Comparison of FACTS Devices for Transient Stability Enhancement of Multi-machine Power System

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ABSTRACT *In this paper an examination has been performed for the up gradation of transient stability limit in two area multi-machine power system using different FACTS devices. The simulation of two area multi-machine power system including FACTS devices has been carried out in the MATLAB Simulink. The performance of unified power flow controller (UPFC) for the upgradation of transient stability limit has been investigated along with Static synchronous compensator (STATCOM) and Static synchronous series compensator (SSSC) respectively. The paper establishes the superiority of UPFC over STATCOM &SSSC.*

Keywords: *STATCOM; SSSC; UPFC; Two Area System; Transient Stability*

Introduction

Modern electrical power systems have become complex owing to increase in interconnections, installation of numerous generators, extra high voltage tie lines, variety of loads and transformers etc. From the inception of power system, stability has been considered as a major concern in power system operations [1]. Transient stability is the capability in the power system to maintain synchronism when it undergoes critical transient disturbances, such as multi-phase short circuit fault, unanticipated change in generation or loss of large loads. The resulting system response involves change in generator rotor angles and is governed by the nonlinear power angle relationship [2].

Due to advancement in power electronics technology and its uses in high voltage applications has influenced the power system engineers to use the flexible a. c. transmission system (FACTS) controller in the power system. FACTS controllers has the capability to rapidly control the power system network parameters in order to improve steady state stability, voltage stability or transient stability of a complex power systems [3]. In addition, it also empowered the increased utilization of existing network closer to its thermal limit, and hence avoids the need to construct new transmission lines.

FACTS devices has been classified predominantly into two categories one based on thyristor switched reactor like static var compensator (SVC), while others like STATCOM, SSSC and UPFC employing power electronics based voltage source converters (VSCs).

The STATCOM is a shunt connected device of the FACTS families which regulates the voltage at the point of common coupling by injecting into or absorbing the reactive power from the power system. At the time of low voltage conditions in the system, STATCOM generates reactive power or enforce its controller to work in capacitive region. Whereas at system high voltage conditions, it absorbs reactive power from the system or enforce controller to work in inductive region[4-5].

The SSSC is a series connected device of the FACTS family which injects the compensating voltage in series with the transmission line through coupling transformer irrespective of the line current. It consists of a solid state voltage source converter which generates controllable alternating current voltage at fundamental frequency. When the injected voltage is keptin quadrature with the line current, it can emulate as inductive or capacitive reactance so as to influence the power flow through the transmission line. SSSC can control the power flow through the transmission line by injecting voltage which is in quadrature with the transmission line current[6-7].

Among all the devices in FACTS family, the UPFC is most versatile FACTS device which can simultaneously control network impedance, bus voltage magnitude and angle and power flow through the transmission line in order to achieve optimal performance of power system[8-10]. It is used to improve the steady state stability, dynamic stability and transient stability. The UPFC can independently control many parameters since it is the combination of static synchronous compensator (STATCOM) and SSSC. These devices offer an alternative mean to mitigate power system oscillations.

This paper explore the improvement in transient stability limit of a multi machine two area system using different FACTS controllers in the system. A Matlab Simulink based model has been developed for multi-machine system including FACTS controllers such as STATCOM, SSSC and UPFC. The performance of UPFC is compared with STATCOM and SSSC on transient stability improvement in two area system. The simulation results illustrate the effectiveness of UPFC over STATCOM and SSSC in two area power system by enhancing the transient stability. This paper is organized as follows: Section II describes about multi-machine two area power system. In section III, simulation studies on multi-machine two area power system including FACTS devices has been presented. Lastly, conclusions are included in sectionIV.

Inter-areaPowerSystemModel:

In this work, a study has been carried out on two area four machines system[1].The test system used for stability studies has shown in Fig-1.The test system comprises of two areas connected by weak transmission line between bus 7 and bus 9.Two generators, each having 900MVA Capacity has been installed at each area. Two constant loads are applied to the system at bus 7 and 9. The location of FACTS devices such as SSSC,STATCOM and UPFC has been installed at bus 8.

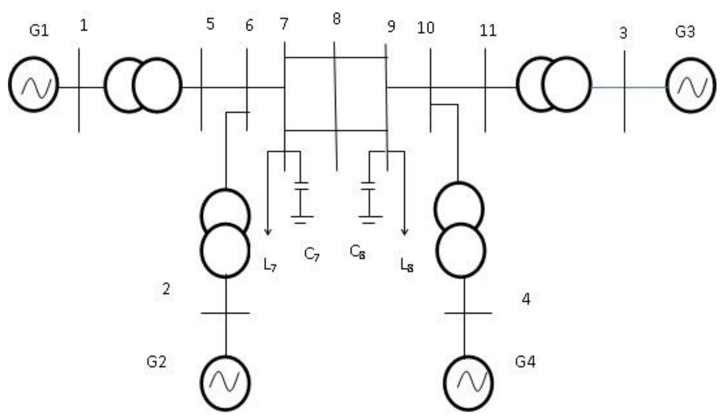


Fig. 1: FOUR MACHINE TWO AREA TEST SYSTEM

SIMULATION RESULTS

Inter-area System withSSSC:

In modified model of test system, SSSC is located at bus 8, and is in series with tie line. The phasor model of typical three levels PWM inverter has been used for SSSC with a rating of ± 100 MVA

To study the test system during disturbances, a three phase symmetrical short circuit fault of 20 cycle duration has been created at bus 7. The fault clearing time was taken 4 cycles after initiation of the fault [11]. The variations of different parameters such as terminal voltage generators, load angle δ and terminal voltages of load 1 and load 2 are shown in Fig. 2 to Fig. 5.

