PSC 2006

13 – 15 Nov. 2006 Tehran - Iran

Static Synchronous Compensator (STATCOM) modeling and analysis Techniques by MATLAB & SAT/FAT Acceptance tests in the light of commissioning& Installation scenarios

Tariq MASOOD.CH
Qatar Petroleum
Dukhan Qatar

Dr. Abdel-Aty Edris
(Manager Power Delivery R & D)
EPRI **USA**

Pro. Dr. RK Aggarwal
University of Bath
Bath _ UK

Prof. Dr. Suhail A. Qureshi
University of Engineering & Technology
Lahore Pakistan

Prof. Dr. Abdul Jabber Khan
Rachna College of Engineering &Technology
Gujranwala Pakistan

Yacob Y. Al-Mulla
IEEE Chair
Doha Qatar

Author contact Details:
Email: maaat 2001@ ieee.org Ph:: 00974 560 75 72;; P.O Box 1000 52 Dukhan Qatar

Key words:

- FACTS Devices - MatLAB, measuring transfer function - control transfer functions - STATCOM Characteristics and performance comparison with other devices**.**

Abstract: Herewith, the straightforward technique has been used to simulate and analyzed the STATCOM control model by MatLAB. The work has been segregated in variant corridors for proper realization in power system; and this is theoretical step toward power quality improvement. STATCOM, self commuted switching power converters are playing viable and vital role in power delivery in the recent era of transmission and distribution system. In the first step, we have conferred the current statistics of FACTS an emerging technology in transmission and distribution system. In second step our work emphasized the typical functionality of STATCOM parallel to SVC static Var compensator inform of simplest model. In the third step, we have characterized and analyzed the STATCOM as well as SVC in power operational scenarios how we can be benefited prior to proper execution of FACTS devices. In the fourth step, we have also thrashed out the STATCOM application in power system to improve power quality with our holistic approach in control system. In our fifth to tenth step, we have conversed the voltage sources converters, Phasor diagram for VSC, harmonics reduction, STATCOM Losses and combine compensators characteristics and their chronological functionality to improve power quality. At the last, we have simulated STATCOM to its respective control blocks with typical transfer control functions and performance comparison with other devices. Resulting in, we are in excellent position to get clear perception of STATCOM functionality which is most appropriate accomplishment toward oriented power quality objective.

Introduction: STATCOM is defined by IEEE as a self commutated switching power converter supplied from an appropriate electric energy source and operated to produce a set adjustable multiphase voltage, which may be coupled to an AC power system for the purpose of exchanging independently controllable real and reactive power. The controlled reactive compensation in electric power system is usually achieved with the variant STATCOM configurations corridors. The STATCOM has been defined as per CIGRE/IEEE with following three operating scenarios. First component is **Static:** based on solid state switching devices with no rotating components; second component is **Synchronous:** analogous to an ideal synchronous machine with 3 sinusoidal phase voltages at fundamental frequency; third component is **Compensator:** rendered with reactive compensation.

1) Three generation reactive compensation
2) How the typical STATCOM is functioning in variant power operation corridors
3) STATCOM characteristics
4) STATCOM Power system applications
5) Principle of voltage sourced converters (VSCs)
6) Basic Six-pulse two-level voltage source converter (VSC)
7) Harmonic Reduction
8) STATCOM losses
9) STATCOM & SVC characteristics
10) STATCOM Voltage regulations
11) STATCOM control modeling and analysis
12) STATCOM individual performance
13) Test criteria of STATCOM for installations
14) STATCOM Performance comparison with other devices

