Application of FACTS Technology in Power Systems for Mitigation of Sub Synchronous Oscillation Damping

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Abstract-*In its most general expression, the FACTS concept is based on the substantial incorporation of power electronic devices and methods into the high-voltage side of the network, to make it electronically controllable (IEEE/CIGRE, 1995). Many of the ideas upon which the foundation of FACTS rests evolved over a period of many decades. Nevertheless, FACTS, an integrated philosophy, is a novel concept that was brought to fruition during the 1980's at the Electric Power Research Institute. FACTS looks at the ways of capitalizing on many breakthroughs taking place in the area of high-voltage and high current power electronics, aiming at increasing the control of power flows in the high voltage side of the network during both steady-state and transient conditions.*

Power electronic devices have had a revolutionary impact on the electric power systems around the world. The availability and application of thyristors has resulted in a new breed of thyristor-based fast operating devices devised for control and switching operations. This paper deals with basic operating principles of FACTS devices and provides detailed discussions about the structure, operation, and modeling of the SVC, TCSC, STATCOM and the UPFC.

I. TYPES OF FACTS CONTROLLERS

FACTS controllers can be broadly divided into four categories, which include series controllers, shunt controllers, combined series-series controllers, and combined series-shunt controllers.

II. PRINCIPLE OF THE SERIES CONTROLLERS

A series controller may be regarded as variable reactive or capacitive impedance whose value is adjusted to damp various oscillations that can take place in the system. This is achieved by injecting an appropriate voltage phasor in series with the line and this voltage phasor can be viewed as the voltage across an impedance in series with the line. If the line voltage is in phase quadrature with the line current, the series controller absorbs or produces reactive power, while if it is not, the controllers absorb or generate real and reactive power. Examples of such controllers are Static Synchronous Series Compensator (SSSC), Thyristor-Switched Series Capacitor (TSSC), Thyristor-Controlled Series Reactor (TCSR), to cite a few. They can be effectively used to control current and power flow in the system and to damp oscillations of the system.

III.PRINCIPLE OF THE SHUNT CONTROLLERS

Shunt controllers are similar to the series controllers the difference being that they inject current into the system at the point where they are connected. A variable shunt impedance connected to a line causes a variable current flow by injecting a current into the system. If the injected current is in phase quadrature with the line voltage, the controller adjusts reactive power while if the current is not in phase quadrature, the controller adjusts real power. Examples of such systems are Static Synchronous Generator (SSG), Static Var Compensator (SVC). They can be used as a good way to control the voltage in and around the point of connection by injecting active or reactive current into the system.

IV. PRINCIPLE OF THE COMBINED SERIES – SERIES CONTROLLERS

A combined series-series controller may have two configurations. One configuration consists of series controllers operating in a coordinated manner in a multi line transmission system. The other configuration provides independent reactive power control for each line of a multi line transmission system and, at the same time, facilitates real power transfer through the power link. An example of this type of controller is the Interline Power Flow Controller (IPFC), which helps in balancing both the real and reactive power flows on the lines.

V. PRINCIPLE OF THE COMBINED SERIES – SHUNT CONTROLLERS

A combined series-shunt controller may have two configurations, one being two separate series and shunt controllers that operate in a coordinated manner and the other one being an interconnected series and shunt component. In each configuration, the shunt component injects a current into the system while the series component injects a series voltage. When these two elements are unified, a real power can be exchanged between them via the power link. Examples of such controllers are UPFC and Thyristor- Controlled Phase-Shifting Transformer (TCPST). These make use of the advantages of both series and shunt controllers and, hence, facilitate effective and independent power/current flow and line voltage control.

