Power System Transient Stability Enhancement Using Facts Devices

Prakash Kumawat[1], Mr. Ravi Kumar Soni[2]
[2] Assistant Professor
[1, 2] Sobhasaria Group of Institutions Sikar

Abstract- *The massive growth of interconnected power systems due to increasing demand for electrical energy has given rise to numerous challenges. These include power swings and oscillations due to outages, blackouts, natural disturbances and system faults that occur along transmission lines, load and generation points. Blackouts have been witnessed in the recent years in countries around the world. These major disturbances cause power system instability and pose difficulties to system operation, planning and maintenances scheduling. In these circumstances, Flexible Alternating Current Transmission System (FACTS) controllers such as the Interline Power Flow Controller (IPFC) Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) can considerably improve transient stability thus enhance overall system stability during disturbances. Alongside the property of fast control of active and reactive power in power system, SSSC, IPFC and UPFC devices also play an additional role in transient stability enhancement and therefore play vital in system stability control. This research has delved into the specific and comparative performances of three devices as far as damping of system oscillations is concerned. It has gone further to look at voltage support and loss reduction features attributed to each device vis-à-vis damping of oscillations to enable power system planners merge the transient stability, loss reduction and voltage support characteristics of the three/ devices. In this research, use of UPFC, SSSC and IPFC FACTS controllers were applied in Transient Stability Enhancement (TSE) analysis considering dynamic environment of the standard IEEE 14 bus test system. TSE for single compensation device (SSSC) and double compensation devices (UPFC and IPFC) were accomplished successfully. The inherent properties of the three devices were deduced for TSE. The research is inspired by the need of automating power system transient stability control by outlining the distinguishing features of three FACTS devices for TSE using with focus on their compensation properties. By incorporating fast acting and appropriately located FACTS devices, the corresponding time domain responses were obtained and analysed with and without the devices. This research has effectively brought out the specific and comparative performances of three devices as far as damping of system oscillations is concerned. The results have shown significant enhancement of the transient stability when the FACTS devices are applied by considerably reducing post-fault settling time of power system as well as effectively damping network oscillations in contrast with when the devises are not applied. Synchronous machine parameters' responses for the three FACTS devices, appropriately placed, were obtained and analysed successfully.*

I. INTRODUCTION

Background

An electrical power system is a complex interconnected network comprising of numerous generators, transmission lines, variety of loads and transformers. The term Flexible Alternating Current Transmission System (FACTS) devices describes a wide range of high voltage, large power electronic converters that can increase the flexibility of power systems to enhance AC system controllability, stability and increase power transfer capability. Demand for power and ensuing development of the modern power system has led to an increasing complexity in the study of power systems, presenting new challenges to power system stability, and in particular, to the aspects of transient stability and small-signal stability [1]. Instabilities in power system are caused by insulation breakdown or collapse, long length of transmission lines, interconnected grid, changing system loads and other unforeseen disturbances in the system. These instabilities result in reduced line flows or even line trip. FACTS devices stabilize transmission systems with increased transfer capability and reduced risk of line trips.

Problem statement

Disturbances and faults in power systems pose adverse challenges. They include power swings, oscillations, loss of synchronism and outages. This circumstances causes power system problems of instability and even collapse. Voltage collapse results when active and reactive power balance equations fail or the inability of load dynamics attempt to restore power consumption beyond the capability of the transmission network and the connected generation to provide the required reactive support. Large disturbances such as a three-phase fault decelerates loads and cause instability to generating units. Further still, continuous demand in electric power system network as well as heavy loading leading to system instability and straining of the thermal limits. FACTS can be applied at these instances to avert voltage collapse and settle the swings. These controllers have varied and unique compensation features when connected to power system. Single compensating controller (series or shunt) like the series SSSC controllers and double compensating characteristics of series-series IPFC and series-hunt UPFC have to be analyzed for TSE and reactive power control (voltage injection) since FACTS devices are very expensive although very versatile.

Objectives

The main objective of this research was to investigate impacts of incorporating SSSC, UPFC and IPFC FACTS devices in a multi-machine power network on transient stability enhancement using a dynamic model with and without FACTS devices.
1.To determine suitable location of UPFC, SSSC and IPFC FACTS devices
2.To develop dynamic power system models for the FACTS devices.
3.To analyze the extent of transient stability enhancement with FACTS devices.

