ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, January 2016

A FUZZY-PD Controller Based SSSC for Damping of SSR

Raghvendra Singh Rajput[1], Arpan Rahangdale[2], Kumar Prabhakar[3]

M.E Student, Department of E.X, IES College of Technology, Bhopal, India

M.E Student, Department of E.X, IES College of Technology, Bhopal, India

Assistant Professor, Department of E.X, IES College of Technology, Bhopal, India

ABSTRACT: In this paper steam-turbine generator connected to a series compensated long transmission line. Which increase the power transfer capability of the system. It result SSR appear in the system. SSSC decease or damp out the SSR problem in the system caused during fault. FUZZY-PD Controller is used to damp out the SSR oscillation. In this paper voltage source converter acts as SSSC FACTS device. The study is performed on the system adapted from the IEEE First Benchmark Model and Time domain simulations result carried out with MATLAB/SIMULINK.

KEYWORDS:SSR, SSSC, FACTS, FUZZY-PD Controller.

I.INTRODUCTION

The demand of the electricity and growth of the electrical power system (such as large loads like industrial plants) isincreasing continuously. This result in increasing the power system networks as well as long transmission lines. So for improving performance of the power transfer capability and system stability series compensation are used in long power transfer system. For series compensation, series capacitors are widely used which are available at low cost, easy to maintain and easy to install. By using series capacitors, the power transfer capability and steady state stability of the system increased. When series capacitors are used in the system, anunfavourable effect known as Sub Synchronous Resonance (SSR) occurs in the system. SSR is a significant problem. It is related to the interaction between mechanical system of the generator unit and series compensated long transmission line. TheSSR problem is divided in two categories namely, Torque Amplification (TA) also knownas transient torque andsteady state SSR.

SSR is further divided into Torque Interaction (TI) and Induction Generator Effect (IEG). In this paper TI problem is taken into consideration which endorse a threat to power system. In order to avoid SSR, suitable damping controllers should be installed to prevent the system from damage.Flexible AC Transmission System (FACTS) devices can be used to enhance the performance of the transmission line, improve power quality, power security, scheduling fast power flow, limiting short-circuit currents, regulating continuous reactance, mitigating SSR, damping the power oscillation, or enhancing transient stability.

In this paper a SSSC-FACTS device is connected to the transmission line to damp out the SSR. SSSC is a Voltage Source Converter (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 reducing the network resonance.

This paper presents the behavior of the FUZZY- PD controller in damping out the oscillations in the fault period. In this paper, a comparative study between the systems under fault condition has been studied and the system under the fault with the FUZZY-PD controller has been studied, and the simulation results are compared. The study is performed on the system adapted from the IEEE First Benchmark Model (FBM) and time domain simulations result carried out with MATLAB/SIMULINK**.**

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, January 2016

II. ANALYSIS SYSTEM MODEL AND ASSUMPTION

This system is an IEEE FBM, used to study sub-synchronous resonance. The single line diagram of the power system network connected with the SSSC. 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.

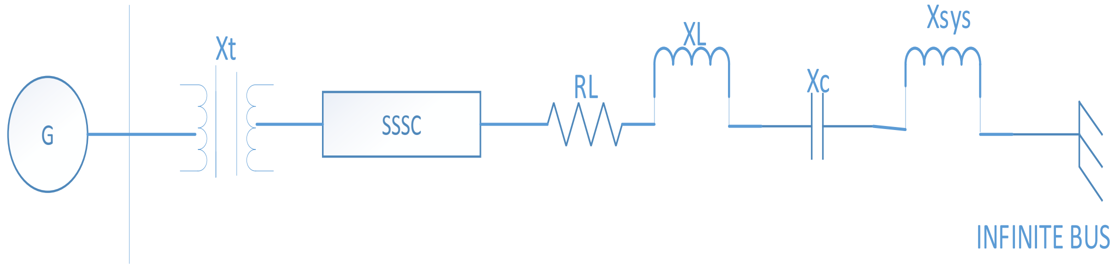


Fig. 1. Single Line Diagram of IEEE FBM Along with SSSC

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 mechanical power generating system consists of one Low Pressure Turbine (LP), High Pressure Turbine (HP), Generator (G), and an Exciter system (EX). All the masses are mechanically connected to each other by elastic shaft.