VI. EXAMPLE OF FACTS CONTROLLERS FOR ENHANCING POWER SVSTEM CONTROL

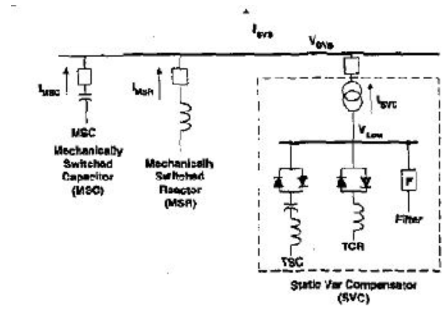
*Static Synchronous Compensator (STATCOM) – Controls Voltage.
*Static Var Compensator (SVC) –Controls Voltage.
*Unified Power Flow Controller (UPFC)
*Couvenible Series Compensator (CSC)
*Inter-phase Power Flow Controller (IPFC)
*Static Synchronous Series Controller (SSSC)
*Thyristor Controlled Series Compensator (TCSC)-Controls Impedence.
*Thyristor Controlled Phase Shifting Transformer (TCPST) – Controls angle.
*Super Conducting Magnetic Energy Storage (SMES)- Controls Voltage and Power.

VII. OVERVIEW OF FACTS CONTROLLERS

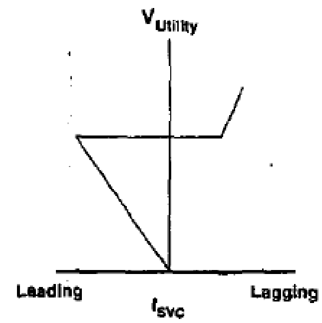
7.1 Static Var Compensator:

A static VAR compensator is used to for providing reactive power on high-voltage electricity transmission networks.. The SVC is designed to bring the system closer to unity power factor. If the power system's reactive load is capacitive (leading), the SVC will use reactors to consume VARs from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage. They also may be placed near high and rapidly varying loads, such as arc furnaces, where they can smooth flicker voltage. It is known that the SVCs with an auxiliary injection of a suitable signal can considerably improve the dynamic stability performance of a power system .

The basic circuit for Static Var Compensator is given below:



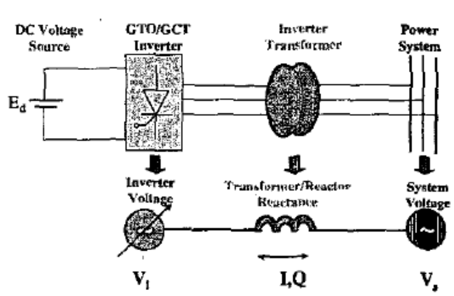
The voltage current characteristics:



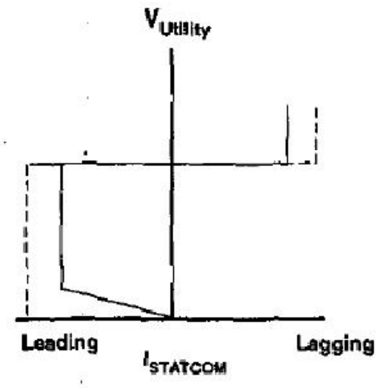
7.2 Static Synchronous Compensator:

A static synchronous compensator (STATCOM) is a member of FACTS family is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. There are however, other uses, the most common use is for voltage stability.From the power system dynamic stability viewpoint, the STATCOM provides better damping characteristics than the SVC as it is able to transiently exchange active power with the system.