II. LITERATURE REVIEW

Overview

The development of FACTS devices started with the growing capabilities of power electronic components. Devices for high power levels have been made available to converters for different voltage levels. The overall starting points are network elements influencing the reactive power the parameters of power system. FACTS controllers are power electronic devices that enhance power system operation through their control attributes and injection modes [12]. The devices are mainly grouped as:

Series controllers such as Thyristor Controlled Series Compensator (TCSC), Thyristor Controlled Phase Angle Regulators (TCPAR or TCPST), and Static Synchronous Series Compensator (SSSC).

Shunt controllers such as Static Var Compensator (SVC), and Static Synchronous Compensator (STATCOM).

Combined series-series controllers and combined series-shunt controllers such as Interline Power Flow Controller (IPFC), Unified Power Flow Controller (UPFC).

2.2 Benefits of utilizing facts devices

The benefits of utilizing FACTS devices in electrical transmission systems can be summarized as follows [12]:They lead to increased loading capacity of transmission lines, prevention of blackouts, boosting generation productivity, reduce circulating reactive power, improvement of system stability limit, reduction of voltage flickers, damping of power system oscillations, guaranteeing system stability, security, availability, reliability and system economic operation [12].

III. RESULTS, DISCUSSIONS AND ANALYSIS

This chapter deals analysis of the results. The results of the FACTS controllers' location are initially outlined. Thereafter, the TSE simulation results with and without the controllers, in time domain, were subsequently obtained. The results of determination of suitable location of FACTS devices have been obtained by use of CPF method in the PSAT platform. Accordingly, dynamic TSE simulations using TDS tool incorporated in power system simulation software PSAT Toolbox are performed for the three devices. TS parameters including rotor speed, settling time and angle have been simulated and analysed. Initially, Transient Stability Enhancement (TSE) analysis for single parameters was dealt with before multiple parameters machines were considered.

Placement of facts devices

Location of facts devices using PSAT CPF

Continuation power flow simulation was done using PSAT software. The power flow results revealed that the buses with lowest voltage magnitudes are 04 and 14. The P-V nose curves for the weakest buses are illustrated in figure 1. It was deduced from the curves for the 14-bus test system, that bus 14 was the weakest bus for IEEE 14 bus system. Continuation power flow technique has been used to successfully identify weakest bus in the system to locate the devices.

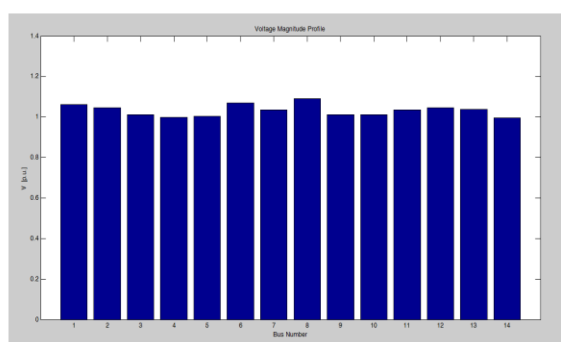

Figure 1: Voltage profile magnitude

From the above outcome, buses 04 and 14 possess the lowest voltage magnitudes of 0.998 p.u and 0.996p.u, respectively. Thus, the weakest bus is 14. The next step was to generate and plot the P-V curves for the lowest voltage buses. It was performed and curves generated effectively. The curves are illustrated in figure 4.2.

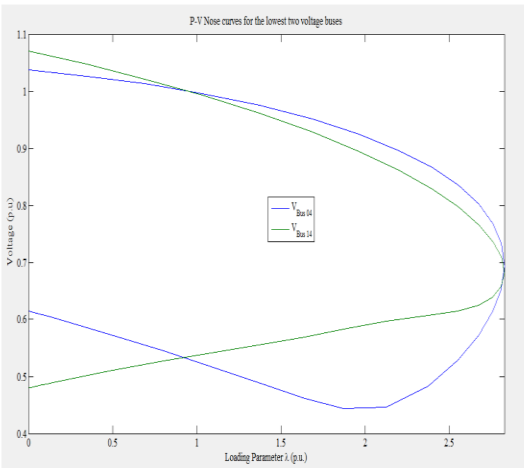

Figure 2: Voltage P-V nose curves for two low voltage buses in IEEE 14 bus system

The figure above shows the changes of bus voltage with the loading factor lambda (λ) for IEEE 14 bus test system. From the plots of buses 04 and 14, it is deduced that bus number 14 is the most insecure bus as the voltage at each reactive load of bus 14 is minimum. Thus, this is the best location for the three FACTS devices for TDS. The P-V is plot of variation of bus voltage with the loading factor.