The analysis is carried out by considering the following assumptions and initial operating condition.
(a) The mechanical input power to the turbine is made constant.
(b) The generator supplies power (P_g) of 0 p.u. to the transmission line.
(c) The total series compensation is kept at 0.76 p.u. The study is carried out for the following cases
Case-1: With SSSC
Case-2: Without SSSC
In Case-1, 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.

In Case-2, fixed capacitor alone is used for the series compensation with $X_c = X_{c1} = 0.76$ p.u. To validate theeffectiveness of SSSC under severe fault, a three-phase to ground fault applied at generator terminal at 0.022 sec. and cleared after 0.039 sec.

III. STATIC SYNCHRONOUS SERIES COMPENSATOR

Static synchronous series compensator (SSSC) is series connected compensator facts device. SSSC is a modern power quality FACTS device that employs a VSC connected in series to a transmission line through a transformer. The SSSC operates like a controllable series capacitor and series inductor. The primary difference is that its injected voltage is not related to the line intensity and can be managed independently.
The principle of SSR mitigation using the traditional control is to replace the fundamental frequency voltage created by inserted fixed capacitor banks by injecting a similar voltage that has been generated by the SSSC. The capacitive reactance from the capacitor bank is reduced, the electric resonance of the system become shifted, thus nullifying the risk of SSR.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, January 2016

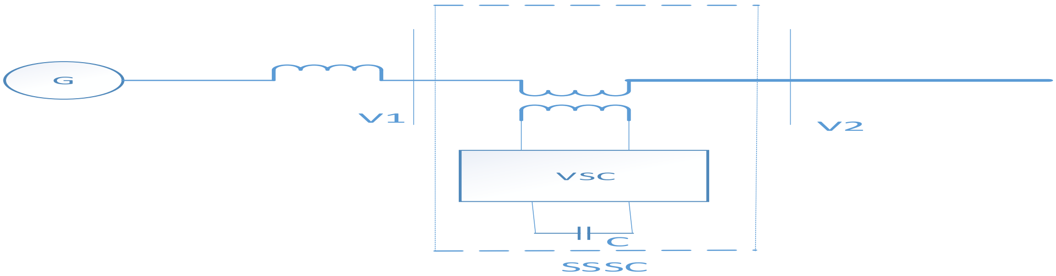


Fig.2. Single Line Diagram ofSSSC

This feature allows the SSSC to work satisfactorily with high loads as well as with lower loads. The SSSC provides fast control and is inherently neutral to SSR.SSSC is capable to change its reactance characteristic from capacitive to inductive . In all FACTS devices, SSSC play important role in reactive power compensation and voltage support because of its operating characteristics and steady state performance. Benefits of using SSSC, eliminate bulky passive components such as capacitors and reactors and symmetric capability in both inductive and capacitive operating modes.

IV. FUZZY- PD CONTROLLER

PD controller with the FLC is proposed. Since human knowledge is used for designing fuzzy controllers, there are many ways to design FLCs. here, to design a firing angle controller, a simple fuzzy PD controller is used, and it is implemented by the Fuzzy Inference System toolbox in MATLAB/SIMULINK software.

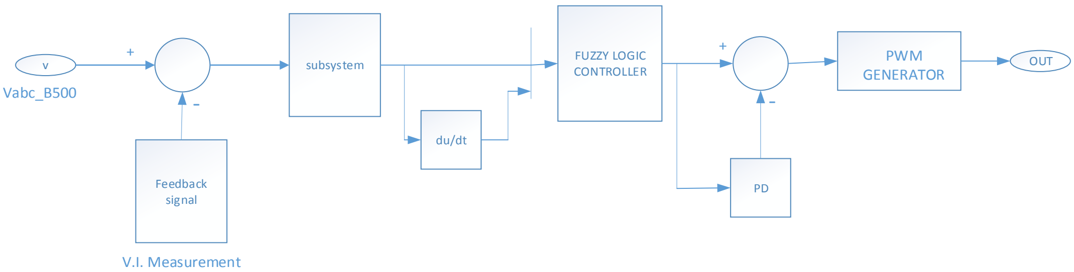


Fig.3. FUZZY- PD Controller

The firing angle is obtained by limiting the output of the FUZZY PD controller in capacitive mode, while the input limiters put the variables in the normalized range. The schematic of the FUZZY PD is shown in Figure.The value give to PD Controller is
P = 0.5, and D = 20.
Compensator formula for PD controller is