The basic circuit for a Static Synchronous



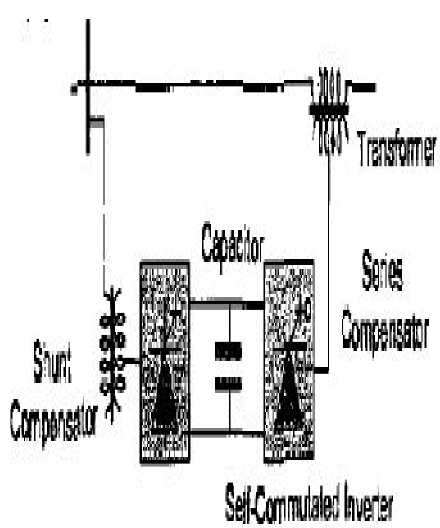
The voltage current characteristics



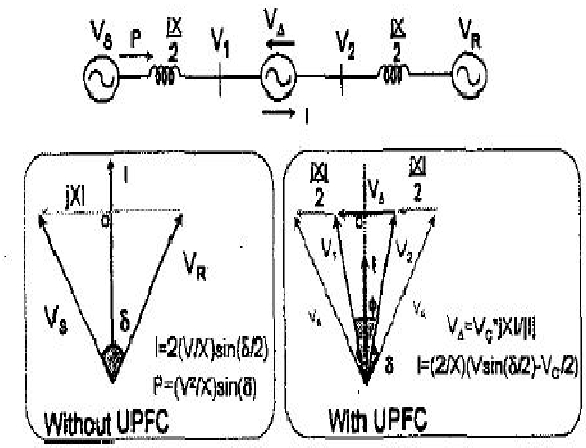
7.3 Unified Power Flow Controller:

A unified power flow controller (UPFC) is the most promising device in the FACTS concept. It has the ability to adjust the three control parameters, *i.e.* the bus voltage, transmission line reactance, and phase angle between two buses, either simultaneously or independently. A UPFC performs this through the control of the in-phase voltage, quadrature voltage, and shunt compensation. The UPFC is the most versatile and complex power electronic equipment that has emerged for the control and optimization of power flow in electrical power transmission systems. It offers major potential advantages for the static and dynamic operation of transmission lines. The UPFC was devised for the real-time control and dynamic compensation of ac transmission systems, providing multifunctional flexibility required to solve many of the problems facing the power industry. Alternatively, it can independently control both the real and reactive power flow in the line unlike all other controllers.

The basic circuit of UPFC:



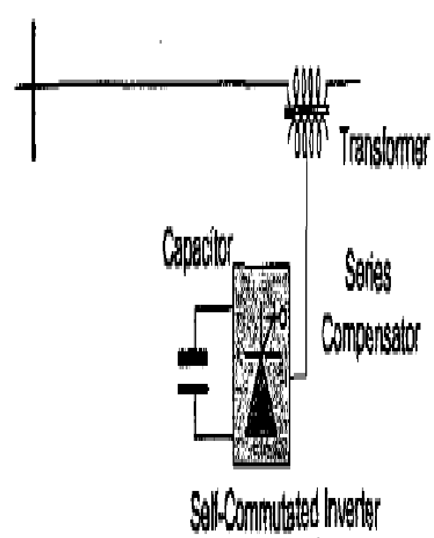
UPFC phasor diagram and the impact in power systems:



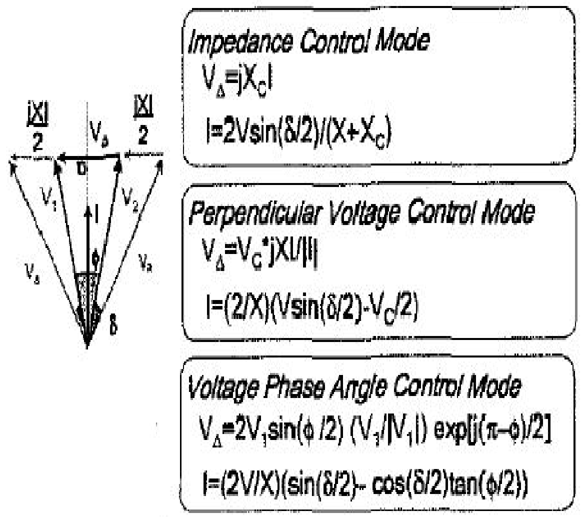
7.4 Static synchronous series compensator:

This device work the same way as the STATCOM. It has a voltage source converter serially connected to a transmission line through a transformer. It is necessary an energy source to provide a continuous voltage through a condenser and to compensate the losses of the VSC. A SSSC is able to exchange active and reactive power with the transmission system. But if our only aim is to balance the reactive power, the energy source could be quite small. The injected voltage can be controlled in phase and magnitude if we have an energy source that is big enough for the purpose. With reactive power compensation only the voltage is controllable, because the voltage vector forms 90º degrees with the line intensity. In this case the serial injected voltage can delay or advanced the line current. This means that the SSSC can be uniformly controlled in any value, in the VSC working slot.

