



# **Damping of SSR Using Fuzzy Logic Based SSSC**

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**ABSTRACT:** The enlargement in power demand has compelled the power system utilities to use series capacitive compensation in long transmission lines. A problem called sub synchronous resonance occurs in long lines because of series compensation. In this paper fuzzy logic based SSSC is used to damp out the sub synchronous oscillations from the system. An IEEE first benchmark model is used for scrutinizing the SSR problem, where a three phase short circuit fault is applied on the compensated transmission line for analysis. A MATLAB/SIMULINK model is used to study the time domain analysis of the system. An enhancement in damping is seen with the use of SSSC which is controlled by a fuzzy logic controller.

**KEYWORDS:** Flexible A.C. Transmission System (FACTS), Sub Synchronous Resonance (SSR), Static Series Synchronous Compensator (SSSC), Fuzzy Logic Controller (FLC), Voltage Source Converter (VSC).

## **I. INTRODUCTION**

The power utilization by the utility is subsequently increasing day by day. The increase in power demand had urged the power engineers to use long transmission line which enables bulk power transfer. In order to gratify the load demand in long transmission lines, series capacitive compensation is being used which expands the power delivering capability of the transmission line effectively. Further, it also improves the transient stability of the system. Because of series capacitive compensation the problem of SSR may arise in long transmission lines. The SSR problem relates to the torsional interactions between the generator rotor section and turbine section of the plant. The interactions between these two masses are caused due to sub harmonic frequencies produced by the series capacitive compensator. These interaction causes shaft failure in the turbo-generator system. The SSR problem is further divided in two categories namely, Torque Amplification (TA) also known as transient torque and steady state SSR. The steady state SSR is further divided to Torque Interaction (TI) and Induction Generator Effect (IEG). In this paper TI problem is taken into consideration which endorse a threat to power system.

FACTS devices make series compensation more attractive as they can solve some of the problems introduced by fixed series compensation eliminating the risk of SSR phenomena. A FACTS device is used in power system to improve power quality, power security and its integration. In this paper a SSSC is connected to the transmission line to damp SSR. SSSC is a VSC based FACTS controller, and has one degree of freedom (i.e., reactive voltage control) injects controllable reactive voltage in quadrature with the line current. The risk of SSR can be minimized by a suitable combination of hybrid series compensation consisting of passive components and VSC based FACTS controllers such as SSSC. The reactive voltage control mode of SSSC reduces the potential risk of SSR by detuning the network resonance.

The purpose of this paper is to investigate a novel control strategy for SSSC dedicated to SSR mitigation. The controller abolishes the frequency components of the line current corresponding to the natural resonance frequencies of the generator shaft. The control strategy for the SSSC will be presented. To be able to make the device more compact, leading to a cost-effective solution to SSR mitigation, the SSSC is constituted by three-phase VSC. Simulation results show that with the proposed system, SSR mitigation is provided by injecting low amount of voltage in the grid, leading to a reduced power rating of the SSSC.

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## II.SYSTEM MODEL AND ASSUMPTIONS

The system investigated for this paper is the well-known IEEE First Benchmark Model (FBM). The system has a synchronous generator connected to an infinite bus having two transmission lines in parallel. In the considered study system one of the transmission lines is compensated by a series capacitor. A 600 MVA turbine-generator is connected to an infinite bus, with the rated line voltage of 500KV, while the rated frequency is 60Hz. The shaft system as shown in Fig.1 consists of four masses: the Generator (G) and Rotating Exciter (EX), Low Pressure Turbine (LP), and a High Pressure Turbine (HP). All the masses are mechanically connected to each other by elastic shaft. The system under study is adapted from IEEE FBM which consists of a turbine, generator, series compensated long transmission line and SSSC injecting a series voltage in the transmission line is shown in fig.1.

