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EFFECT OF FUZZY CONTROLLER AND CHANGING MEMBERSHIP FUNCTIONS IN THE OPERATION OF STATIC SYNCHRONOUS SERIES COMPENSATOR AND POWER SYSTEM STABILIZER

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Abstract : Synchronous generators in any power system exhibit rotor oscillations around their nominal steady state and power system stabilizers are used to damp out these oscillations. The Static Synchronous Series Compensator (SSSC) serves the function of power flow control, voltage and angle stability enhancement. SSSC can induce both capacitive and inductive series voltage on a line and gives a better possibility for damping electromechanical oscillations. This paper investigates the operation of an SSSC-PSS model in the operation of a generation system. It compares the response of the generating station to a conventional PSS & SSSC along with a fuzzy based PSS & SSSC. The paper investigates the effect of fuzzy based PSS in the power system operation and also the effect of membership function in the operation of fuzzy controller.

Key words : **Power system stabilizers, Fuzzy logic, Static synchronous series compensator**

1. INTRODUCTION

An electric power network integrates generation and load centers within each utility system and, through interconnection among neighboring systems, share power with vast regional grids. The purpose of interconnection of utilities is to take advantage of the diversity of loads in vast areas, changes in peak demand due to weather and time differences, the availability of different generation reserves in various geographic regions, power sharing arrangements among utilities, shifts in fuel prices, regulatory charges and other discrepancies.

One of the major criteria, deciding the power system operation is its stability. Stability of the power system is the ability to maintain the machines connected to the system in synchronism. But disturbances always occur either due to the sudden addition or removal of load, short circuit of lines, lightning etc. Advancements in semi-conductor electronics have helped in the development of new control technologies for stability enhancement, which includes the use of FACTs controllers.

FACTs controllers [1] are high power electronic controllers, which can be applied individually or collectively in power system, to control the line parameters like series and shunt impedances effectively. For economical and environmental reasons, the growth of the power system in future will rely on increasing the capability of existing transmission systems, rather than building new transmission lines and power stations. This gives rise to the requirements of the new power flow controllers, which are capable of increasing the transmission capability. FACTS devices enhance the stability of the power system with its fast control characteristics and continuous compensating capability. The control of power flow and increase in the transmission capacity of the existing transmission lines are the two main objectives of FACTS technology [3]. These objectives help in the optimal utilization of the existing power system and increase the controllability of the power system. Unified Power Flow Controller is one such FACTS device [9] , capable of improving the dynamic control of real and reactive power flow.

2. SSSC & PSS

The Static Synchronous Series Compensator (SSSC), one of the key FACTS devices, consists of a voltage-sourced converter and a transformer connected in series with a transmission line. The SSSC [1] injects a voltage of variable magnitude in quadrature with the line current, thereby emulating an inductive or capacitive reactance. This emulated variable reactance in series with the line can then influence the transmitted electric power. The SSSC [6] is used to damp power oscillations and the basic configuration is shown in Fig. 1.