$$P + D\frac{N}{1 + N\frac{1}{s}}$$

Benefits of PD controller:-

(1) Derivative part in PD controller, it improves overshoot and the transient stability of the control system.
(2) It reduces the time constant of the system and makes the system faster.
(3) It has no effect on the steady state error.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, January 2016

V. DESIGN OF 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.

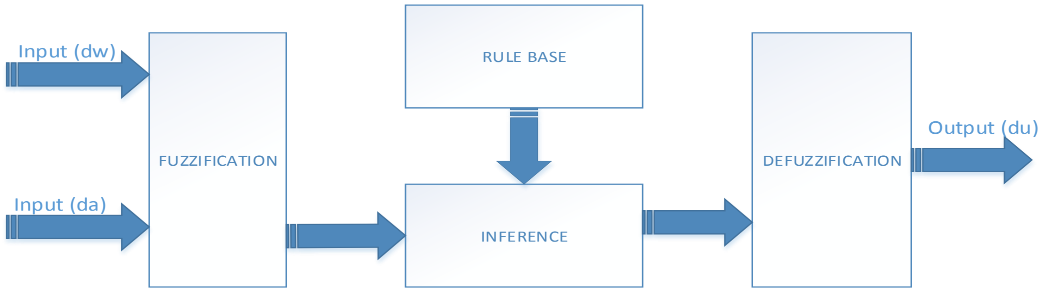


Fig.4.Control Process of FLC

Fig.4 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.

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.5

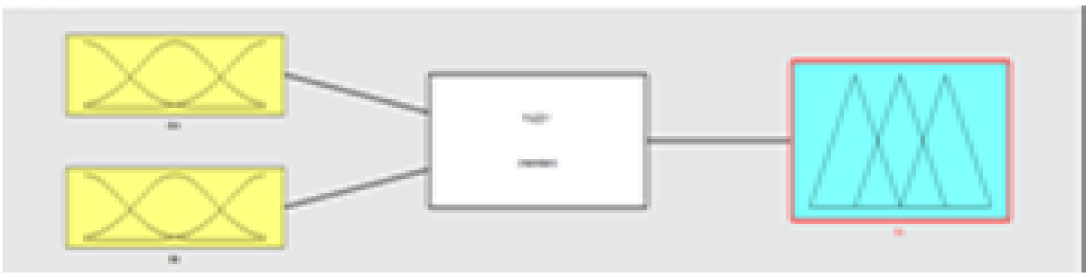
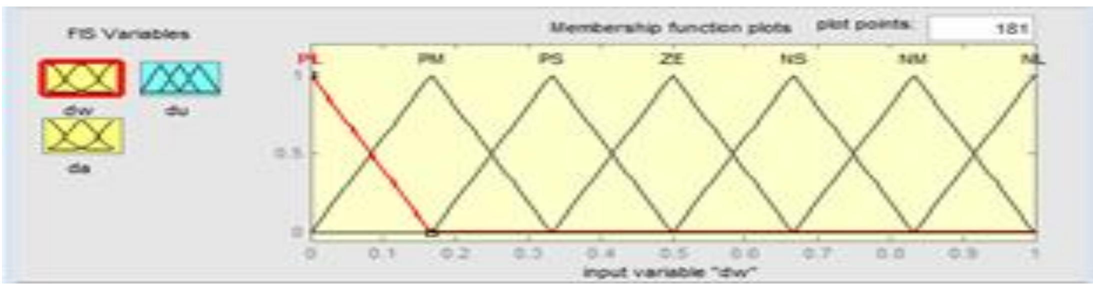


Fig.5. Input and Output Fuzzy Membership Function



(a)