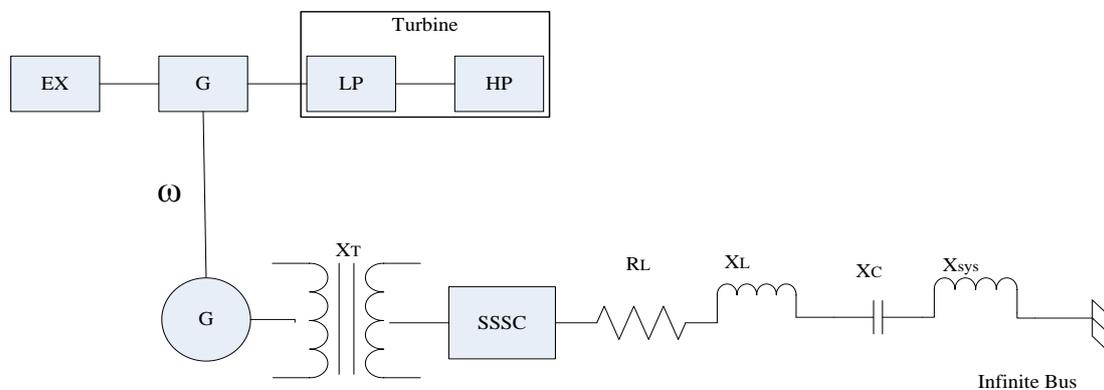


Fig:-1. Single line diagram of IEEE FBM along with SSSC.

The analysis is carried out by considering the following assumptions and initial operating condition:-

1. The generator supplies power ( $P_g$ ) of 0(p.u.) to the transmission line.
2. The mechanical input power to the turbine is made constant.
3. The total series compensation is kept at 0.76 (p.u.) The study is carried out for the following cases

Case-1: Without SSSC

Case-2: With SSSC

In Case-1, Fixed capacitor alone is used for the series compensation with  $X_C = X_{C2} = 0.76$  (p.u.).

In Case-2, hybrid compensation is used wherein 0.25 (p.u.) of series compensation is met by SSSC ( $X_{SSSC} = V_R/I$ ) and the remaining compensation is provided by fixed capacitor  $X_C = X_{C2} = 0.51$  (p.u.).

4. To validate the effectiveness of SSSC under severe fault, a three-phase to ground fault applied at generator terminal at 0.022 s and cleared after 0.039 s.

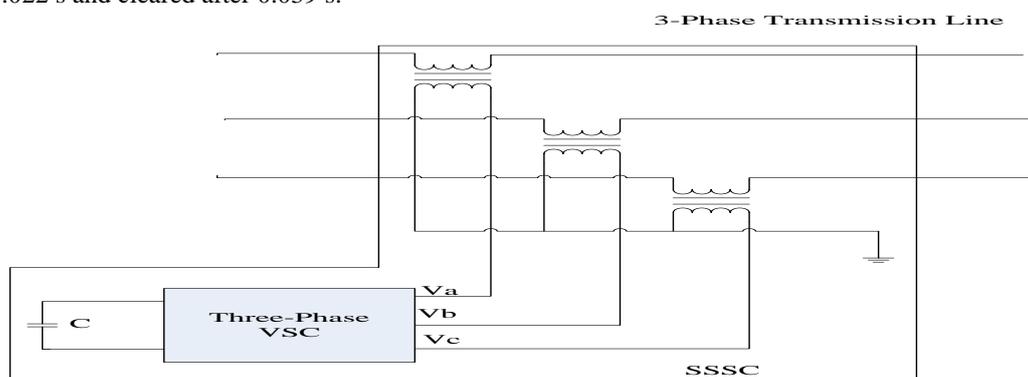


Fig. 2. Diagram of a three-phase VSC based SSSC.

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Fig. 2 shows the typical configuration of a VSC based SSSC connected to the grid. As shown, the SSSC uses a three phase VSC, a capacitor bank connected to the dc-side of the VSC and an injection transformer. A filtering stage (not shown) is typically added at the firing circuit of the VSC to reduce the harmonic pollution in the injected voltage. When used for reactive power compensation only, the dc capacitors must provide the active power needed to compensate for losses in the system. Otherwise, when active power injection is allowed, the dc capacitor is also used as energy storage.