From the results it can be observed that terminal voltage of generators settle down to about 1.03 p. u. for G1 & G4, 1.01p.u.for G2 and 1.0 p. u. for G3 under steady state conditions. From Fig. 8 it is evident that inter-area oscillations have been damped out and generators G1, G2, G3 and G4 have settled at 43.39°, 42.42°, 43.75°and 42.42° respectively. It is clear from Fig. 4 and Fig. 5 that voltage magnitude at load terminals of area 1 and area 2 have settled at 0.96 p. u., which is practically acceptable.

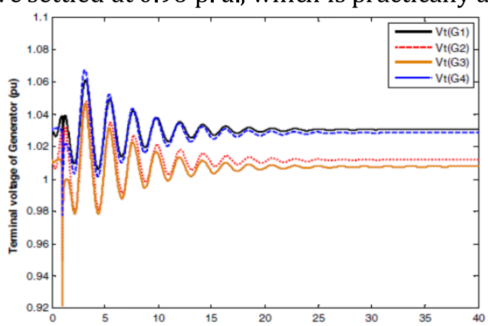


Fig. 2 Variation in terminal voltage of the generator with SSSC

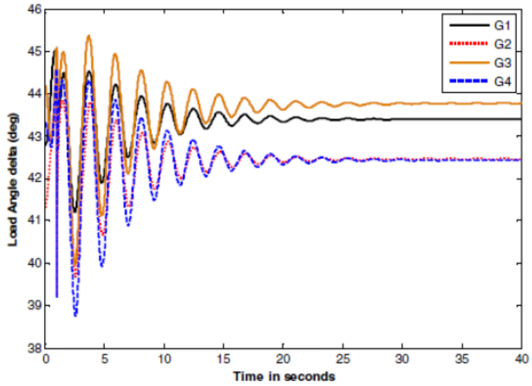


Fig. 3 Variation in load angle of the generator with SSSC

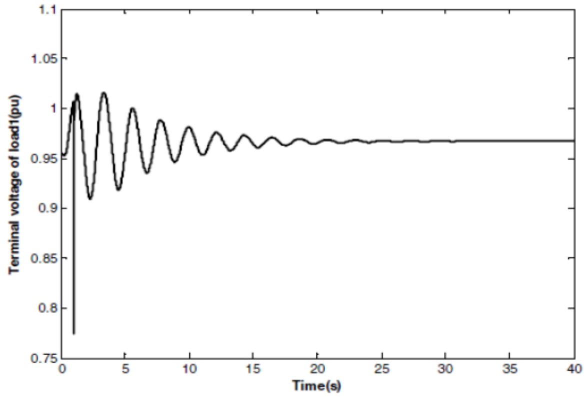


Fig. 4 Variation of terminal voltage at load 1 with SSSC

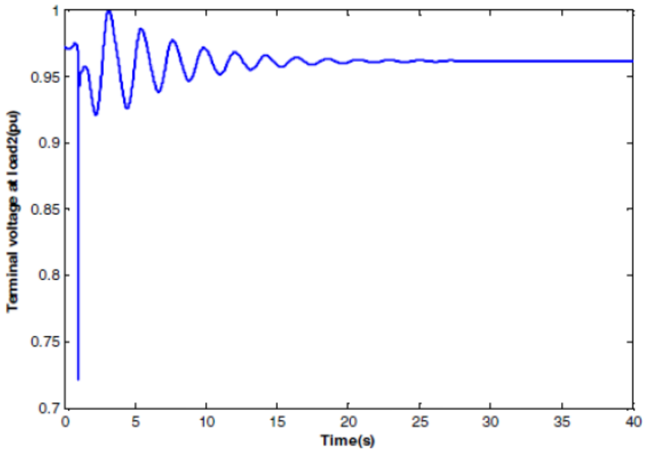


Fig. 5 Variation of terminal voltage at load 2 with SSSC

Inter-area System withSTATCOM:

The modified model of test system with STATCOM. In modified model, STATCOM has been placed in shunt position at bus 8 with a rating of ± 250 MVA. In test system with STATCOM, a simulink based phasor model of a typical three level PWM has been used. To study the test system during disturbances, a three phase symmetrical short circuit fault of 20 cycle duration has been created at bus 7. The fault clearing time was taken 4 cycles after initiation of the fault.

The variations of parameters such as terminal voltage of generators, load angle δ and terminal voltage of load 1 and load 2 are shown from Fig. 6 to Fig. 9. It is clear from Fig. 6 that terminal voltages at generator terminals have settled to acceptable values of about 1.03 p. u. for G_1& G_4 and 1.0 p. u. for G2 & G3 after initial oscillations under steady state conditions.