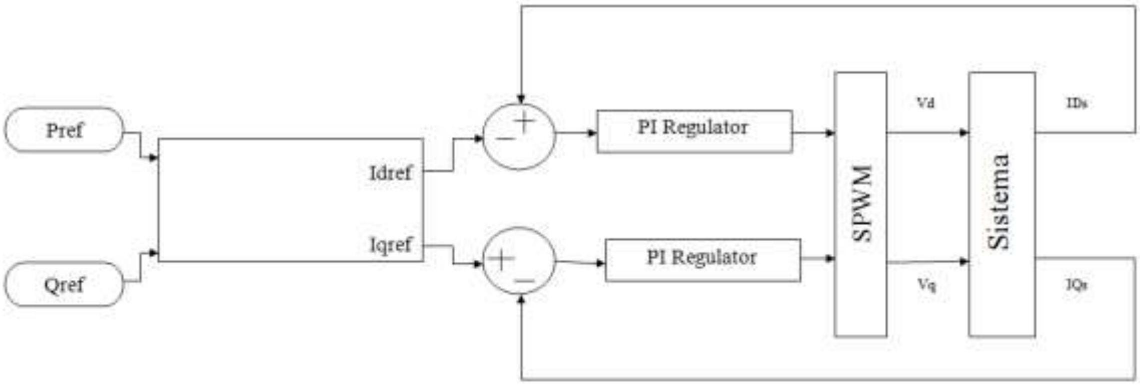


Fig 1 Basic conventional configuration of SSSC

In principle, an SSSC is capable of interchange of active and reactive energy with the power system. However, if only reactive power compensation is intended, the size of energy source could be quite small. The injected voltage could be controlled in magnitude and phase if sufficient energy source is provided. For the reactive power compensation function, only the magnitude of the voltage is controllable since the vector of the inserted voltage is perpendicular to the line current. In the case, the series injected voltage can either lead or lag the line current by 90 degrees. This makes the SSSC, smoothly controllable at any values leading or lagging within the operating range of VSI. Thus the behaviour of SSSC is similar to a controllable series capacitor and a controllable series reactor. The basic difference is that the voltage injected by SSSC is not related to the line current and can be independently controlled. The importance of this characteristic is that an SSSC is effective for both low and high loading. The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators. These oscillations, also called power swings, must be effectively damped to maintain the system stability. Power System Stabilizers (PSS) [5] in power systems are used to add damping to these rotor oscillations of the synchronous machine by controlling its excitation [13]. This is done by altering the excitation field voltage, in order to produce an electrical torque, in phase with the rotor oscillations. Synchronous generators in power systems exhibit three modes of rotor oscillations : Inter-machine, Plant-network and Inter-area [10]

Conventional PSS [15] have limited ability when it comes to damping of inter-area mode of oscillations. Recent advancements in technologies [16] have come up with various power system stabilizer designs to enhance the damping function of these stabilizers. The use of Fuzzy logic controllers in the design of PSS, adds flexibility in the changing PSS parameters [11].

3. FUZZY LOGIC CONTROLLERS

Fuzzy control has tremendous potential in various control applications. Over the past few years, many control equipments were built using fuzzy control. Fuzzy systems are nothing but knowledge-based or rule-based systems. The general input to the Fuzzy controller is the error signal and the rate of error signal. The rate of error signal is the difference between the variation of error at current sampling and its previous sampling. The heart of the fuzzy system is a knowledge base, consisting of the so called fuzzy IF-THEN rules. These rules are defined by taking help from expert's experience and knowledge about the system behavior. The performance of the system is improved by the correct combinations of these rules. The Fuzzy Logic Controller [2] (FLC) consists of three stages: the fuzzification, rule execution, and defuzzification. The basic operation of FLC is as shown in Fig.2

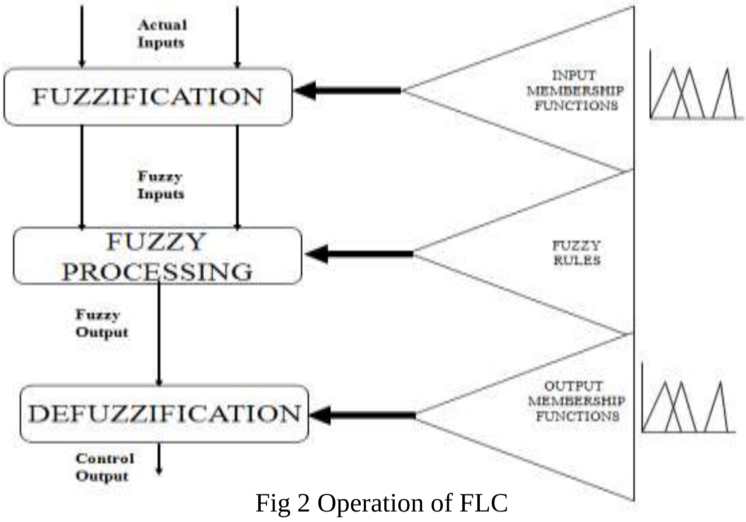


Fig 2 Operation of FLC

In the first stage, the crisp variables are converted into fuzzy variables using the membership functions as shown in Fig. 3. The signals error and error rate are described as linguistic variables in the FLC such as large negative (LN), medium negative (MN), small negative (SN), very small (VS), small positive (SP), medium positive (MP) and large positive (LP).