Analysis for a single synchronous generator

TSE simulations were carried in TDS tool embedded in MATLAB® PSAT toolbox. The simulations were carried out initially without FACTS controllers. Later, simulations with three FACTS controllers were also done and the results recorded. Though there are numerous TSE variables were done in the development of this work, the thesis can have very many plots. For purposes of this work, rotor speed, q- axis voltage component behind transient reactance, generator power and rotor angle and speed parameters were selected for time domain simulations (TDS) and analysis. TDS have been carried out to evaluate the effectiveness of the three FACTS device models in this work. Three-phase fault is has been applied to provide the source of disturbance with fault time occurring at 1.00 second cleared time at 1.25 seconds with and without FACTS. Single parameter-responses for singular machines were obtained and studied initially before consideration of multiple machines.

4.4 Analysis with UPFC

1. Rotor speed responses

a. Rotor Speed Response of Generator 1

Without UPFC, the oscillations of the rotor speed (angular frequency) of synchronous generator 1 settle to steady state condition after 40 seconds as observed in figure 4.3. The damping to steady state operating condition of post fault oscillations is significantly enhanced by UPFC FACTS device. The UPFC damps the oscillations at a time of about 25 seconds as shown in figure 4.4.

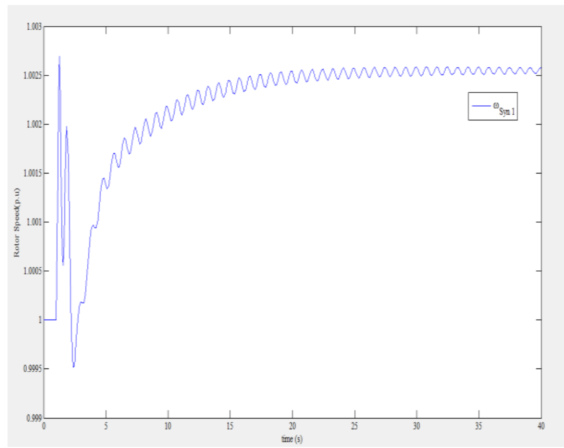

Figure 3: Generator 1 rotor speed with fault applied at bus 4

Figure 4: Generator 1 rotor speed with fault applied at bus 4 and UPFC close to 14.

Rotor Speed Response of Generator 5

For synchronous generator number 5, UPFC damps the oscillations of the rotor speed (angular frequency) of synchronous generator 5 after about 25 seconds. The damping of post fault oscillations to steady state operating condition is significantly achieved faster with UPFC FACTS device. The oscillations phenomena with and without UPFC are shown below, in figures 5 and 6 respectively.

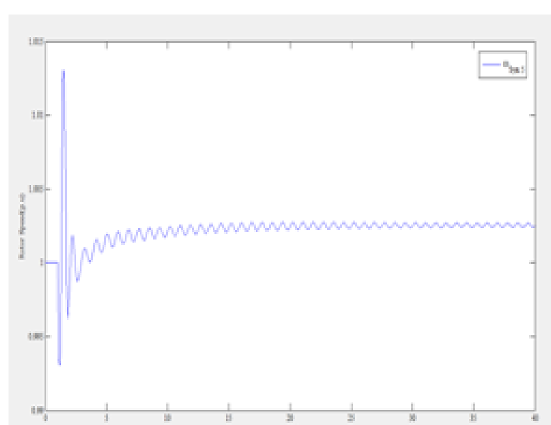

Figure 5: Generator 5 rotor speeds with fault applied at bus 4

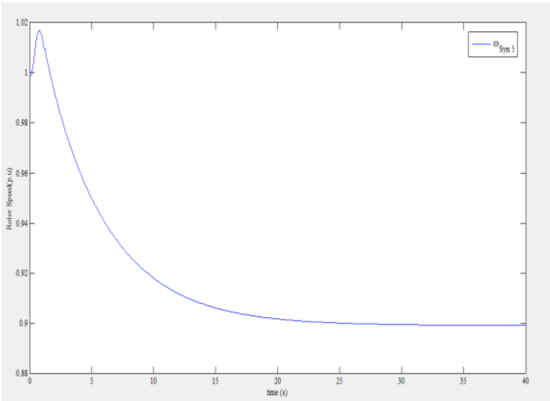

Figure 6: Generator 5 rotor speed with fault at bus 4 and UPFC at Bus 14

Generator 3 real power response

Real power, P, response of synchronous generator 3 without UPFC is shown in figure 7. Figure 4.8 below displays the response with UPFC. Oscillations after fault clearance at 1.25 seconds remain unstable and go beyond the simulations ending time set at 40 seconds. However, with UPFC the swings are damped to steady sate operating condition at about 15 seconds at real power magnitude of about 0.4 p.u.

