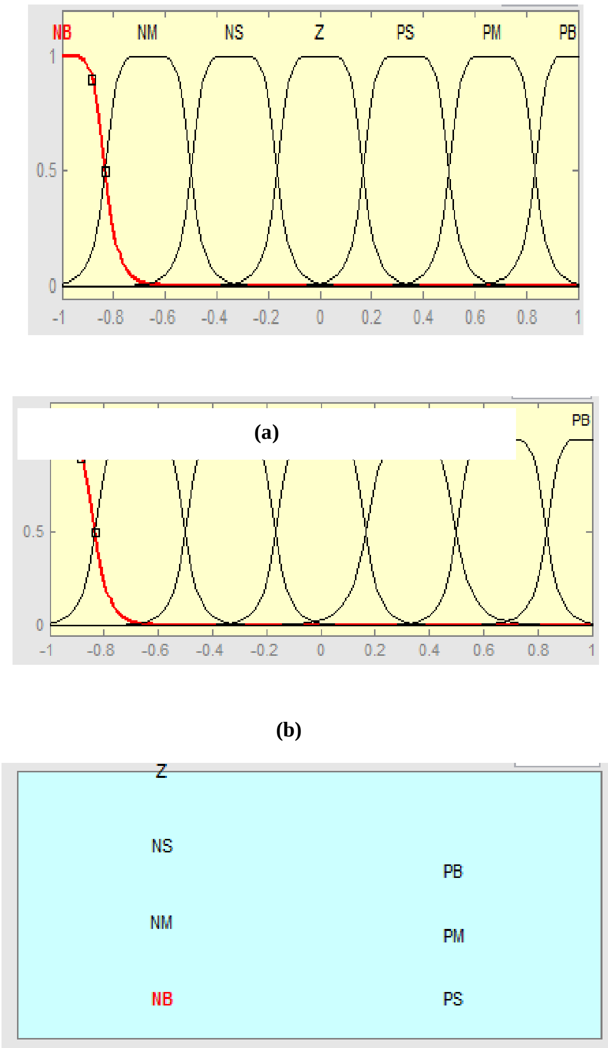

(a)

(b)

(c)

Fig (9): Membership functions for ANFIS Controller

(a) ACE , (b) ΔACE , (c) f(u)

Table I. FUZZY LOGIC RULES

ΔACE / ACE	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NM	NS	Z	PS	PM
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	Z	Z	Z

For the proposed controller, Sugeno fuzzy inference engine was selected and realized by generalized bell membership functions for each of the three linguistic variables (ACE, ΔACE, f (u)) with suitable choice of membership functions shown in Fig.9. Where ACE and ΔACE are the inputs of the controller and f(u) is the regulated fuzzy output of the controller. Defuzzification has been performed using weighted average method. The appropriate fuzzy rules, as used in our study, for the fuzzy logic controller are given in table.I.

VIII. MATLAB/SIMULINK RESULTS FOR BUS – 2 WITH ANFIS:

Adaptive neuro fuzzy tuned SSSC is simulated in MATLAB environment and the simulation plots are obtained for real power, reactive power, voltage and current profiles of the two machine power system.

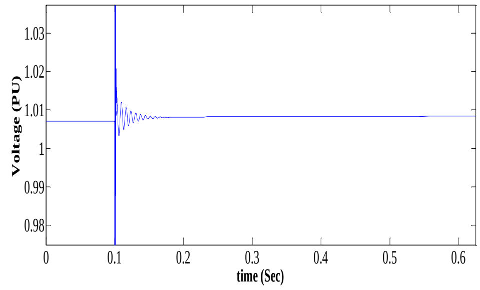

Fig (12): Voltage at bus-2 with ANFIS

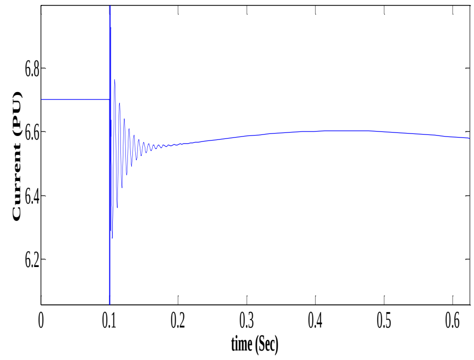

Fig (13): Current at bus-2 with ANFIS

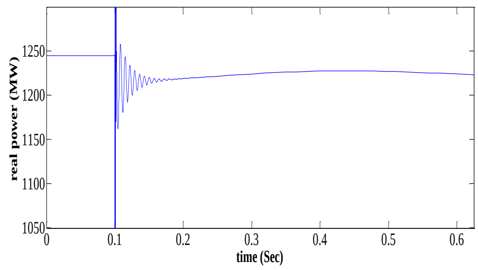

Fig (14): Real power at bus-2 with ANFIS

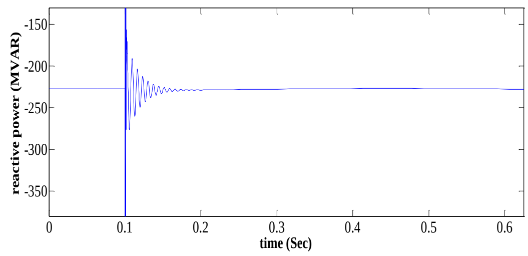

Fig (15): Reactive power at bus-2 with ANFIS

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As compared with conventional PI controller, ANFIS tuned SSSC provide fast damping of oscillations and steady state stability is achieved in the range of 0.1 to 0.2 seconds.

Table II. COMPARISON BETWEEN PI and ANFIS FOR REAL and REACTIVE POWER PROFILES

BUS. NO	PI CONTROLLER		ADAPTIVE NEURO FUZZY LOGIC CONTROLLER	
	REAL POWER (PU)	REACTIVE POWER (PU)	REAL POWER (PU)	REACTIVE POWER (PU)
1	19.99	-4.74	20.07	-3.65
2	11.26	-1.84	12.22	-2.28
3	14.82	-0.24	14.85	-0.50
4	7.09	-0.24	8.63	-0.62

Table III. COMPARISON BETWEEN PI and ANFIS FOR VOLTAGE and CURRENT PROFILES

BUS .NO	PI CONTROLLER		ADAPTIVE NEURO FUZZY LOGIC CONTROLLER	
	VOLTAGE (PU)	CURRENT (PU)	VOLTAGE (PU)	CURRENT (PU)
1	1	13.5	1	13.5
2	1	7.6	1	6.5
3	1	9.8	1	10.01
4	1	4.6	1	5.2

Table II and Table III provides the comparison results of various power system parameters with PI and ANFIS. It has been seen that real power enhancement of the system has been improved very much and reactive power damping is efficient. The voltage and current limits also maintained in a stable condition.

IX. CONCLUSION

It has been found that the ANFIS tuned SSSC is capable of controlling the flow of power at a desired point on the transmission line well compared to conventional PI controller. It is also observed that the SSSC injects a fast changing voltage in series with the line irrespective of the magnitude and phase of the line current. Based on obtained simulation results the performance of the ANFIS tuned SSSC has been examined in a two-machine system, which provide fast settling time and power oscillations damping. Applications of the SSSC will be extended in future to a complex system to investigate the problems related to the various modes of power oscillation in the power systems.

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