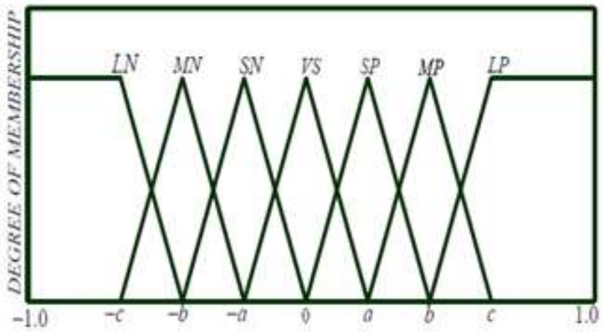


Fig 3 Membership function in an FLC

4. SYSTEM UNDER STUDY

Two power generation stations and one major load are taken as the system of study as shown in Fig.4. A three-phase fault (using a fault breaker) is simulated at the midpoint of the transmission line in the model. A typical three-level PWM SSSC model (with Power oscillation Damping Controller) is implemented in this system of study. The generating stations are equipped with PSS, which also aids in power oscillation damping. The operation of the generating stations with Conventional PSS and Conventional SSSC are studied, and compared with the performance of Fuzzy Based PSS & Fuzzy Based SSSC in the generating station performances.

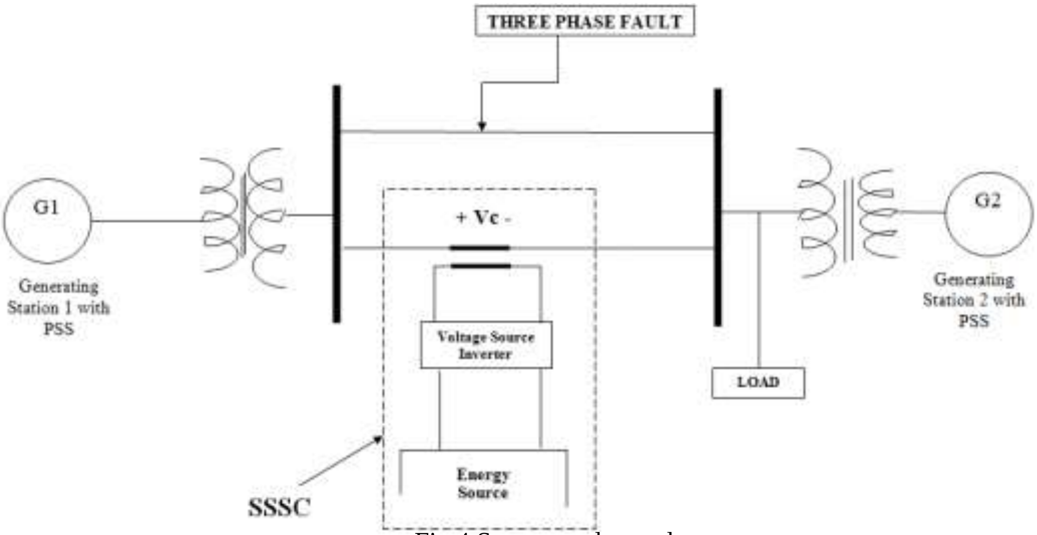


Fig 4 System under study

5. FUZZY BASED PSS

The conventional PSS [14] are nowadays replaced with Intelligent or Fuzzy based PSS, which finds greater enhancement in power oscillation damping. The error signal, calculated from the difference between the output power and the reference input power, is given as the input to the fuzzy controller in the PSS. The fuzzy controller then infers the control signal from the rule base provided and gives the appropriate excitation voltage, to damp out the power oscillations, if any. A mamdani type of inference engine is taken for the fuzzy controller in the design. The operation of the fuzzy controller with both triangular & trapezoidal membership functions for both the input and output signals are studied and the results inferred. The fuzzy controller in this paper uses fourteen simplified rules to infer the excitation voltage value from the error of the power signal. The simplified structure of the implementation of the conventional and fuzzy based PSS is as shown in Fig. 5.