### III. SUBSYNCHRONOUS RESONANCE

Generally, SSR happens in series compensated transmission lines. Series compensation of transmission line can be lead to the excitation of oscillatory modes of the rotor shaft in SSR. A series capacitor-compensated power system has an electrical resonant with natural frequency ( $f_e$ ) which is following by:

$$f_e = f_0 \sqrt{\frac{X_c}{X_1}}$$

Where,  $X_1$  is the reactance of compensated line,  $X_c$  is the reactance of series capacitor and  $f_0$  is the synchronous frequency of the power network in Hz. At this sub-synchronous natural frequency, these oscillatory modes cause rotor torques and currents at the complementary frequency,  $f_r$  as  $f_r = f_0 - f_e$ . Therefore, if  $f_r$  is nearby one of the torsional frequencies of the rotor shaft, the torsional oscillations will be excited and this situation will be caused undesirable occurrences namely SSR. Generally, SSR has two major parts: transient torque or transient SSR and the second part are self-excitation which is named by steady-state SSR. Self-excitation is divided into two major parts: the first one is IGE, and the second one is TI. The IGE is impracticable in series compensated power networks. However, the TI and transient SSR are mostly happen in series compensated power networks. Because the main purpose of this study is to damp out the SSR in series compensated transmission line, the suggested controller is planned to eliminate major SSR problems, transient torque and TI.

### IV. FUZZY LOGIC CONTROLLER

During the past years, the FLC is one of the best methods to control of power system characteristics compared with classical methods. It is easy to be implemented in a large-scale nonlinear dynamic system and not so sensitive to the system models, parameters and operation conditions. The FLC performance is based on its capability to simulate many functions at its same time process and output results of the FLC is noticeably thorough. Fig.3 shows schematic of the FLC which is used for improving capability of the SSR damping by the SSSC. The basic formation of a fuzzy controller is contained of four parts: Fuzzification Block, Fuzzy Knowledge Based Block, Fuzzy Inference Engine and Defuzzification Block.

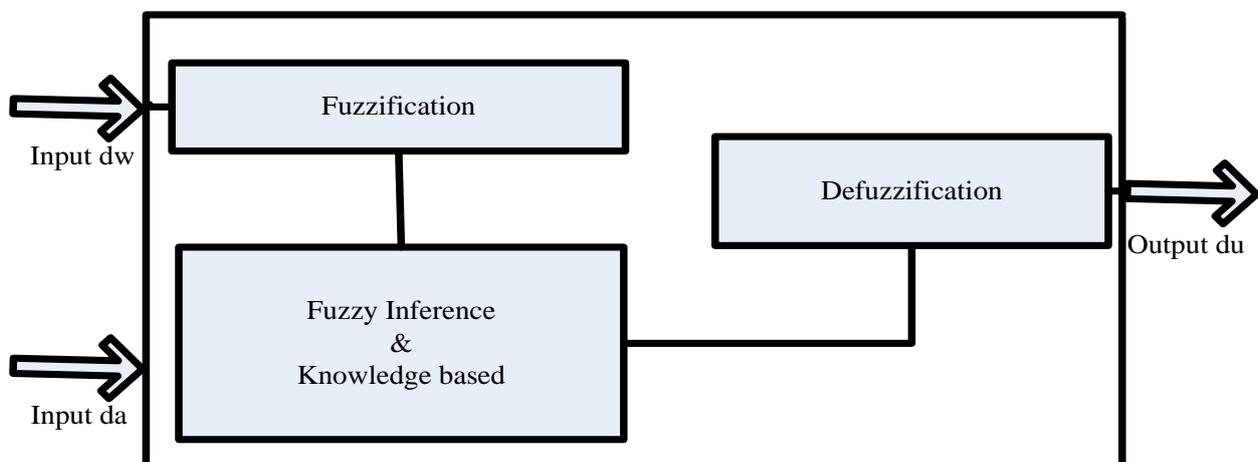


Fig:-3. Fuzzy logic control scheme

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In this paper, the inputs and output are normalized for the base values defined for the system. The rule and number of the membership functions explaining the fuzzy value of controller for the inputs and output are described off-line. Standard triangular membership functions were employed for the inputs and output fuzzy sets of the FLC. In input dw, voltage is given as input signal and in input da, the derivative of voltage is given as input signal. The designed membership functions for: dw and da as inputs and du as output are shown in Fig.4.