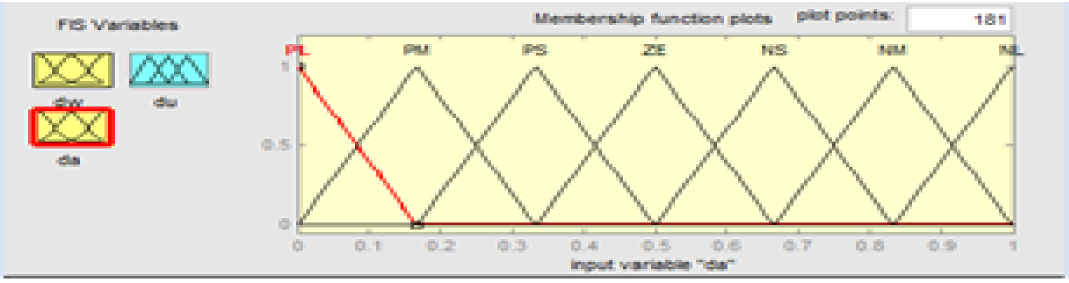
 DOI:10.15662/IJAREEIE.2015.0501028

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

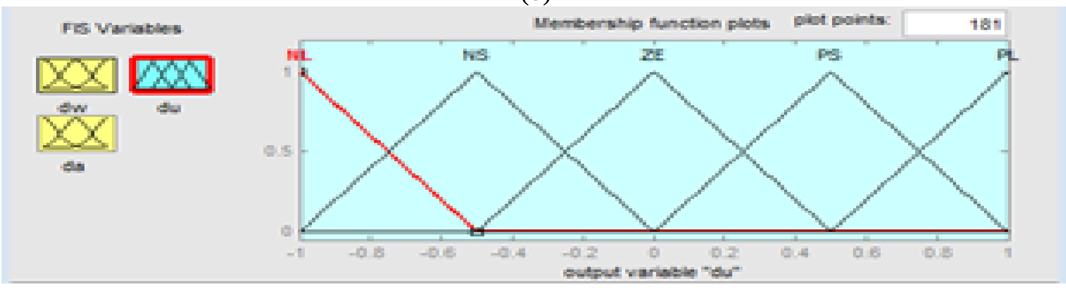
International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, January 2016



(b)



(c)

Fig.6. (a, b) Membership Function for Error Input and (c) is Output Membership Function

The rule based system play an important role in the designing of controller.The waveform has been split into various parts depending on the sign of error and change in error. The control rules of the fuzzy controllers are showed by set of heuristically selected fuzzy rules. There are 49 rules [7*7]. 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.

Table. I

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

VI. SIMULATION RESULTS

The Torsional Oscillations of the given system are the major SSR interaction when a steam turbine-generator is connected to a series compensated transmission line. Without FACTS controllers SSSC the system become more unstable at different levels of series compensation.The simulation model for IEEE FBM is shown in Fig.8 and simulation carried out on MATLAB/SIMULINK. Time domain simulation for three phase fault at infinite bus is observed. Initial fault duration for three phase fault is 0.022 to 0.039 sec. The simulation results for without SSSC and with SSSC are analyzed.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, January 2016