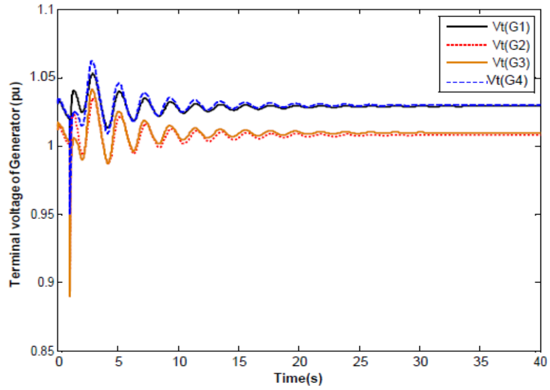


Fig. 6 Terminal voltage of generators with STATCOM

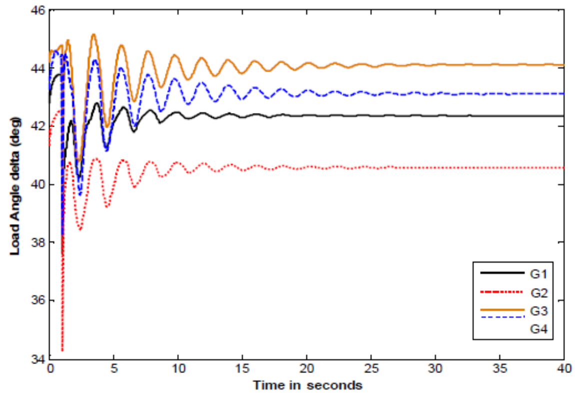


Fig. 7 Variations of load angle of generator with STATCOM

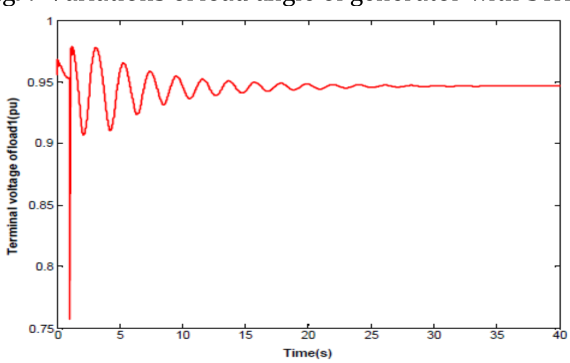


Fig. 8 Variations of terminal voltage at load 1 with STATCOM

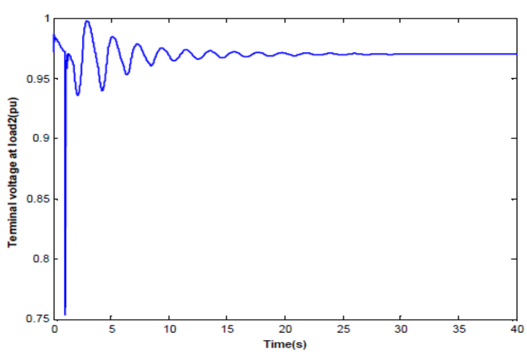


Fig. 9 Variations of terminal voltage at load 2 with STATCOM

From Fig. 7 it is evident that inter area oscillations have been damped out and generators G1, G2, G3 and G4 have settled at 42.43°, 40.58°, 44.08° and 43.09° respectively. It can also be observed from Fig. 8 and Fig. 9 that terminal voltages at load terminals of area 1 and area 2 have settled to acceptable values of 0.95 p. u.

and 0.97 p. u. respectively. It can also be observed from Table I that active power transfers from area 1 to area 2 have been increased to 413. 5MW.

Inter-area System withUPFC:

In the modified model of two area system, UPFC has been placed at bus 8 and is in series with the tie line. In the modified model of test system, the simulink based phasor model of UPFC comprising of two IGBT based converters one connected in shunt (±250 MVA) and other connected in series (± 100 MVA) with bus 8 has been used. Similar to SSSC and STATCOM, to study the system during disturbances, a three phase symmetrical short circuit fault of 20 cycle duration has been created at bus 7. The fault clearing time was taken 4 cycles after initiation of the fault. The simulated results of terminal voltage of generators, load angle δ and terminal voltages of load 1 and load 2 are shown from Fig. 10 to Fig. 13. The variations of terminal voltage at each generator in area 1 and area 2 are shown in Fig. 10.

From the result it can be observed that terminal voltage of generators settle down to about 1.03 p. u. for G_1& G_4 and 1.01 p. u. for G2 & G3 under steady state conditions. From Fig. 11 it is evident that inter-area oscillations have been damped out and generators G1, G2, G3 and G4 have settled at 42.44°, 40.7°, 44.18° and 43.23°respectively.