The basic circuit of SSSC*:*



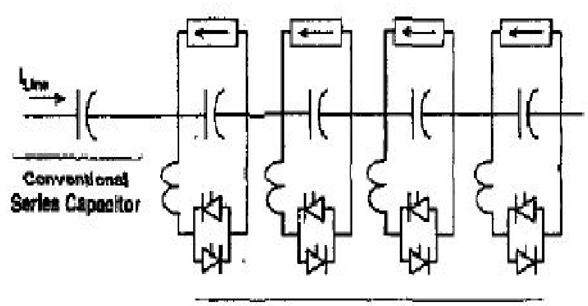
The control modes of series compensator



7.5 Thyristor Controlled Series Compensator:

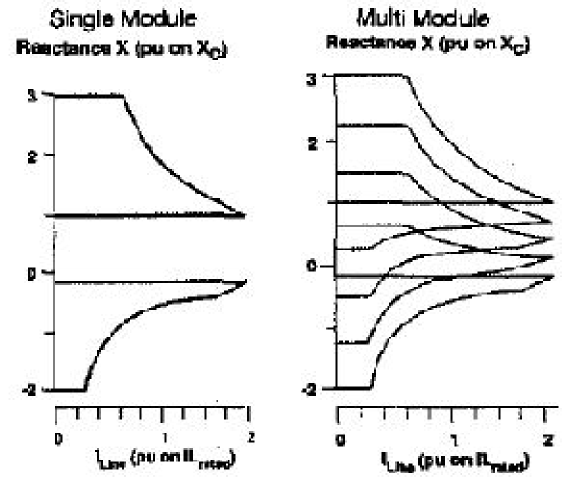
TCSC controllers use thyristor-controlled reactor (TCR) in parallel with capacitor segments of series capacitor bank. The combination of TCR and capacitor allow the capacitive reactance to be smoothly controlled over a wide range and switched upon command to a condition where the bi-directional thyristor pairs conduct continuously and insert an inductive reactance into the line. TCSC is an effective and economical means of solving problems of transient stability, dynamic stability, steady state stability and voltage stability in long transmission lines. TCSC, the first generation of FACTS, can control the line impedance through the introduction of a thyristor controlled capacitor in series with the transmission line. A TCSC is a series controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range. The functioning of TCSC can be comprehended by analyzing the behavior of a variable inductor connected in series with a fixed capacitor

The basic circuit for a Thyristor Controlled Series Compensator (TCSC).



Multi-Module TCSC

The impedance current (X-I) characteristics for both a single-module and multi-module controllers



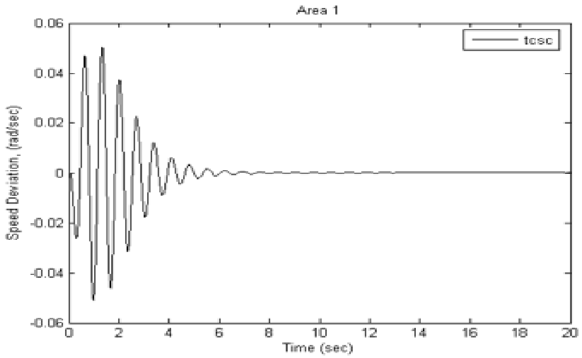
One of the serious power system problems is spontaneous system oscillations at low frequency. The low frequency oscillations are related to the small signal stability of a power system are detrimental to achieve to goal of maximum power transfer and power system security. Using damper windings on the generator rotors and turbines to control these oscillations fails as power system began to operated closer to the stability limit.In the large interconnected power system another concern was the transfer of large amount of power across extremely long transmission lines. The addition of supplementary controller in to the control loop provides the means to reduce the inhibitory effects of low frequency oscillations.