---

1. Three generation reactive compensation

i. <u>First Generation Devices</u>

- Fixed shunt reactor (FR)
- Fixed shunt capacitor (FC)
- Mechanical switched shunt reactor (MSR)
- Mechanical switched shunt capacitor (MSC)

ii. <u>Second Generation Devices</u>

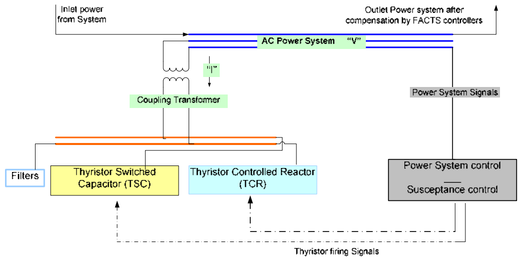
- Thyristor controlled Reactor (TCR)
- Thyristor switched capacitor (TSC)
- Static Var compensator (SVC)
- Thyristor switched series compensator (Capacitor or reactors) (TSSC/TSSR)
- Thyristor controlled series compensator capacitors or reactors (TCSC/TCSR).
- Thyristor controlled braking resistors (TCBR)
- Thyristor controlled phase shifting transformers (TCPST)
- Line commutated converter compensator (LCC)

iii. Third Generation Devices

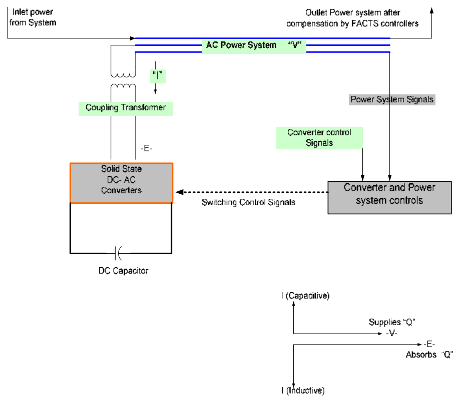
- Static synchronous compensator (STATCOM)
- Solid state series compensator (SSSC)
- Unified power flow controller (UPFC)
- Interline power flow controller (IPFC)
- Self commutated compensator (SCC)

2. How the typical STATCOM is functioning

i. Typical Static Var compensator (svc)

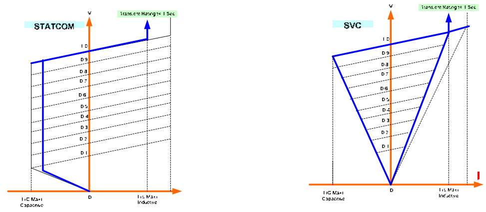


ii. Typical STATCOM Compensator

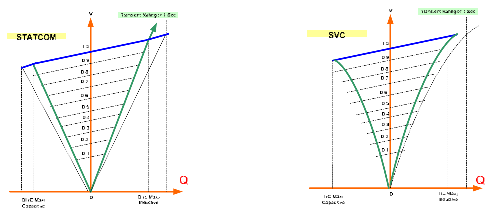


3. STATCOM Characteristics

i. V-I Characteristics different in between STATCOM & SVC

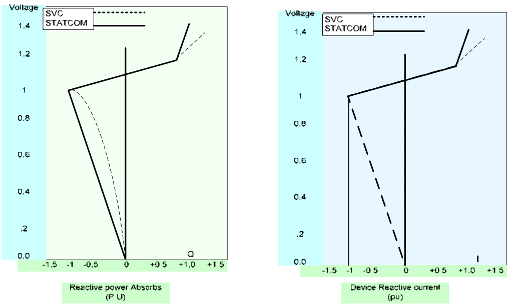


ii. V-Q Characteristics different in between STATCOM & SVC



iii. V-Q & V-I Characteristics different in between STATCOM & SVC

0156-6604-1400-6/00/$$10.00© 2006 PSC-Iran



4. STATCOM Power system applications

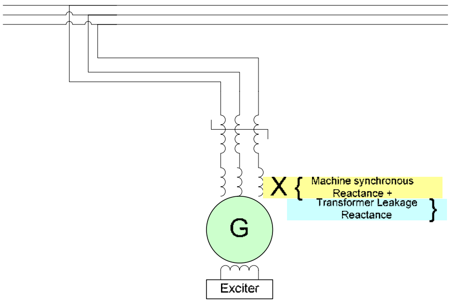
The STATCOM does have following operating corridors with degree of precision toward emphasized dynamic power quality control.