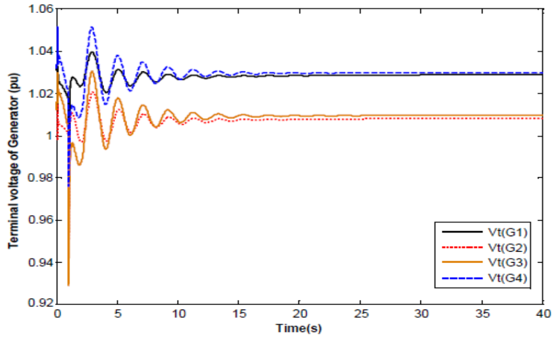


Fig. 10 Terminal voltage of generators with UPFC

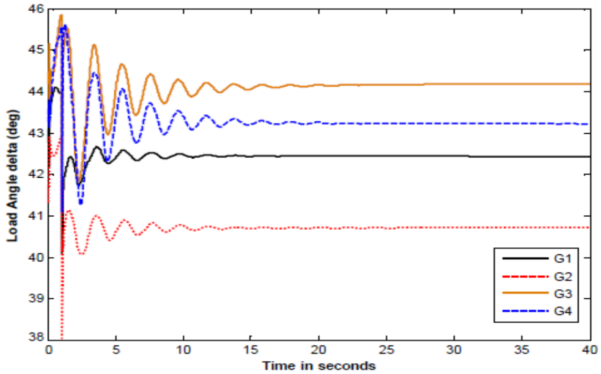


Fig. 11 Variations in load angle of generators with UPFC

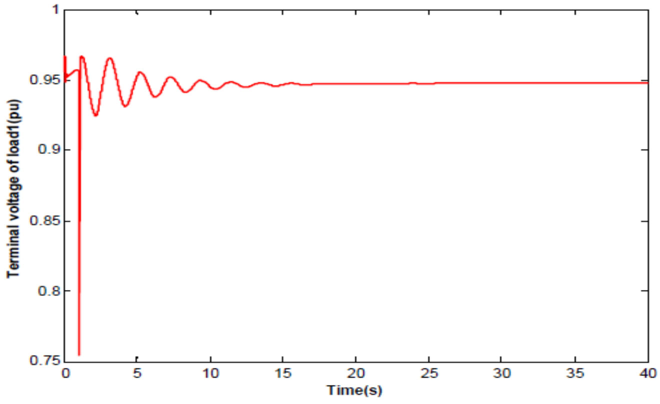


Fig. 12 Variations of terminal voltage at load 1 with UPFC

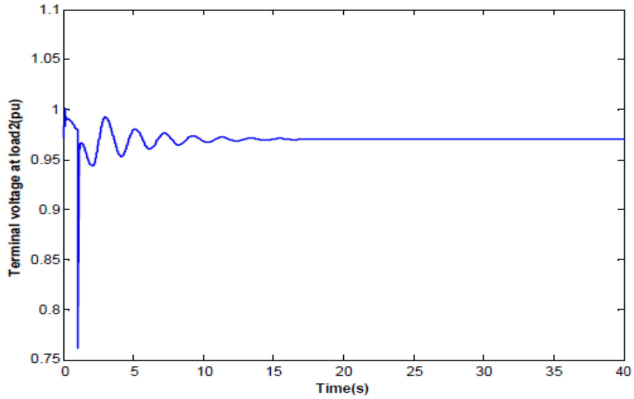


Fig. 13 Variations of terminal voltage at load 2 with UPFC

It is clear from Fig. 12 and Fig. 13 that voltage magnitudes at load terminals of area 1 and area 2 have settled at 0.95 p. u. and 0.97 p. u. respectively, which is practically acceptable. It can also be observed from Table I that active power transfers from area 1 to area 2 have been increased to 415.1 MW. A comparison study has shown in Fig. 14 to illustrate the effect of different FACTS devices for stability enhancement of two area multi-machine power system

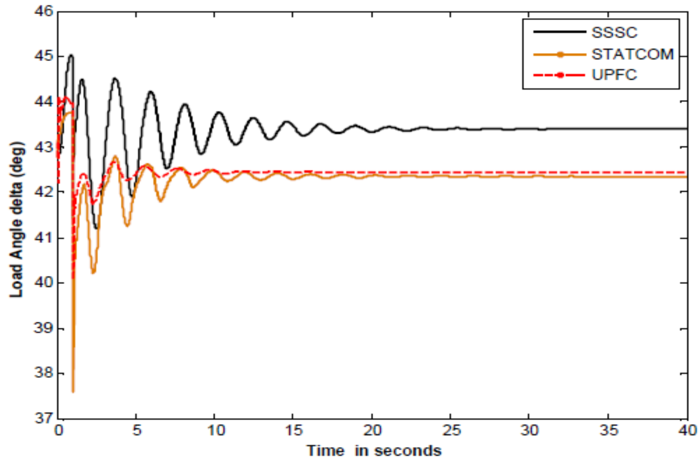


Fig. 14 Variations of load angle of Generator 1with different FACTS devices

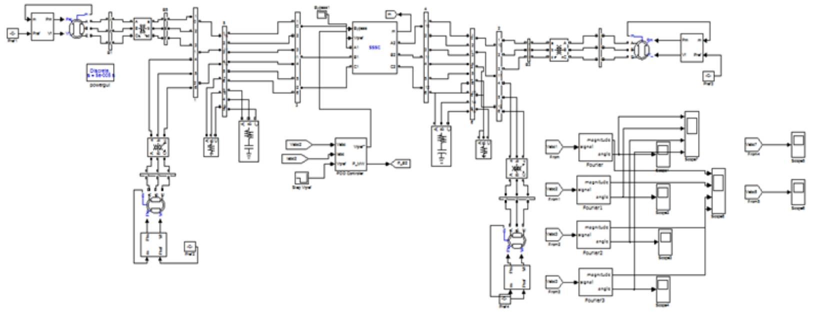
Facts devices	Voltage magnitude (p.u.), 1V1				Load angle (degree), δ				Inter Area Power Flow (MW)
	G1	G2	G3	G4	G1	G2	G3	G4	Ptie
SSSC	1.03	1.01	1.0	1.03	43.49	42.42	42.42	42.42	376.7
STATCOM	1.03	1.0	1.0	1.03	42.43	42.43	40.48	43.09	413.5
UPFC	1.03	1.01	1.01	1.03	42.44	42.44	4.07	43.23	415.1

Table1.Performance comparison of different FACTS devices for inter-area system.