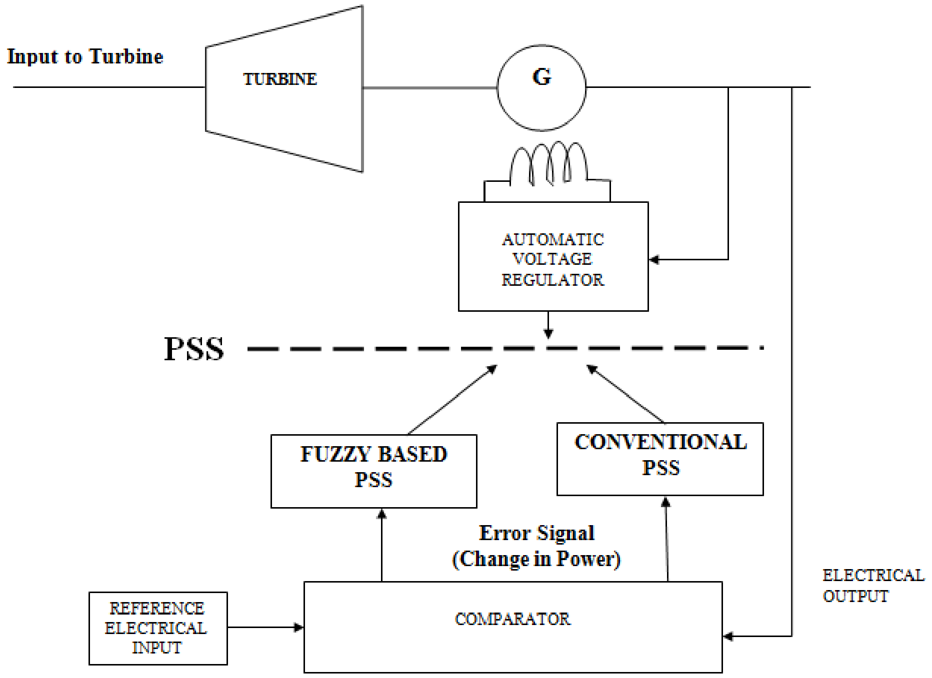


Fig 5 Simplified structure with Conventional & Fuzzy based PSS

6. FUZZY BASED SSSC

In the system under study, the conventional SSSC using PI controllers are replaced with Fuzzy based SSSC. The PI regulators in the conventional architecture of SSSC are replaced with Fuzzy controllers and the operation of the Fuzzy based SSSC is studied. The structure of fuzzy based SSSC is as shown in Fig.6. The fuzzy controllers for the SSSC are also based on Mamdani Inference system and processes the output based on fourteen simplified fuzzy rules. The inputs to the fuzzy controllers are the error in real and reactive power flow in the lines and the output is the firing angle to the inverter, to minimise the error signals. The Fuzzy based SSSC is studied for bath triangular and trapezoidal membership functions.

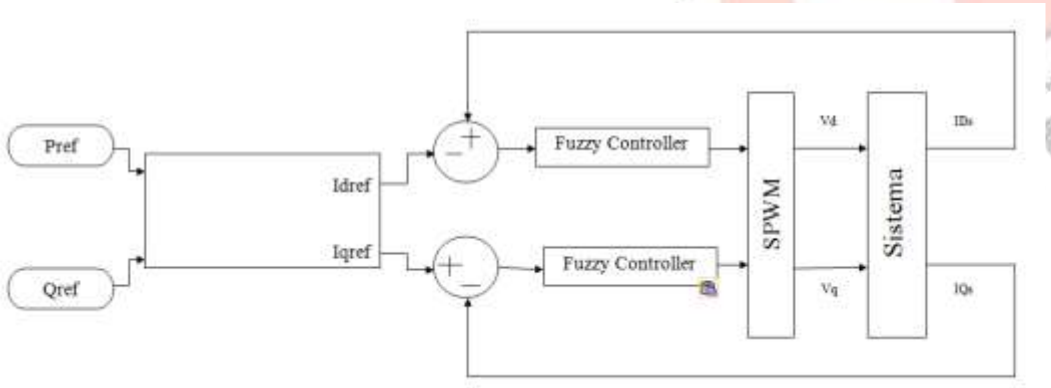
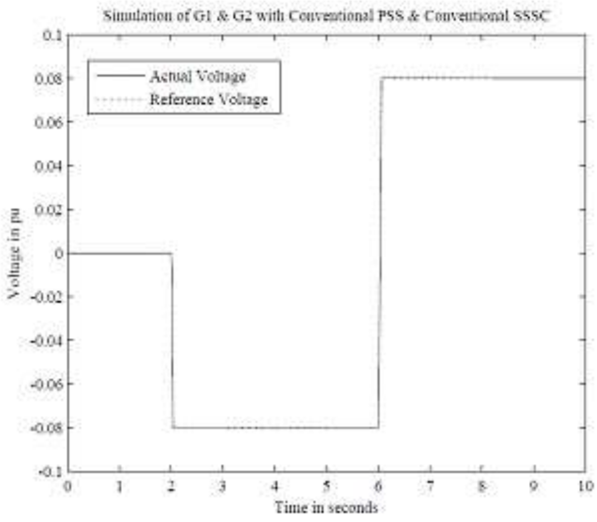
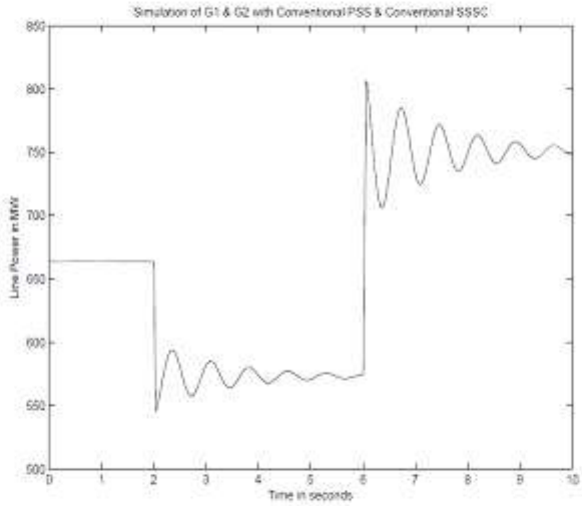