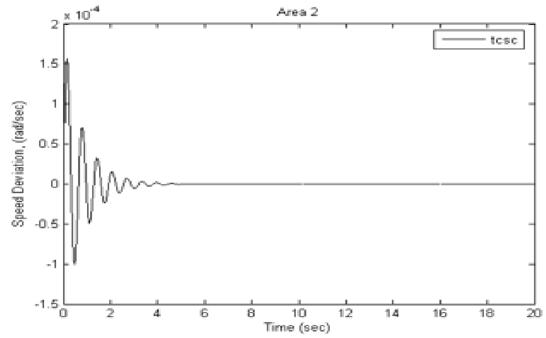
A power system may lose its stability due to the lack of damping or inadequate synchronizing torque as shown in fig 4a and 4b respectively. The sustained low-frequency oscillations of a large electric power system are due to lack of damping of the system mechanical mode. A synchronous machine may have mechanical damping adequate for the machine itself, but not sufficient for the machine operating in a large electric power system. Therefore, supplementary damping like incorporating FACTS devices is must.

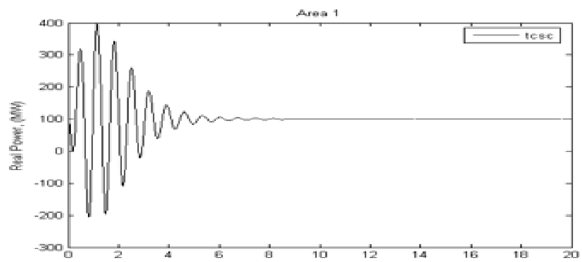
XI. RESULTS

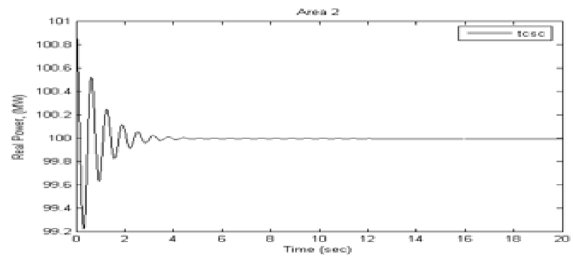
Simulation is done in MATLAB/SIMULINK and the wave forms are analyzed for the both series and shunt type of FACTS devices. Damping of oscillations of power angle, real power, rotor kinetic energy and speed deviation TCSC,SVC and STATCOM FACTS controller and the results are analysed.

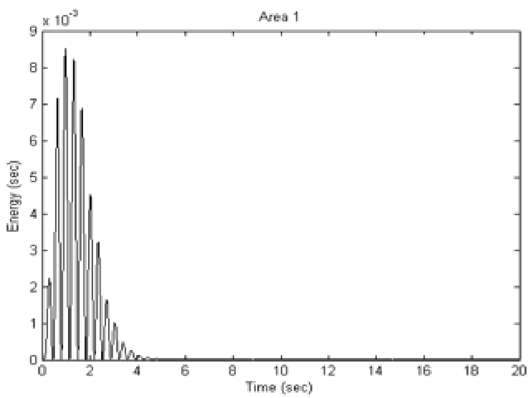
9.1 Results of the damping of power system parameters using TCSC as controller:

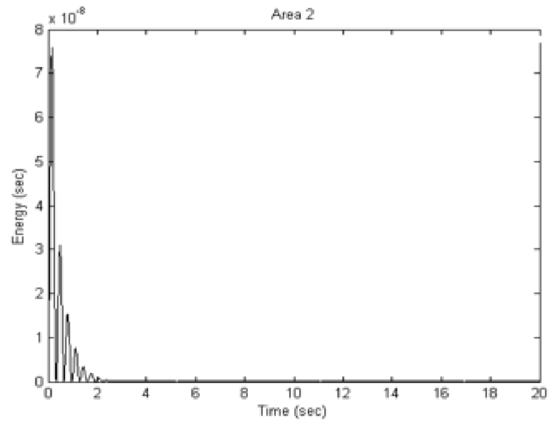




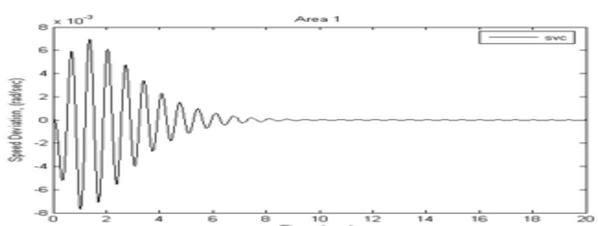


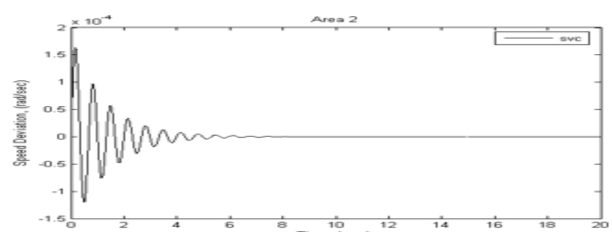


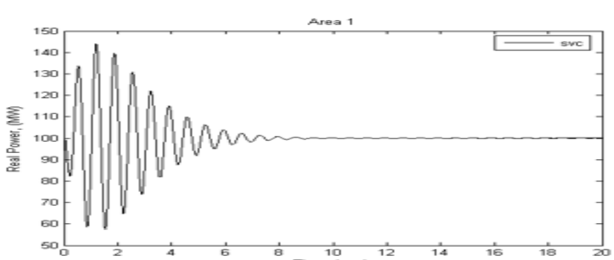


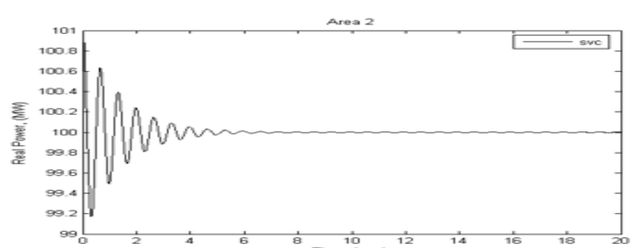


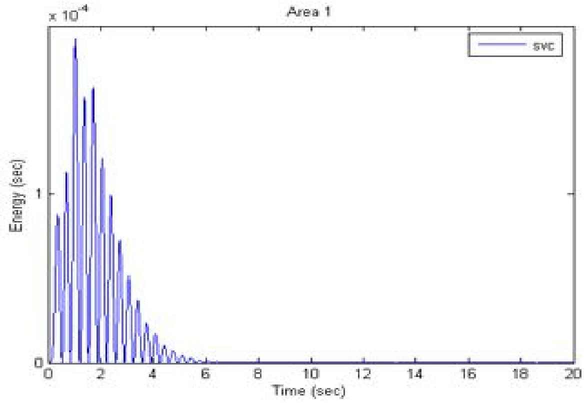
Results of the damping of power system parameters using SVC as controller:

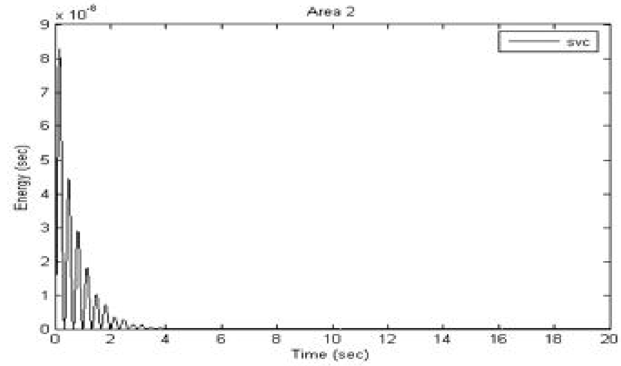




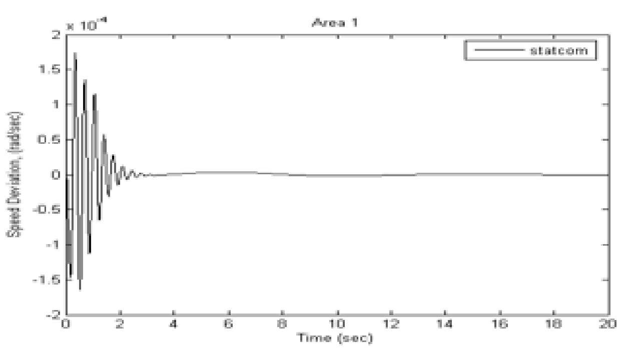


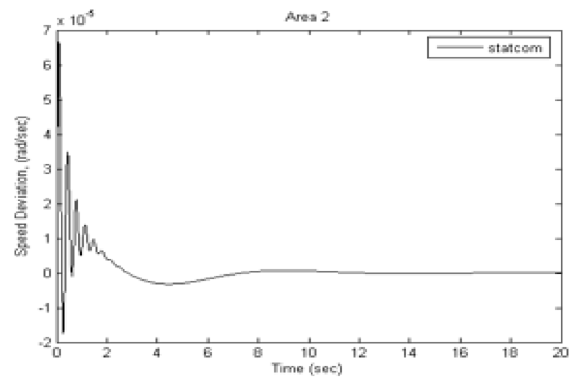


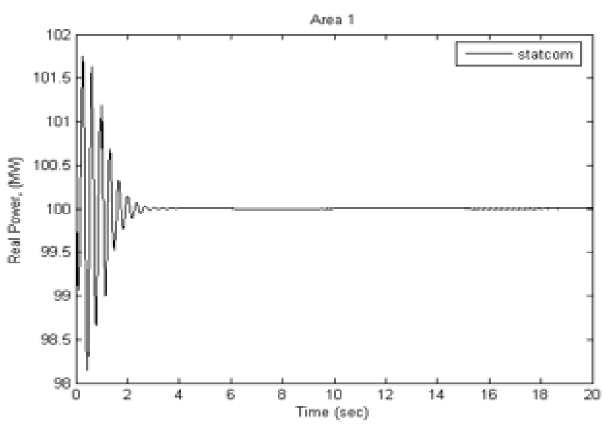


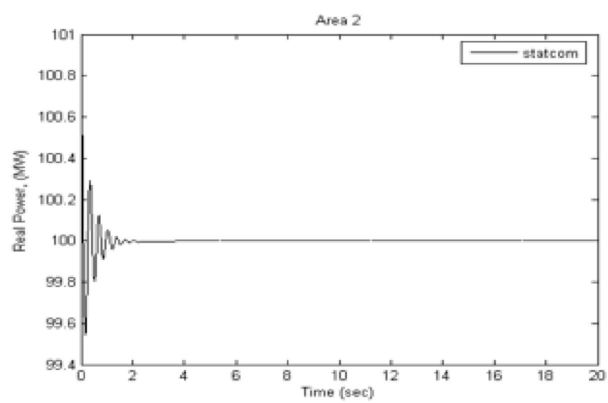


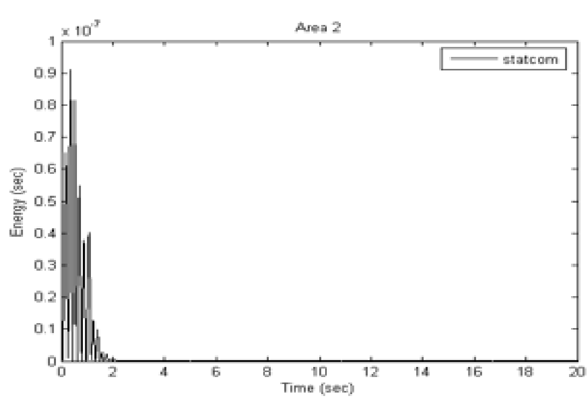
Results of the damping of power system parameters using STATCOM as controller