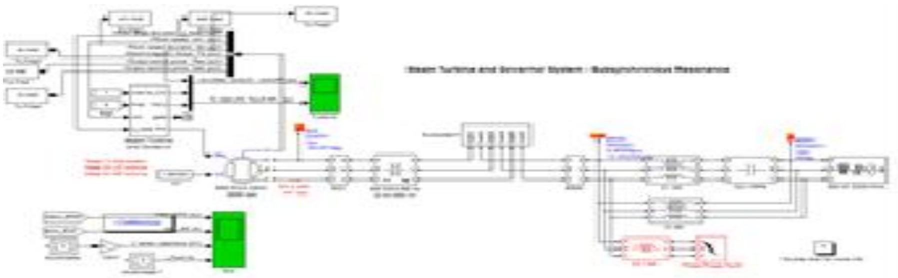


Fig. 7. Simulated System Model of IEEE FBM with SSSC Controller

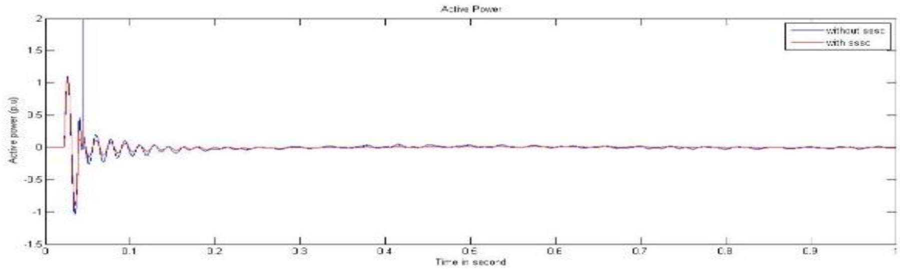


Fig. 8. Active Power

In fig.8,the generator active power is compensated by FUZZY-PD controller and settling time with SSSC is 0.3 sec. and without SSSC is beyond 0.5 sec.

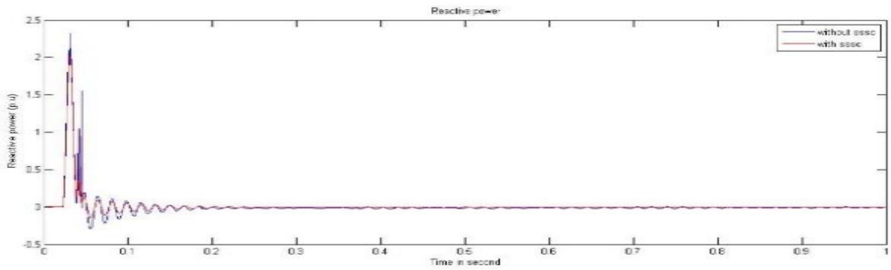


Fig. 9. Reactive Power

In fig.9, the generator reactive poweris compensated by FUZZY-PD controllerand settling time with SSSC is 0.477 sec. and without SSSC the settling time is beyond 0.5 sec.

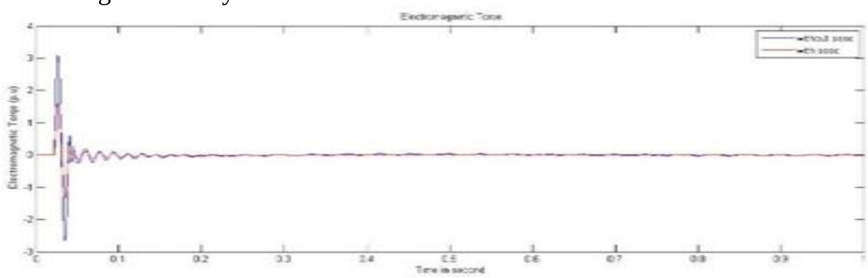


Fig. 10. Electromagnetic Torque

In fig.10, the generator electromagnetic torque is compensated by FUZZY-PD controller and settling time with SSSC is 0.368 sec. and without SSSC the settling time is 0.5 sec.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, January 2016

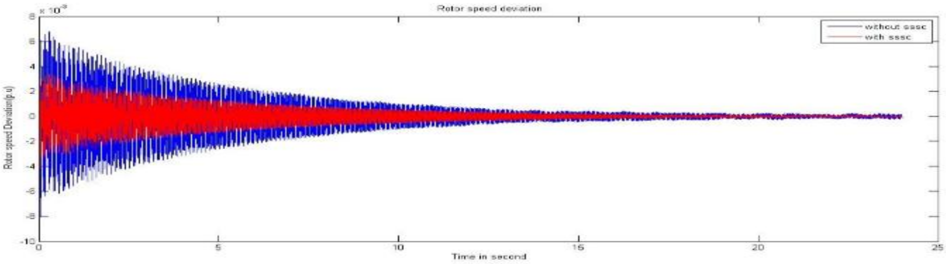


Fig. 11. Rotor Speed

In fig.11, the generator rotor speedis compensated by FUZZY-PD controller and settling time with SSSC is 21 sec. and without SSSC the settling time is beyond 24 sec.