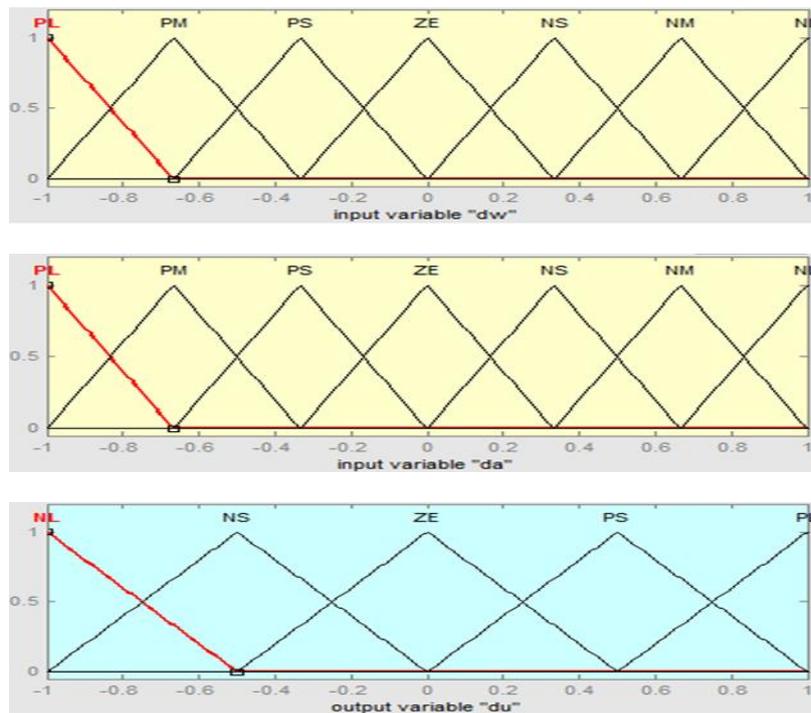


Fig:-4. Fuzzy membership functions

The control rules of the fuzzy controllers are showed by set of heuristically selected fuzzy rules. There are 49 rules. The fuzzy sets have been determined as: NL (Negative Large), NM (Negative Medium), NS (Negative Small) and ZE (Zero), PS (Positive small), PM (positive medium), PL (positive large) respectively. The rule base with two proposed input is shown as Table I.

Table I. Fuzzy Rules

dw \ da	PL	PM	PS	ZE	NS	NM	NL
PL	PL	PL	PL	PL	PS	PS	ZE
PM	PL	PL	PL	PS	PS	ZE	NS
PS	PL	PL	PS	PS	ZE	NS	NS
ZE	PL	PL	PS	ZE	NS	NS	NL
NS	NS	PS	ZE	NS	NS	NL	NL
NM	PS	ZE	NS	NS	NL	NL	NL
NL	ZE	NS	NS	NL	NL	NL	NL

**V. RESULT AND DISCUSSION**

To prove the effectiveness of the proposed control strategy to mitigate SSR, the IEEE FBM with FLC based SSSC has been simulated using the simulation program MATLAB/SIMULINK. At  $t = 0.022$  sec, a three-phase fault has been applied to the grid. The fault clearing time has been set to 0.039 sec. Due to unstable mode, when the fault is cleared, large oscillations will be experienced in the following output signals of the generator.

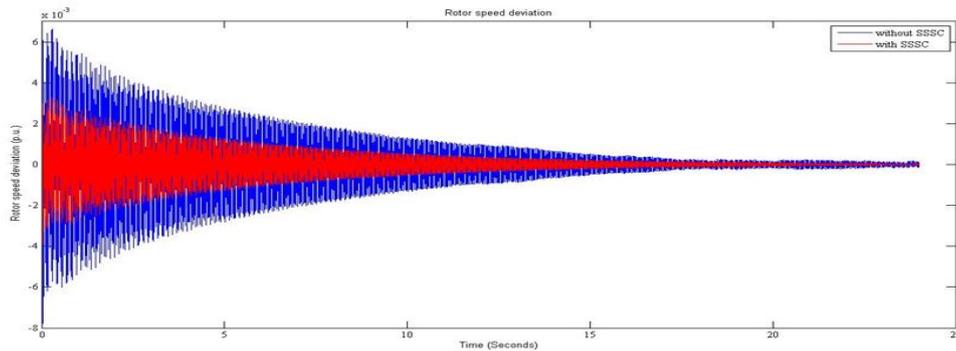


Fig.5. Rotor speed deviation

In Fig. 5, the generator rotor speed deviation consists of resonance of torsional modes. So if the rotor speed deviation is controlled, then in parallel the resonance is also controlled or compensated. The settling point of rotor speed deviation, With SSSC is 20 sec and without SSSC is beyond 24 sec.