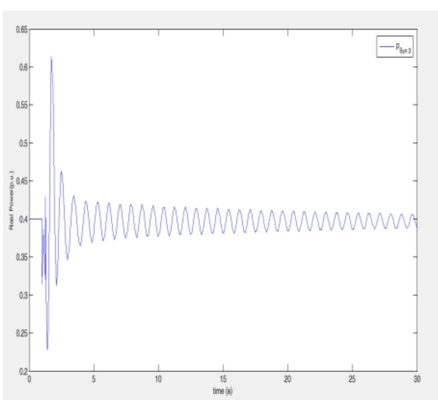

Figure 7: Generator 3 real power response with fault applied at bus 4

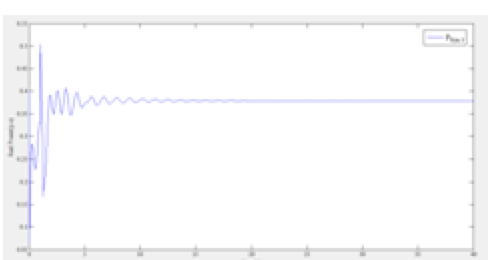

Figure 8 Generator 3 real power response, fault at bus 4 with UPFC at bus 14.

4.5 Analysis with SSSC

1) Rotor speed response

Rotor Speed Response of Generator 1

When the SSSC FACTS was not connected, the oscillations of the rotor speed, also referred to as angular frequency, of synchronous generator 1 are remain un-damped for the simulation time set at 40 seconds as observed in figure 9. The damping of post fault oscillations is improved considerably by SSSC FACTS device. The device damps the oscillations in about 25 seconds as shown in figure 10 shown below

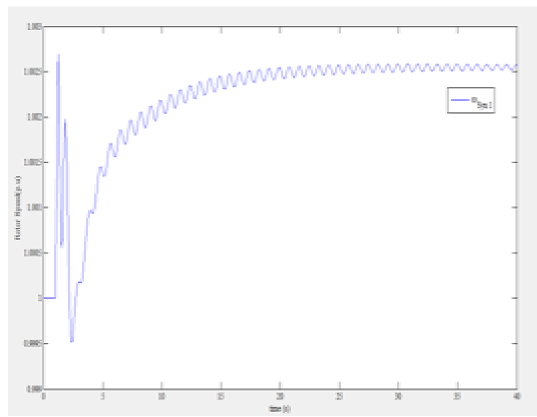

Figure 9: Generator 1 rotor speed with fault applied at bus 4

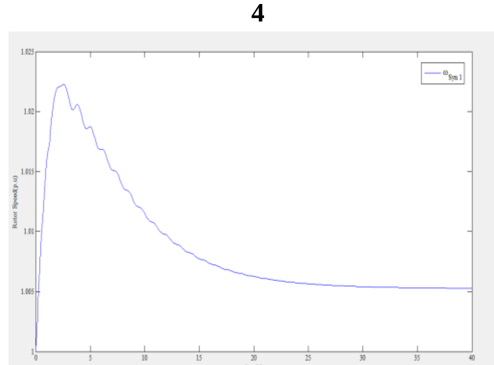

Figure 10: Generator 1 rotor speed, fault at bus 4 and SSSC at bus 14

Generator 3 real power response

Real power, P, response of synchronous generator 3 without UPFC is shown in figure 11. Figure 12 displays the response with SSSC. Oscillations after fault clearance at 1.25 seconds continue unsettled and go beyond the simulations ending time set at 40 seconds. However, with SSSC the swings settle to steady state operating condition at about 22 seconds at real power magnitude of about 0.4 p.u.