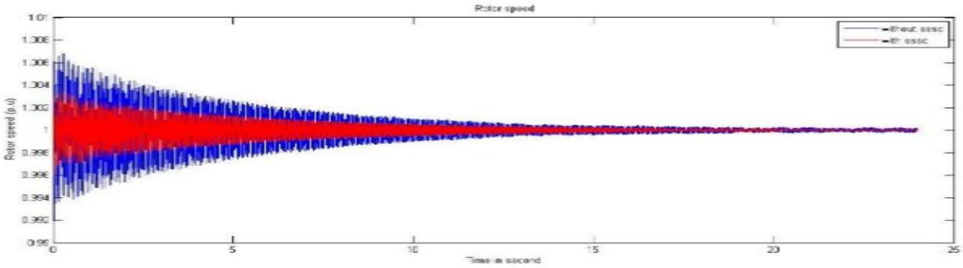


Fig. 12. Rotor Speed Deviation

In fig.12, 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.

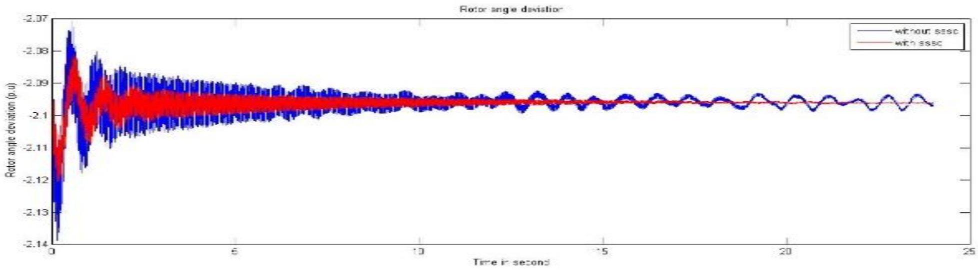


Fig. 13. Rotor Angle Deviation

In fig.13, the generator rotor angle deviation with SSSC, the settling time is 20 sec and in without SSSC the settling time is beyond 24 sec.Fig 8, 9, 10, 11, 12, 13, shows theactive power, reactive power,electromagnetic torque,rotor speed, rotor speed deviation, rotor angle deviation, respectively.

VII. CONCLUSION

In this paper, SSR effect is studied using IEEE FBM and we have presented the analysis and simulation of series compensated system with FUZZY PD Controller. Which damp out the effect of SSR using SSSC in system. The effect of two systems with FACTS device and without FACTS device SSSCis compared. Time domain simulations using the nonlinear system model are carried out to study. The analyzed results shows that the proposed SSSC based FUZZY-PD controller can effectively stabilizes the common mode torsional oscillations and system will be protected.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, January 2016

REFERENCES

1. R. Thirumalaivasan, M. Janaki, Nagesh Prabhu, "Damping of SSR using sub synchronous current suppressor with SSSC," IEEE Transactions on power system, vol. 28, no. 1, February 2013.
2. Massimo Bongiorno, Jan Svensson and Lennart Angquist, "On control of static synchronous series compensator for SSR mitigation," IEEE Transactions on power electronics, vol. 23, no. 2, march 2008.
3. Massimo Bongiorno, Jan Svensson and Lennart Angquist, "Single –phase VSC based SSSC for sub synchronous resonance damping," IEEE Transactions on power delivery, vol. 23, no. 3, July 2008.
4. K. R. Padiyar, Analysis of Sub synchronous Resonance in Power Systems, Boston, MA Kluwer, 1999.
5. IEEE Sub-synchronous resonance working group, "Second benchmark model for computer simulation of sub-synchronous resonance," IEEE Transactions on Power Apparatus and Systems, vol. PAS-104, no. 5, 1985, pp. 1057-1066.
6. M. Venkateswara Rao, K. Jayakara Babu, "Damping Sub Synchronous Resonance in Turbine – Generator Set Using GCSC, UPFCandSSSC," IJAIEM,Volume 2, Issue 9, September 2013.
7. Kalyan K. Sen, "SSSC - Static Synchronous Series Compensator: Theory, Modeling and Applications", IEEE Transactions on Power Delivery, Vol.13, No.1, pp.241-246, January 1998.