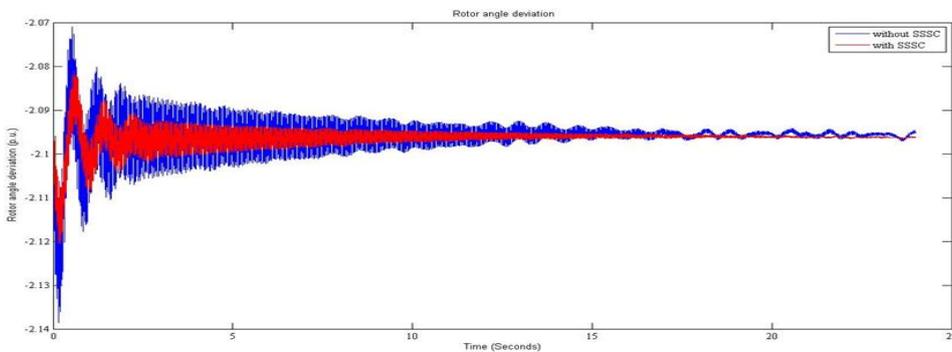


Fig. 6. Rotor angle deviation

In Fig. 6, the generator rotor angle deviation with SSSC, the settling time is 20 sec and in without SSSC the settling time is beyond 24 sec. The generator rotor angle deviation is compensated by fuzzy logic based SSSC.

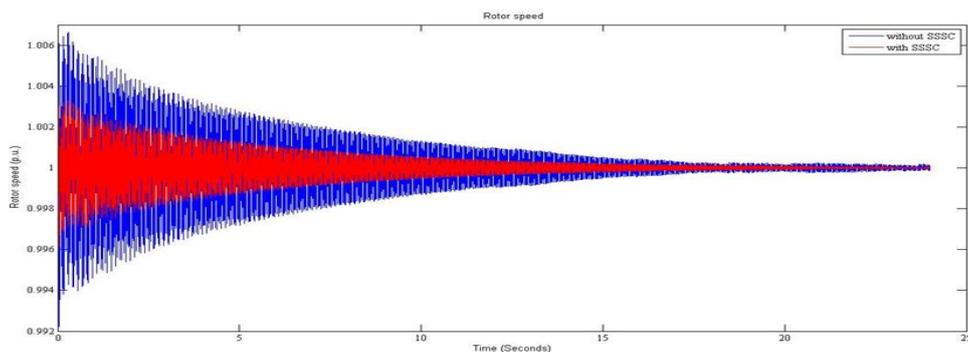


Fig. 7. Rotor speed

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In Fig. 7, rotor speed of generator end causes instability or decreased damping of torsional modes while damping system mode. The generator rotor speed with SSSC, settling time is 21 sec and without SSSC, the settling time is beyond 24 sec.