- Damping of power system oscillations
- Damping of subsynchronous oscillations
- Balanced loading of individual phases
- Reactive compensation of AC-DC converters and HVDC links
- Improvement of transient stability margin
- Improvement of steady-state power transfer capacity
- Reduction of temporary over-voltages
- Effective voltages regulation and control
- Reduction of rapid voltages fluctuations (flicker control)

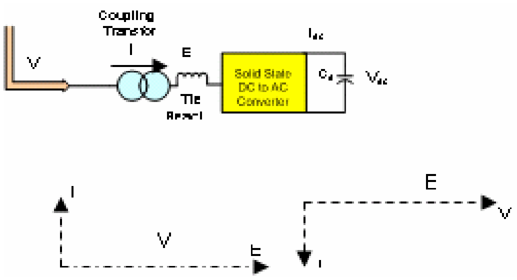
5. Principle of voltage sourced converters and Phasor diagrams for (VSCs)

i. Voltage sourced converter

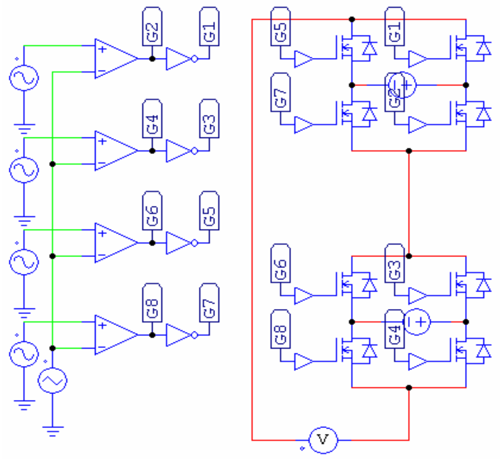
$$I_L = \frac{V-E}{X} >>>> Q = \frac{1-\frac{E}{V}}{X} \times V^2$$

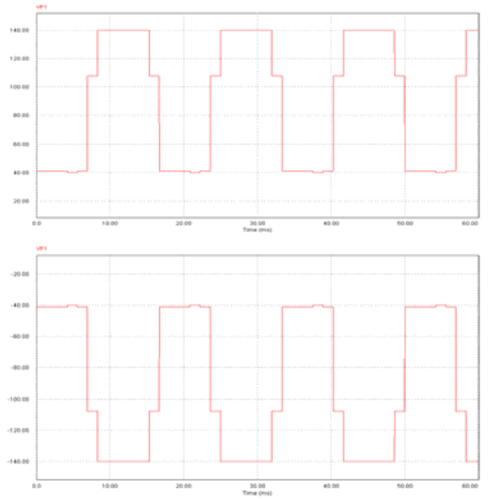


ii. Phasor Diagrams:-



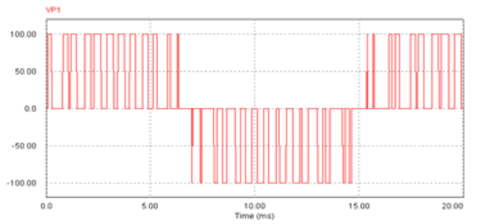
6. Basic Six-pulse two-level voltage source converter (VSC)