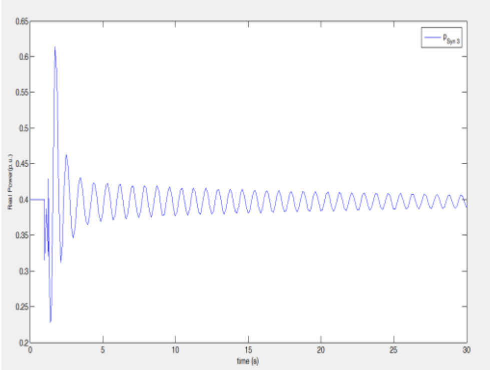

Figure 11: Generator 3 real power response, fault applied at bus 4

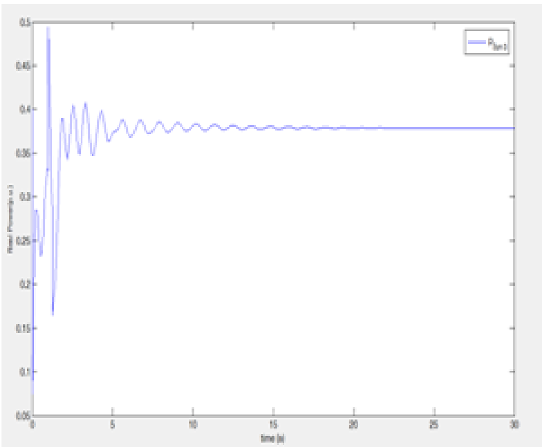

Figure 12: Generator 3 real power, fault applied at bus 4 and SSSC at Bus 14.

Analysis with IPFC

Rotor speed responses

I. Rotor Speed Response of Generator 1

When the IPFC FACTS device is not connected at the weakest buses, the response of the rotor speed of synchronous generator 1 oscillate beyond the simulation time of 40 seconds as observed in figure 4.13. The damping of post fault oscillations is improved significantly by placing independent IPFC FACTS device at bus 04 and 14. The device damps the oscillations giving rotor speed settling time of about 25 seconds as shown in figure 14 shown below.

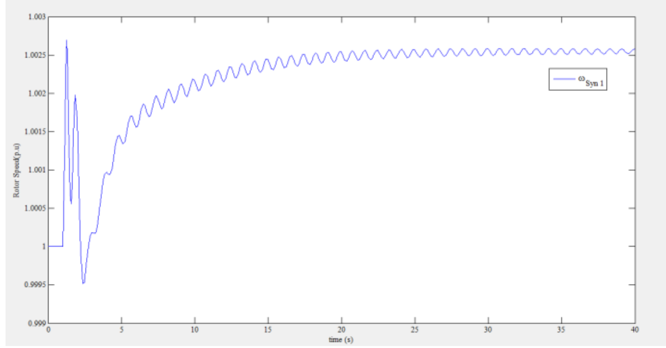

Figure 13: Generator 1 rotor speed for IEEE-14-bus system with fault at bus 4

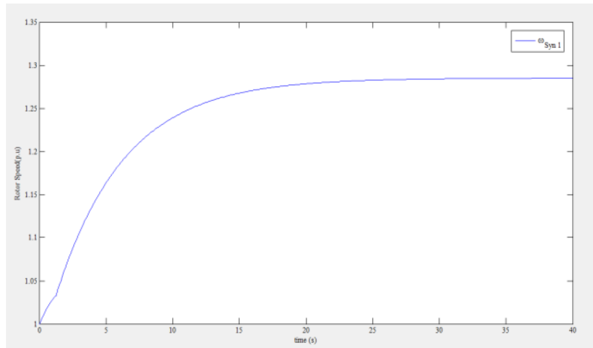

Figure 14: Generator 1 rotor speed with fault applied at bus 4 and IPFC

Generator 4 reactive power response

A similar arrangement for reactive power response of synchronous generator 4 without IPFC is shown in figure 15. Figure 16 is an illustration of Q response with IPFC. Oscillations after fault clearance at 1.25 seconds swung unstably beyond the simulations ending time set at 30 seconds. However, with IPFC of independent configuration (dual SSSC) the swings are damped steady state operating condition at about 5 second as shown in figure 16. It can be observed that after fault clearance, oscillations of rose to a peak of about 0.75p.u. IPFC has been utilized to damp power transients efficiently as shown in figure 16.