Fig 6 Basic configuration of Fuzzy based SSSC

7. SIMULATION RESULTS

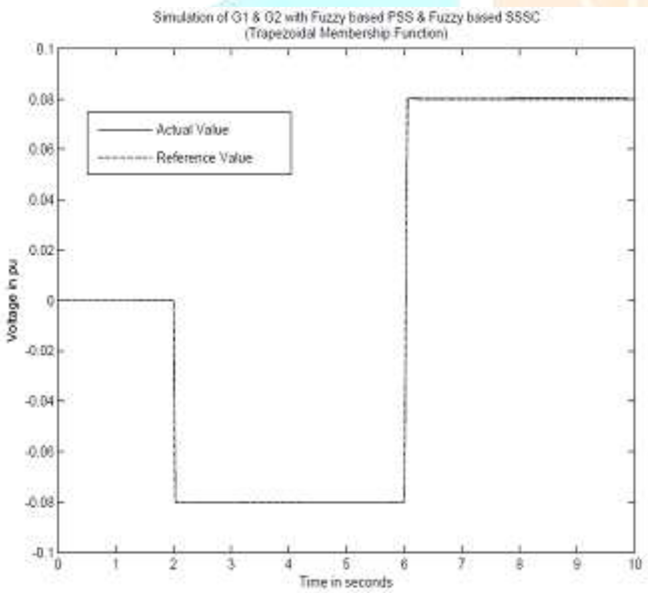
The system under study is simulated using conventional PSS and conventional SSSC in MATLAB/Simulink. A three-phase fault (using a fault breaker) is simulated at the midpoint of the transmission line in the system. The system performance is as shown in Fig.7. The conventional PSS and the SSSC is replaced with fuzzy based PSS and fuzzy based SSSC. The effect of fuzzy logic controllers are compared in the simulation results and are shown in Fig.8. The effect of changing the Membership Function (MF) is also studied using triangular & trapezoidal membership functions and is compared in Fig. 8 and Fig.9.

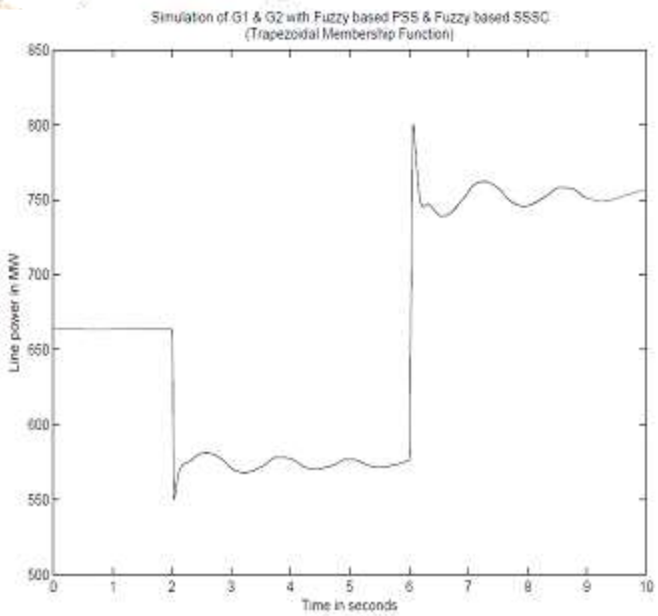




(a) (b)