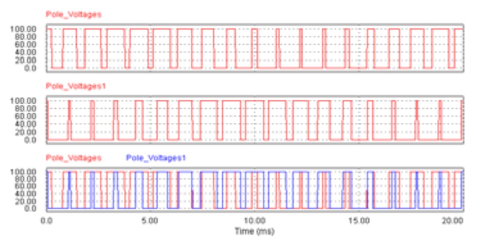




7. Harmonic Reduction corridors

i. PWM (Optimal Pulse width modulations

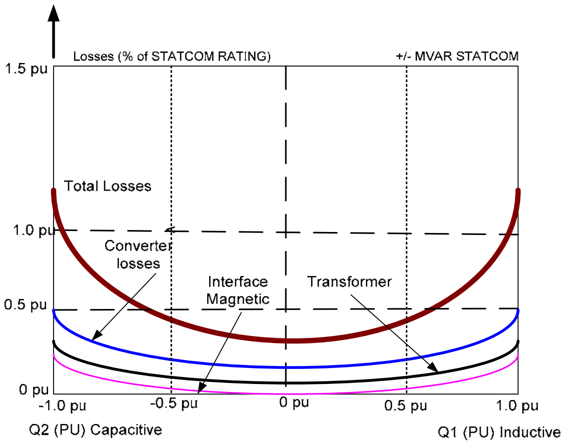




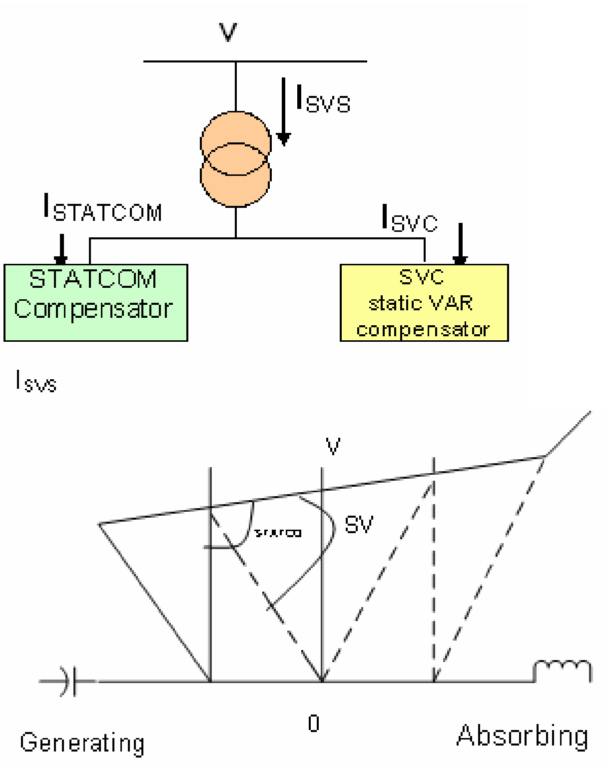
ii. Magnetic to combine output of multiple converters i.e. multi-pulse converters

iii. Multi-level converters
iv. Combination of multi-pulse and multi-level converters

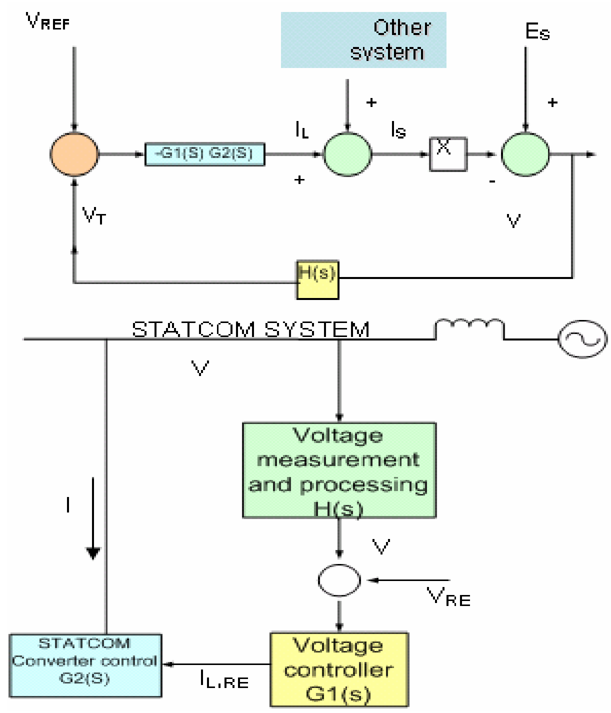
8. STATCOM losses



9. Combine compensator Characteristics



10. STATCOM voltage regulations



Voltage control transfer function with two prompt strategies.

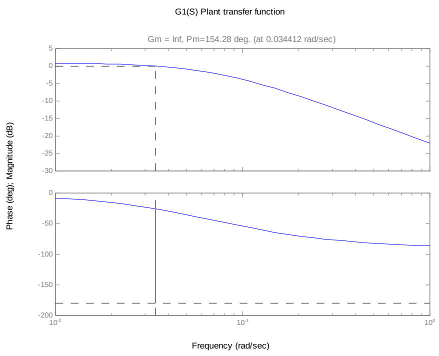
1) First step, we have emphasized on STATCOM and SVC control function as formulated below.