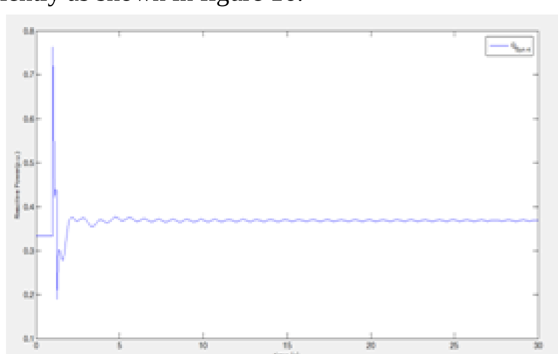

Figure 15: Generator 4 reactive power response with fault applied at bus 4

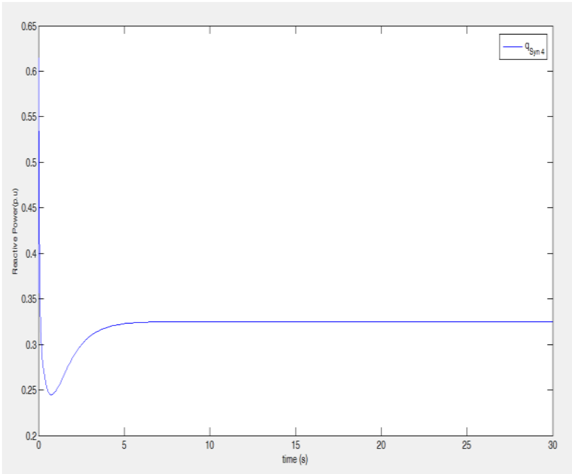

Figure 16: Generator 4 reactive power response with fault and IPFC at bus 14

Analysis for more than one synchronous generator

While considering thee three generators, Time Domain Simulations are carried out to assess the effectiveness of the three FACTS device models developed in this work. Three-phase fault is has been simulated to provide the source of disturbance with fault time occurring at 1.00 second cleared time at 1.25 seconds with and without FACTS.

Generator rotor angle behaviour

Figures 17 to 20 illustrate the rotor angle behavior for three synchronous generators 2, 4 and 5. They show the simulation results of rotor angle responses. Without using the FACTS devices, the rotor angles keeps accelerating and go out of synchronism as shown in figure 4.17. When the dynamic model with the FACTS is simulated, the responses start decreasing. Generally, for the three generators, the three FACTS decrease the acceleration of the rotor angles. For all of the three cases, the rotor angle of generator 5 decreases the most followed by angle of generator 4 and the least decreasing rotor angle is that of the generator 2. The decrease is as a result of damping characteristics of FACTS devices connected. It is more pronounced with IPFC than SSSC and UPFC.

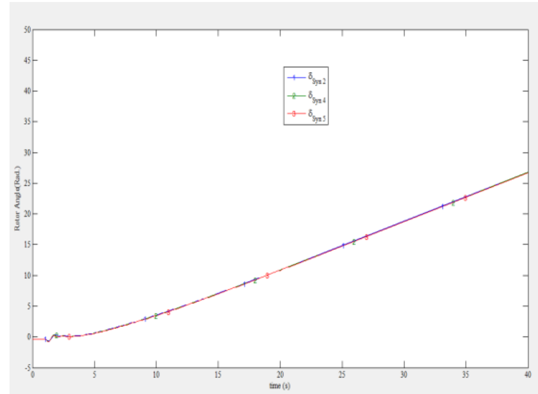

Figure 17: Rotor angle responses without FACTS, fault at bus 04

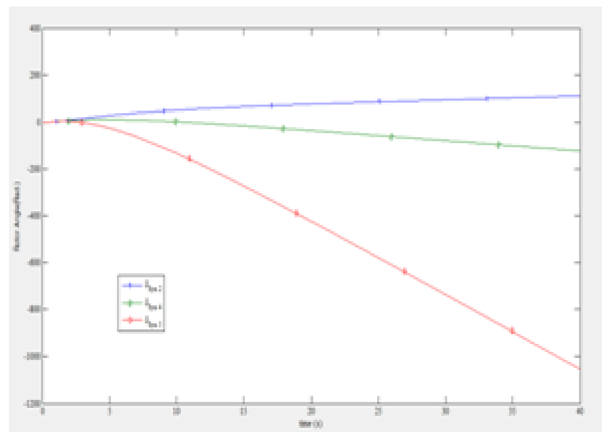

Figure 18: Rotor angle responses UPFC FACTS device, fault applied at bus 04

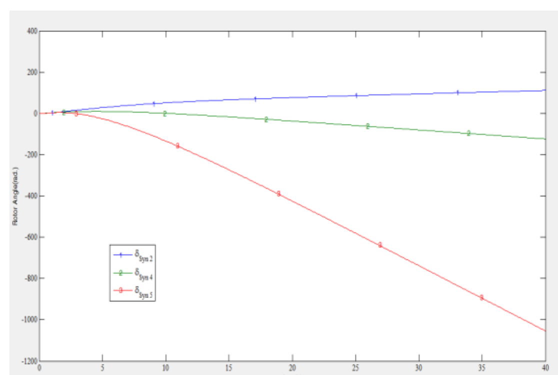

Figure 19: Rotor angle responses for SSSC, fault applied at bus 4

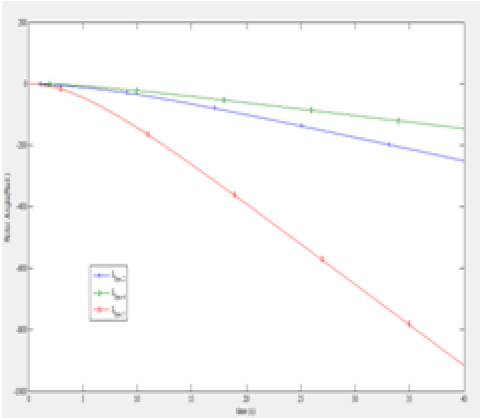

Figure 20: Rotor angle responses with IPFC, fault applied at bus 4.