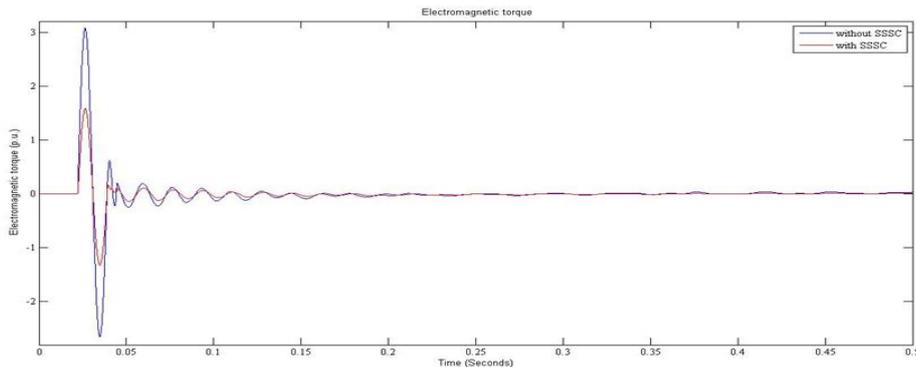


Fig. 8. Electromagnetic torque

In Fig. 8, the generator electromagnetic torque with SSSC is settled in 0.368 sec and without SSSC the settling time is 0.5 sec. The generator electromagnetic torque is compensated by fuzzy logic based SSSC as compared to without SSSC.

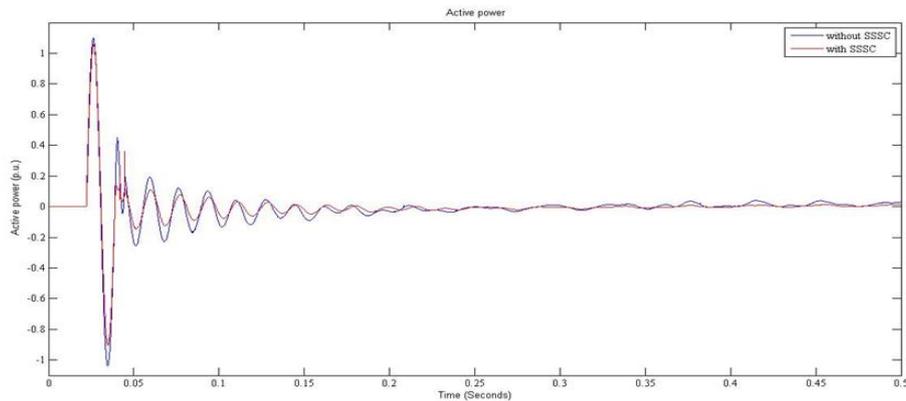


Fig.9. Active power

In Fig. 9, the generator active power, with SSSC the settling time is 0.3 sec and without SSSC settling time is beyond 0.5 sec. The generator active power is compensated by fuzzy logic based SSSC as compared to without SSSC.

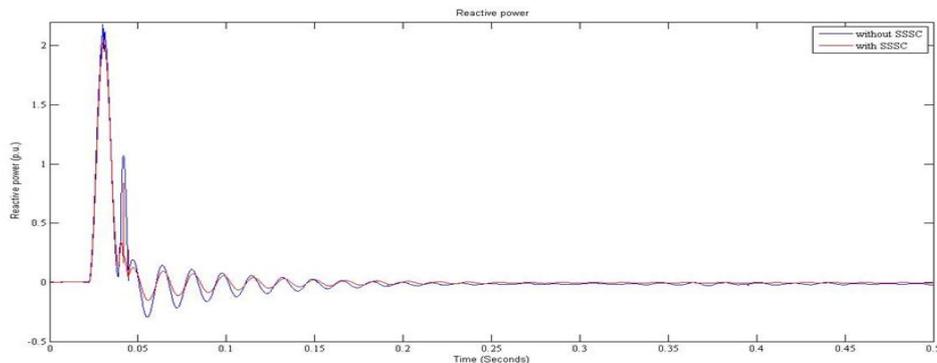


Fig. 10. Reactive power



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In Fig. 10, the generator reactive power, with SSSC the settling time is 0.477 sec and without SSSC the settling time is beyond 0.5 sec. Fig 5, 6, 7, 8, 9,10 shows the rotor speed deviation, rotor angle deviation, rotor speed, electromagnetic torque, active power, reactive power respectively.

## VI. CONCLUSION

This paper explored the performance of Fuzzy Logic based controller of SSSC in a single machine infinite bus power system to damp out sub synchronous resonance. The MATLAB/SIMULINK is carried out on IEEE first bench mark system. The SSSC is used as a voltage source in series with a fixed capacitor and this prevents the sub synchronous oscillations that may be caused by conventional fixed capacitor. The efficacy of the system is studied with the simulation. During the simulation, we have perceived that Fuzzy Logic Controller is able to damp the oscillations which are precipitated by conventional fixed capacitor.

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