Module	*Parameter*	*Definition*	*Typical value*
Measuring	T_1	For time constant	14 ms
Thyristors Control	T_2 T_2	-firing delay -firing delay	5.5 ms (SVC Type) 0.50 ms (STATCOM)
Voltage Regulator	Xs		4.761 for strong system 9.522 for weak system
Slope	K_D	Steady state error	1/0.9 for 10% Slope
	T_H		20-100 ms

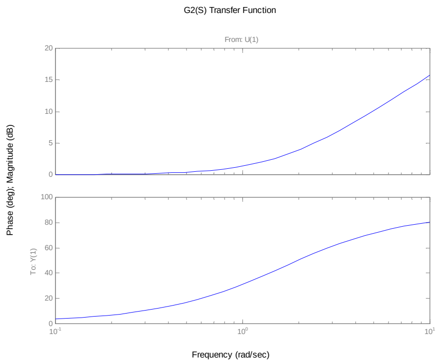
11. STATCOM control modeling and analysis

Step # (1) STATCOM control function

$$G_{1(s)} = \frac{K_D}{1+T_1 s}$$

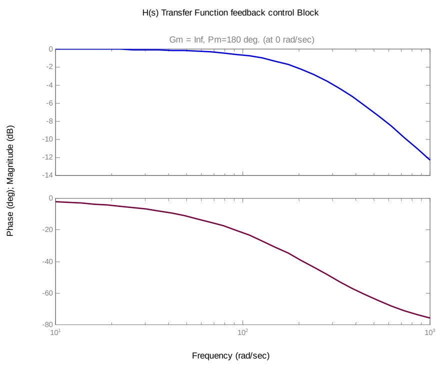


Step # (2) STATCOM control Function $G_{2(S)} = e^{-T_2 S}$



Step # (3) STATCOM Control function

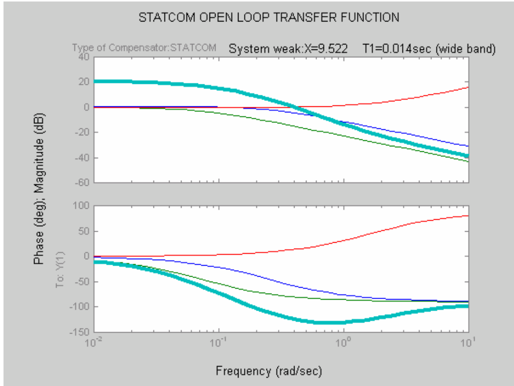
$$H_{(s)} = \frac{1}{1+T_H s}$$



Step 4th STATCOM final control block for

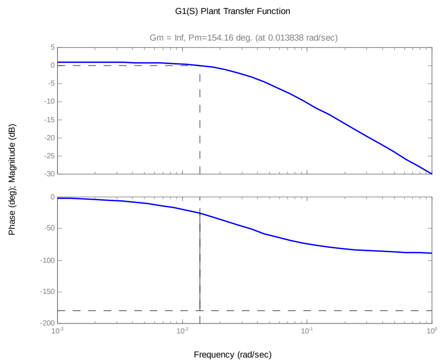
$$\frac{\Delta V}{\Delta E_s} = \frac{1}{1+G_1(s)G_2(s)H(s)X_s}$$

STATCOM open loop control with 65 Hz bandwidth

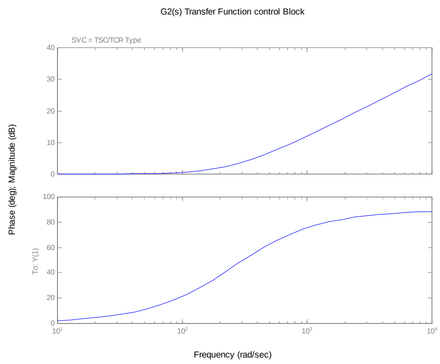


2) Second step, we have emphasized on STATCOM and SVC control function as formulated below.