Q-axis component of voltage behind transient reactance responses

Responses of quadrature axis component of voltage behind transient reactance for the three synchronous generators with and without FACTS are displayed in figure 4.22 to figure 4.25 below. With FACTS, the post fault oscillations are damped. Overall, for the three generators, without facts the responses oscillate beyond the simulation time. With FACTS, the oscillation is damped as follows, for UPFC and SSSC, generator two and four at about 4 seconds and generator 5 at about 12 seconds. For IPFC devices, the oscillations are damped as follows; generators 2 and 4 at about 4 seconds and generator 5 at about 8 seconds. As observed, IPFC provides overall better damping characteristics.

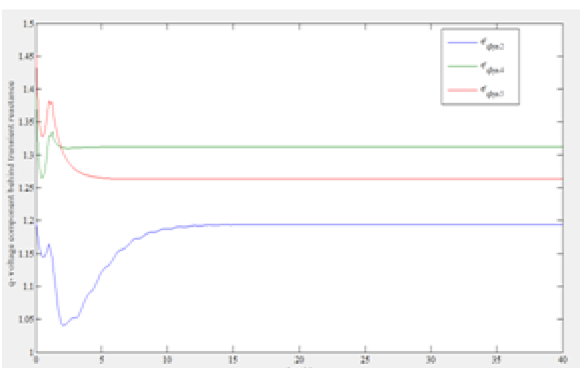

Figure 21: q-axis voltage component behind transient reactance responses without FACTS

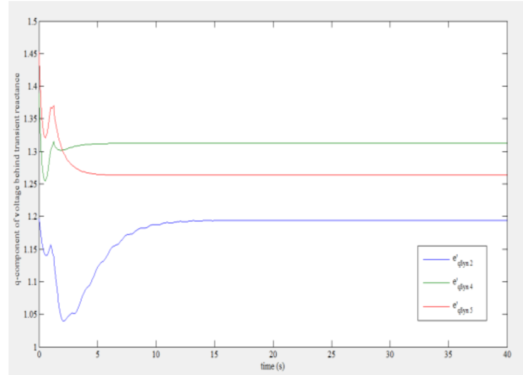

Figure 22: q-axis voltage component behind transient reactance responses with UPFC

Figure 23: q-axis voltage component behind transient reactance responses with SSSC

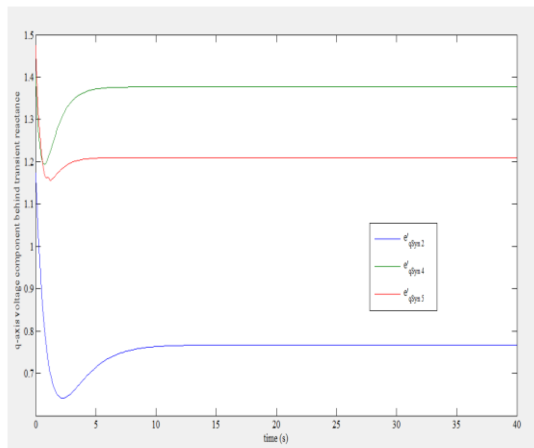

Figure 24: q-axis voltage component behind transient reactance responses with IPFC

Voltage stability and loss reduction with FACTS

FACTS controllers: SSSC, IPFC and UPFC significantly enhance voltage stability. It is evident that IPFC provides better voltage support than UPFC and SSSC as shown in table 2 and figure 25 below. All the three FACTS reduce power losses in poor networks with SSSC and UPFC by 0.03 p.u and IPFC by 0.14p.u hence IPFC is best suited for loss reduction applications among the three devices.