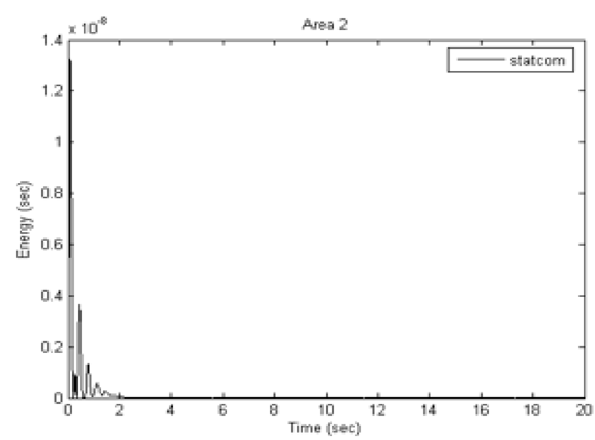












X. CONCLUSION

A new control strategy involving series and shunt type of FACTS devices to effectively damp out low frequency oscillations so as to improve multi area power system stability is proposed and tested in this thesis work. The results of simulation study carried out on a sample two area four generator power system have clearly demonstrated the effectiveness of the proposed technique both in terms of quick response and low amplitude of oscillations of the crucial parameters like rotor speed deviation, rotor kinetic energy deviation and active real power outputs of generators in area 1 as well as in area 2.

All the results are with reference to a step load decrement of 0.01 p.u (1 MW).Further more It is also observed that, out of the three control strategies namely TCSC based strategy, SVC based strategy, and STATCOM based strategy. The best performance is obtained in the case of STATCOM based control strategy.

REFERENCES

[1] N.G.Hingorani “High Power Electronic and Flexible AC Transmission System” IEEE power engineering review, July, 1988.

[2] K.R.Padiyar , A. Lakshmi Devi “ Control and Simulation of Static Condenser”IEEE transactions on power systems, 1994.

[3] K.R.Padiyar,M.K.Geetha “ A novel power flow controller for controlled series compensation” IEE conference publication , AC and Dc Power transmission, may 1996.

[4] N.G . Hingorani and L.Gyugyi,”Understanding FACTS controllers and technology of flexible AC transmission system” IEEE press publishers, 2000.

[5] Li Chun , Jiang Qirong, “Study of STATCOM Controller for Swing Damping Improvement” IEEE transactions on power systems , 2000.

[6] S.C Misra, V.K.Prashar “Application of TCSC –Major role to play in Synchronous Interconnection Between Two region” IEEE transactions on power delivery.2000.

[7] M.Moghavvemi, M.O. Faruque “Effects of FACTS devices on static Voltage Stabilty” IEEE transactions on power systems, 2000.

[8] Dr.B.K.Keshavan, Nagesh Prabu “Damping of Subsynchronous Oscillations Using STATCOM- A FACTS Device” IEEE transactions on power systems, 2001.

[9] Alberto D.Del Rosso ,” A study of TCSC controller Design for Power System Stability Improvement” IEEE transactions on power systems, vol 188, NO 4, Nov 2003

[10] Li Zhang,Y.Liu,Steve Eckroad “ Bulk power system low frequency oscillation suppression by FACTS” Electric Power Research Institute,2003.

[11] Nadarajah Mithulanathan,” Comparison of PSS , SVC , STATCOM Controllers for Damping Power System Oscillations. IEEE transactions on power systems , vol 18, May, 2003..

[12] Rusejla Sadikovic,Petr Korba ”Application of FACTS Devices for Damping of Power System Oscillations” IEEE transactions on power systems, vol 188, NO 4, Nov 2003.

[13] M.H Haque “Improvement of First Swing Stability Limit by Utilizing Full Benefit of Shunt FACTS Devices “IEEE transactions on power systems, March,2004.