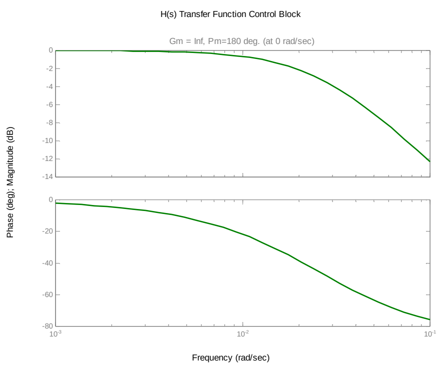
Step # (1) SVC Control Function $G_{1(s)} = \frac{K_D}{1+T_1 s}$



Step #(2) SVC Control function $G_{2(S)} = e^{-T_2 S}$

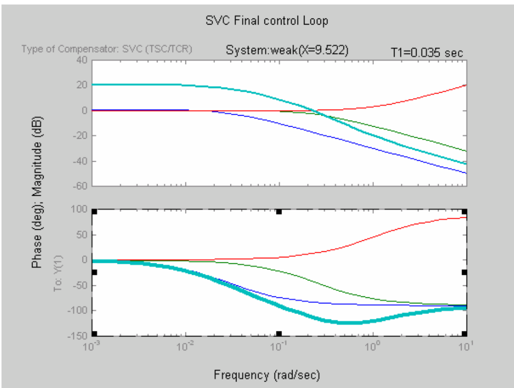


Step # (3) SVC Control Function $H_{(s)} = \frac{1}{1+T_H s}$

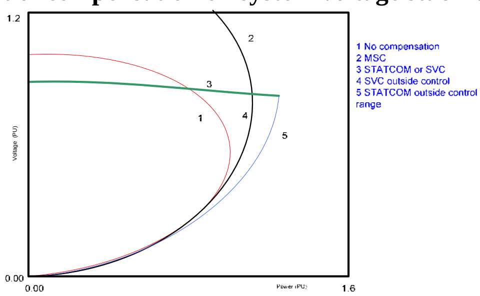


Step 4th SVC final control block for

$$\frac{\Delta V}{\Delta E_s} = \frac{1}{1 + G_1(s)G_2(s)H(s)X_s}$$



Impact of compensation on system voltage stability:-



Conclusion:-

In this paper, we have emphasized STATCOM implementations. Resulting in we have simulated voltage regulation with two prompt strategies how the STATCOM and SVC functionality can improve the power quality by means of voltage controls.

12. STATCOM individual Performance comparison with other devices

- It delivers same full output current (ind/cap) independently of the system voltages magnitude.
- It has short term overload capability of ~20%
- Requires 15-35% less MVA rating then SVC to deliver same level of performance for the system:-
  - System steady state power transfer
  - Dynamic voltages support
  - Transient stability performance
- It will render order of magnitude better performance than SVC in
  - Damping system oscillation
  - Unbalanced (negative sequence) Operation
  - Flickering reduction
- Much smaller environmental footprint than SVC
- Does not
  - Contribute to system responses
  - Introduces responses
  - Add to fault level other than rating
  - Have electromechanically oscillations
- Can act as a voltages source in stating other converter based equipments
- Can be used together with other types of compensations equipments
- Does not require large harmonic filters

13. Test criteria of STATCOM installations & Commissioning

A. STATCOM Test analysis-factory/offsite

i. Switchgear
ii. Transformers
iii. Surge arresters
iv. Reactors and resistors
v. Capacitors and capacitors fuses
vi. Insulators and instrument transformers
vii. Controls/relaying
viii. Simulators test for software's and hardware controls
ix. GTO Thyristors valves
x. Cooling system

B. STATCOM-onsite tests Analysis

i. STATCOM control system test
ii. Voltage regulation performance test
iii. Small disturbance dynamic performance tests
iv. Large disturbance performance test
v. Normal and overloaded capability tests
vi. Harmonics performance tests
vii. Radio interference tests
viii. Environmental test (noise, heating/cooling losses)
ix. Special control features tests