Table 4.2: Voltage magnitude and real power losses

VOLTAGE MAGNITUDE AND REAL POWER LOSSES FROM PF REPORT					
Bus (Voltage Mangitude)	Without fault and Device	Fault at Bus 4 Without Device	Fault at Bus 4 With SSSC	Fault at Bus 4 With UFPC	Fault at Bus 4 With IPFC
	[p.u.]	[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 4	0.978	0.975	0.992	0.992	0.992
Bus 5	0.987	0.984	0.999	0.999	0.999
Bus 14	0.986	0.983	0.995	0.995	1.005
Real Power Losses		0.294	0.291	0.291	0.280

IV. CONCLUSIONS

The best location was determined using bus voltage magnitude profiles. The bus with the least voltage profile or magnitude is best location. The standard IEEE 14 bus test system was used in this work. The suitable location/placement has been effectively implemented through CPF P-V curves. FACTS devices best location in IEEE 14 bus system was found to be bus 14 for placement of the three FACTS controllers (UPFC, SSSC and IPFC). Time domain simulations were performed on dynamic IEEE-14 bus system model. The analysis was done through specific and comparative study with and without the three devices. It was observed that when three phase fault occurs at bus 4 near the generator, synchronous machine oscillations generated do not settle to steady state condition and makes the system unstable for the simulation time under consideration.

Although individual compensations differ, all the three FACTS devices not only damp the system oscillations of the multimachine system but also reduce the oscillations transient periods accordingly. The transient state period of rotor speed responses is longer than those of voltage responses hence FACTS provide better support to system voltages compared to other parameters like rotor angle. To achieve steady state operating condition after disturbances, UPFC and SSSC exhibited similar oscillations damping characteristics for the variables studied. SSSC and UPFC have better damping features for reactive power response, while IPFC provide better damping for generator sub transient voltages, rotor angle and real power oscillations compared than UPFC and SSSC. It's evident that the damping characteristics of the IPFC are comparatively superior to those of SSSC and IPFC. It is unequivocal from this work that FACTS controllers play two key roles in power networks. Firstly, FACTS have the merits of power flow control through injection and/or absorption of voltage real and reactive power. Secondly, they enhance transient stability. Thus, FACTS can be used to complement conventional power system stabilizers since they have the extra advantage of damping oscillations after occurrence of a fault. Thus, the simulations studies revealed that oscillations present after occurrence of fault greatly reduces after the best placement of UPFC, SSSC and IPFC. It is deduced that series compensators have superior damping of oscillations' properties compared to shunt ones.

It's further construed that for the three FACTS controllers, IPFC provides comparatively better voltage stability enhancement than UPFC and SSSC. All the three FACTS reduce power losses in poor networks with SSSC and UPFC by 0.03p.u and IPFC by 0.14p.u hence IPFC is best placed for loss reduction applications than the other three FACTS controllers.

REFERENCES

[1] A. Kumar and S. B. Dubey, "Enhancement of Transient Stability in Transmission Line Using SVC Facts Controller", *International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878*, Volume-2,Issue-2, May 2013

[2] M.Karthik and P.Arul, "Optimal Power Flow Control Using FACTS Devices,'' *International Journal of Emerging Science and Engineering (IJESE) ISSN: 2319–6378*, Volume-1, Issue-12, October 2013

[3] C. Makkar and L. Dewan**, "**Transient Stability Enhancement using Robust FACTS Controllers- A Brief Tour", *Canadian Journal on Electrical & Electronics Engineering* Vol. 1, No. 7, December 2010

[4] A. Satheesh and T. Manigandan**, "**Maintaining power system stability with FACTS controller using bees algorithm and NN", *Journal of Theoretical and Applied Information Technology***,** Vol. 49 No.1, 10th March 2013

[5] M. Krishna and P. K. Rao, "Transient Stability Enhancement in Power System Using DSSC and DSSC with FLC", *Journal of Electrical and Electronics Engineering (IOSR-JEEE) ISSN: 2278-1676, PP 15-24* *www.iosrjournals.or*, Volume 3, Issue 5 (Nov. - Dec. 2012)

[6] J. Machowski, J. W. Bialek and J. R. Bumby, *Power System Dynamics and Stability*, John Wiley & Sons Ltd, 1997, ISBN, 1997.

[7] M. A. Abido, "Power System Stability enhancement using FACTS controllers: a review", *The Arabian Journal for Science and Engineering*, Volume 34, Number 1B, April 2009

[8] K. Venkateswarlu and C. S. Babu, "Analysis and Enhancement of Transient Stability using Shunt Controlled FACTS Controller", International Journal of Engineering Sciences Research-IJESR, http://technicaljournals.org, ISSN: 2230-8504; e-ISSN-2230-8512, Volume 01, Issue 02, May, 2011