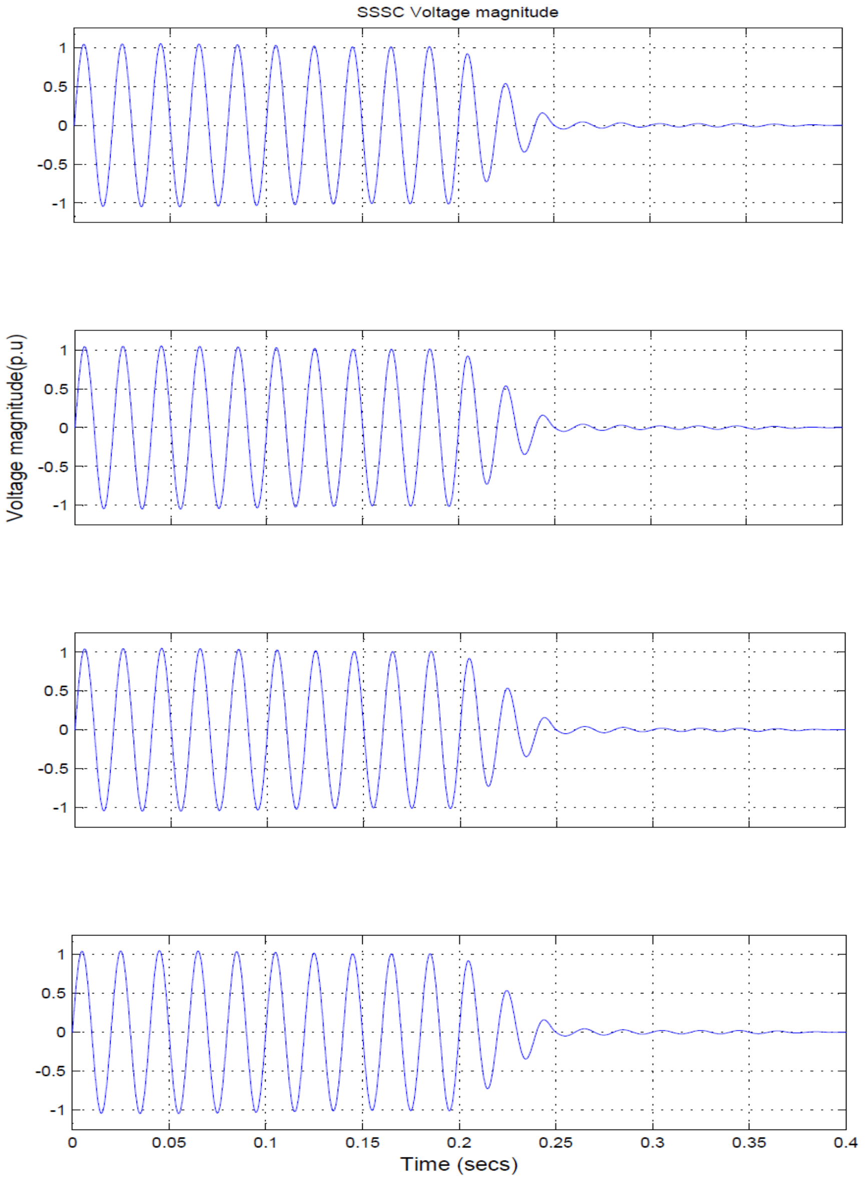
From the Fig. 14, it can be concluded that with the use of UPFC load angle for generator 1 has settled much earlier as compared to other FACTS devices and also from the Table. I, it can be observed that inter area active power flow have been increased to 415.1 MW with the use of UPFC. Therefore, it can be concluded that UPFC is the most powerful device for transient stability enhancement of two area multi-machine system.

Simulation Results:

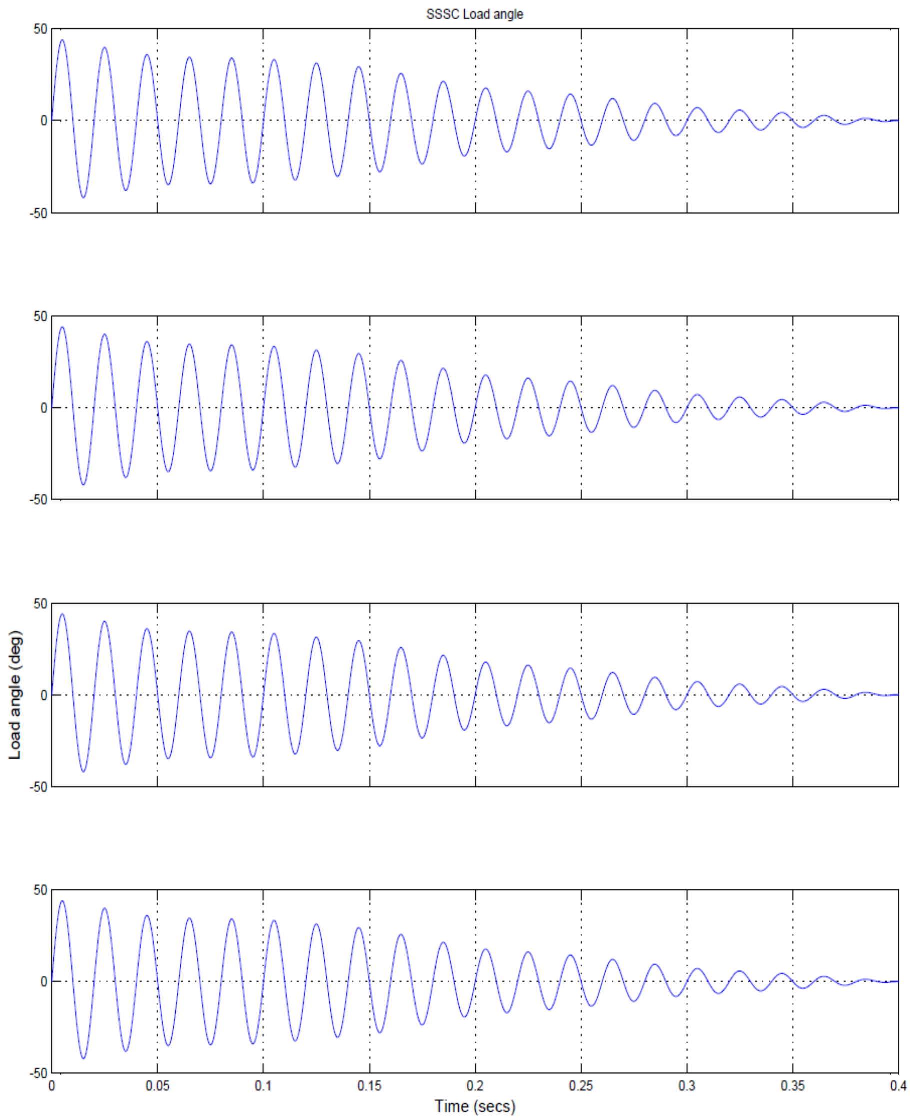
Simulink Block Diagram with SSSC:



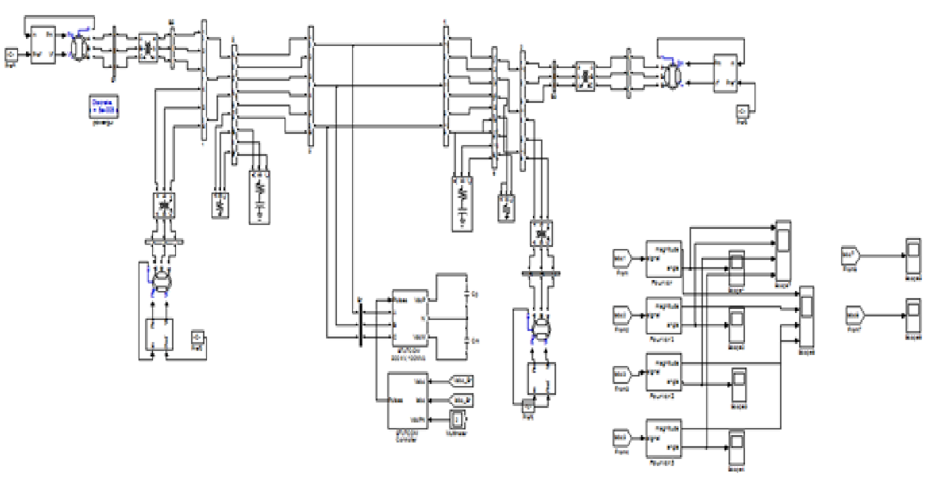
Voltage magnitude waveforms with SSSC:



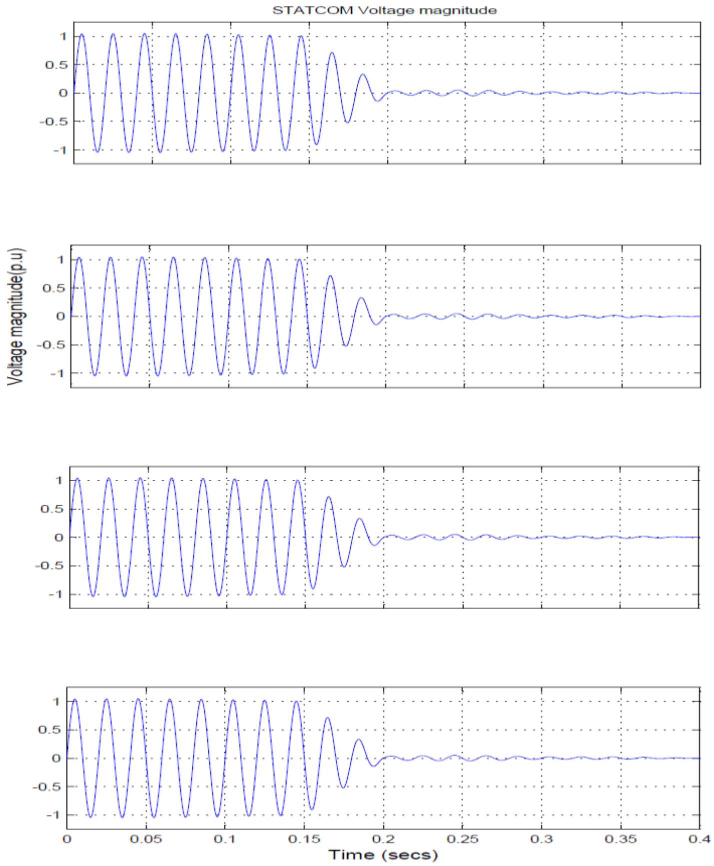
Load angle wave forms with SSSC:



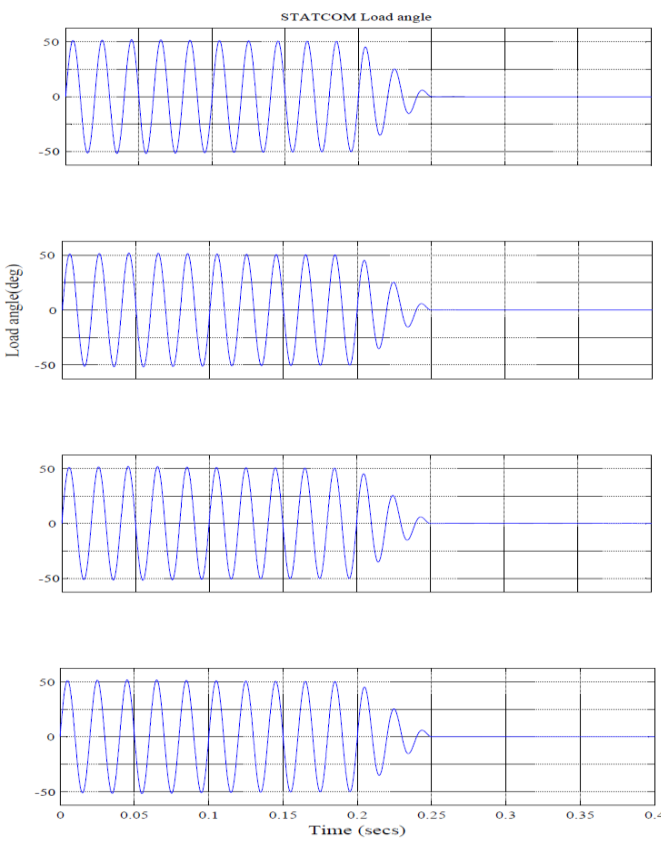
Simulink Block Diagram with STATCOM:



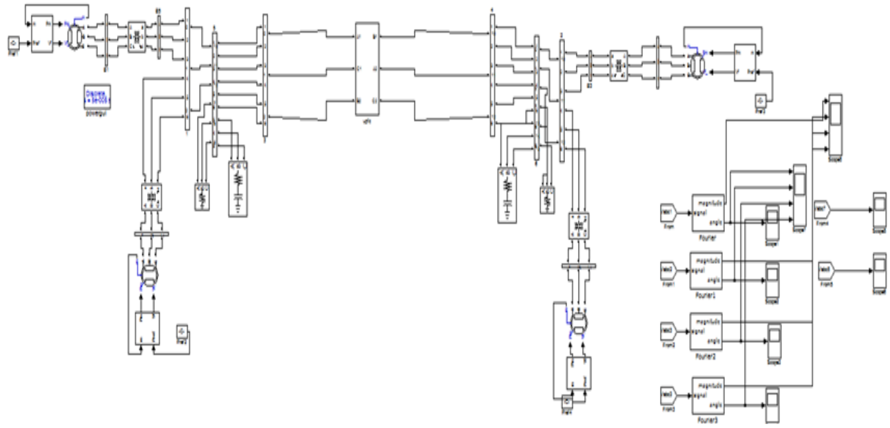
Voltage magnitude waveforms with STATCOM:



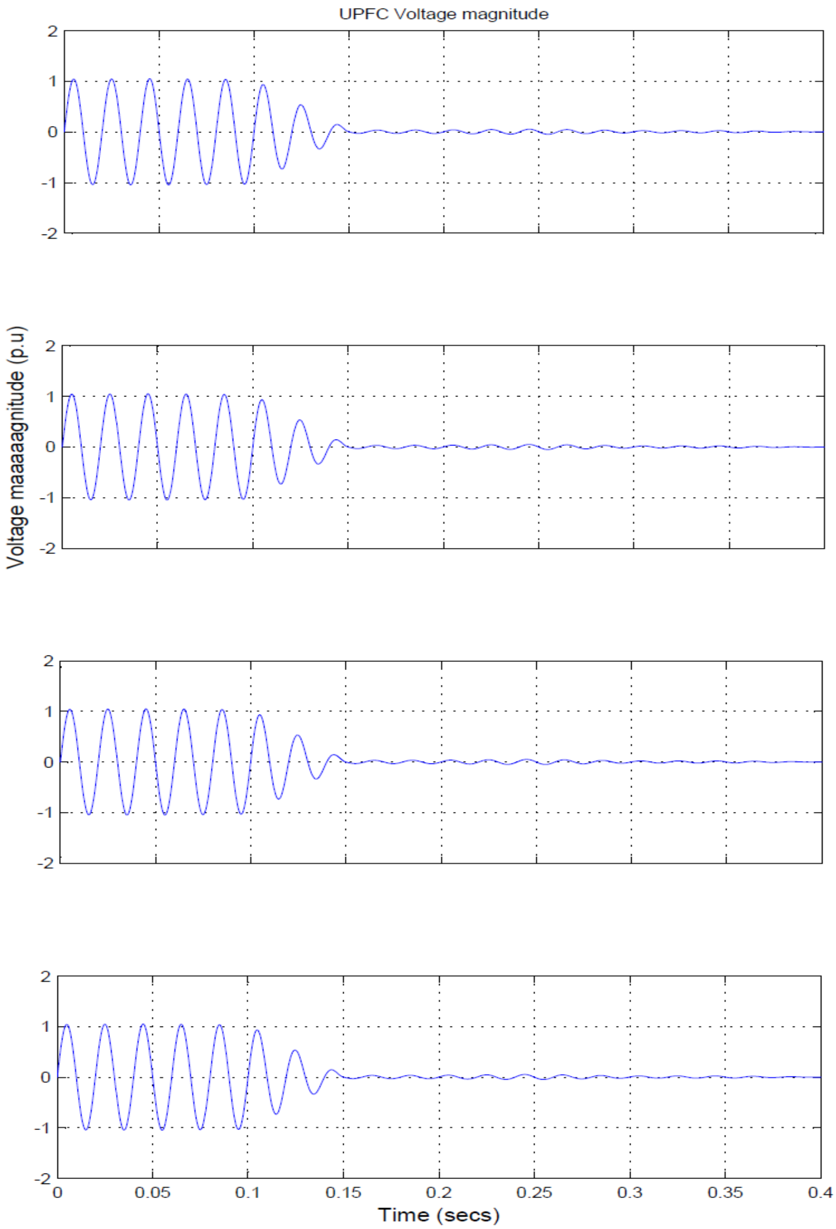
Load angle wave forms with STATCOM:



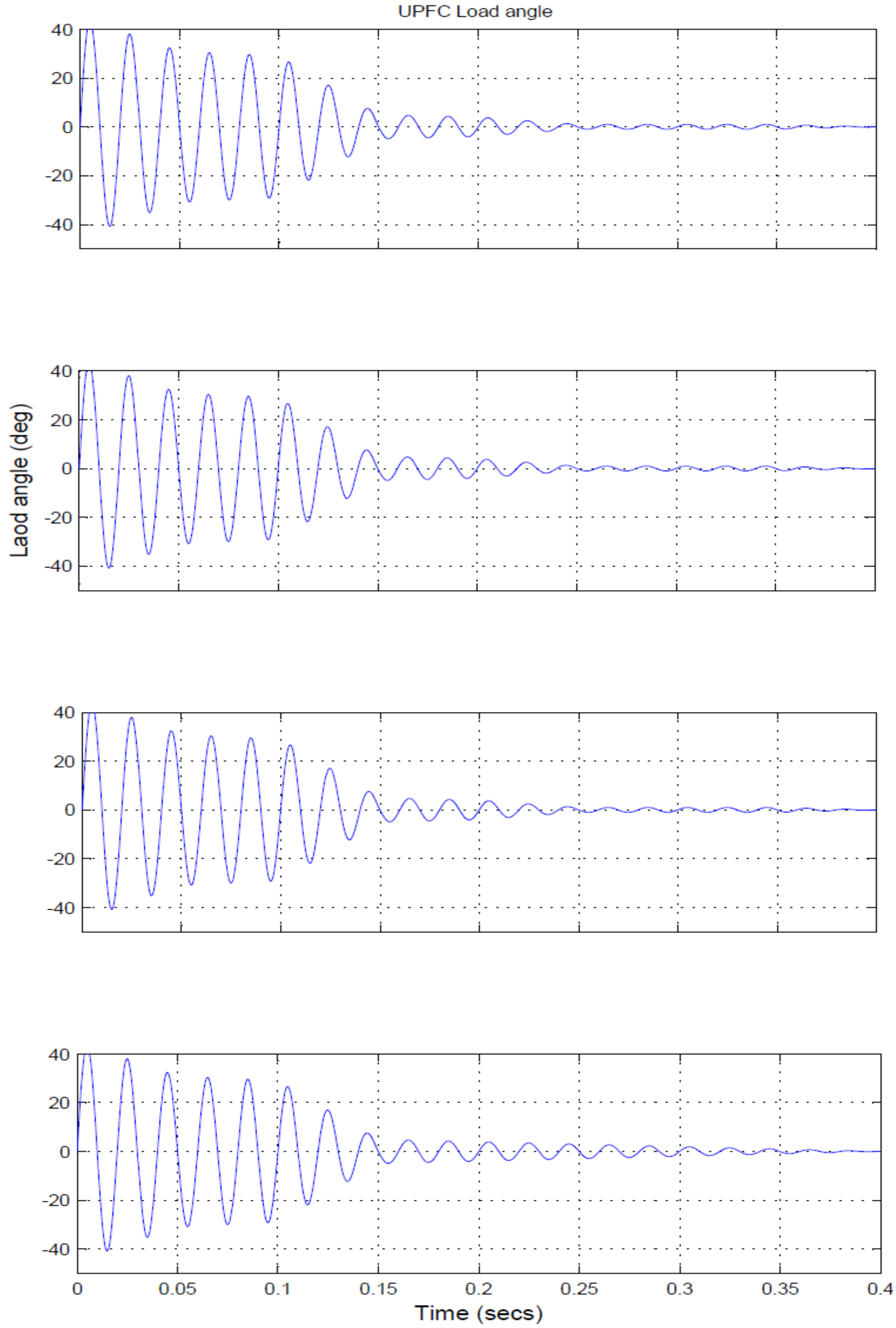
Simulink Block Diagram with UPFC:



Voltage magnitude waveforms with UPFC:



Load angle wave forms with UPFC:



Conclusion:

In this paper, transient stability enhancement of two area multi machine power system including three different FACTS devices has been compared. The various performance of UPFC in terms of voltage magnitude of generators (G1, G2 G3, and G4) and load (L1, L2) along with load angle (δ) are compared with other FACTS devices such as SSSC and STATCOM.

It is clear from simulation results that UPFC is most effective device for transient stability improvement as compared to other FACTS devices.

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