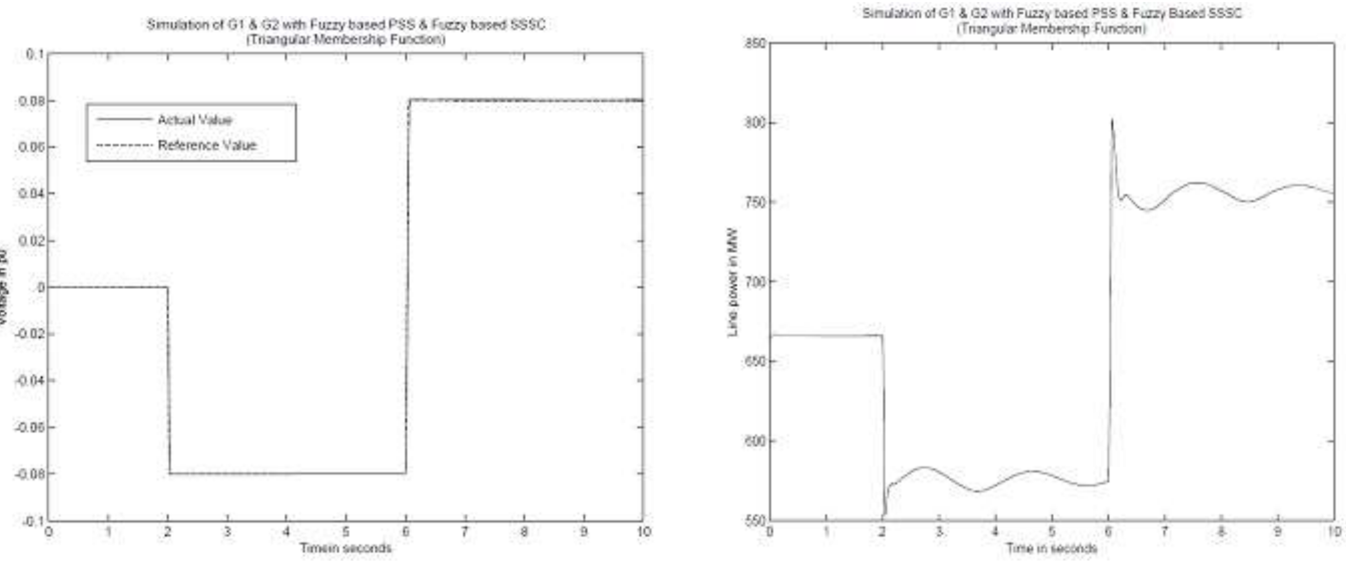
Fig 7 Simulation results with Conventional PSS & SSSC
(a) Voltage in pu (b) Line power in MW





(a) (b)

Figure 8 Simulation results with Fuzzy based PSS & SSSC (Trapezoidal MF)
(a) Voltage in pu (b) Line power in MW



(a) (b)

Figure 9 Simulation results with Fuzzy based PSS & SSSC (Triangular MF)
(a) Voltage in pu (b) Line power in MW

8. CONCLUSIONS

To overcome the limitations of conventional PSS and PI regulators in conventional SSSC, they are replaced with fuzzy controllers in this work. The conventional strategies are compared with fuzzy inference system counterparts, in terms of accuracy, simplicity, robustness and speed dynamics. The new control strategies, take advantages of its positive attributes to enhance the response of PSS and SSSC.

The proposed fuzzy controller for PSS and SSSC improves their performance, reducing the overshoots and settling times in power oscillations, when compared to the conventional designs, during the three phase faults. Thus the combinational fuzzy based PSS and SSSC, helps to a greater extent in damping out the power oscillations due to faults and disturbances.
The comparison of the simulations results also infers that the triangular membership functions for the input and output variables in the fuzzy controller of PSS & SSSC, further enhances its ability to damp out power oscillations, when compared to trapezoidal membership function.

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