14. STATCOM Performance operation Scenarios comparable with other devices

controls	SVC	STATCOM	**R.S.C
Basic operating principle	**Controlled or switched shunt impedance**	**Controlled voltage current source behind reactance**	**Controlled voltage current source behind reactance**
Reactive power output	**Different capacitive and inductive output possible**	**Equal capacitive and inductive output**	**Inductive output less than capacitive output**
Behavior at high/low voltage	Constant impedance /Susceptance. Minimum voltage for Thyristors turn-on/ off	Constant current.	Constant current
Reactive power regulation	Within control range	Within control range	Within control range
Space requirements	Large (reactor, capacitor)	Smaller than SVC	Smaller than SVC
Losses	1.0-1.5%	1.0-1.5%	1.0-1.5%
System frequency variation	Behaves as constant C or L	Behaves as constant current source	Behave as constant current source
Contribution to fault level	None	Maximum rated current	3-4 Times MV A Rating
Voltage control and response	Response depends on system strength and may require variable gain control	Response depends on system strength, but much faster and more robust than SVC	Slower and more robust than SVC
Power transfer, stability damping improvement	Depends upon rating and locations	Depends on rating and locations but significant better than SVC	Limited by excitation system response
Initial Energization	By direct Energization from HV system	Rapid charging of energy storage to operating voltages	Require accelerating system response
Instantaneous real power supply	No	Dependent upon provision of energy storage	No
Fault ride through	Small delay on Thyristors re-enable unless free firing is maintained	No-delay-requires d.c capacitors voltages to be maintained	Yes- as provided by excitation system response
** Rotating synchronous compensator			

Acknowledgements:-

This paper could not be a possible with out Dr. Abdel-Aty Edris stunning and remarkable role. I do pay great homage and concede Dr. Abdel-Aty Edris (Manager Power delivery system at EPRI) for his pioneering in FACTS controllers and his immense technical support to accomplish this goal.
He is "role-model" for third generation for his tireless support and encouragement. I've spent couple of hours with him to share vision and thoughts which are most memorable for me and I look forward to see him again in near future.

References:-

1) How FACTS controllers benefits AC transmission systems: John J. Paserba, Fellow IEEE
2) How FACTS improve the performance of electrical grid: Rolf Grunbaum, Ake Petersson, Bjom Thorvaldsson (ABB Review 3/2002)
3) Dynamical performance of TCSC schemes: By Lennart Angquist,Gunnar Ingestrom, Hans-Ake Jonsson ABB Power system AB Sweden (CIGRE 1996:14-302)
4) Application of STATECOM for damping torsional oscillation in series compensated AC systems: By K.V Patil, J. Senthil, J.Jiang R.M.Mathur:: IEEE Transactions on energy conversion, Vo.,13 No. 3, September 1998.
5) Selection of passive elements for a three-level inverter based static synchronous compensator: By J.B. Ekanayake, N.Jenkins:: IEEE Transaction on Power delivery, vol. 14, no 2, April 1999.
6) Modeling STATECOM into power system: H.F.Wang University of bath, Bath BA2 7AY, UK.
7) Investigation of voltage regulation stability of static synchronous compensator in power system: Li chum, Jiang Qirong, Xu Jianxin. Pg 2642-2647 IEEE-2000
8) Study of a statcom application for voltage stability evaluated by dynamic PV Curves abd time simulations: By Hiroshi Yonezawa, Michiharu Taukada, John j. Paserba: Pg 1471-1476 IEEE-2000
9) Improved statecom model for power flow analysis: Zhiping Yang, chen shen, Maresa L. Crow, Lingli Zhang. Pg 1121-1126 IEEE-2000
10) Application of a 5MVA, 4.16 KV D-statecom system for voltage flicker compensation at seattle iron & metals::Gregory F.Reed, Masateshi Takeda, Fre Ojima: pg 1505- 1512 IEEE-2000
11) Harmonics resonance phenomena in statecom and relationship to parameters selection of Passive components:: Shen Dong, Wang Zhonghong, J.Y.Chen, and Y.H.Song:: IEEE Transaction on Power delivery, vol, 16, No. 1, January 2001.
12) The VELCO STATCOM-Based transmission system Project:: Gregory reed, John Paserba, Masatoshi Takeda, Yoshihiro Hamasaki, Lauri Thomas, George Smith::Pg 1109-115 IEEE-2001.
13)