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STATCOM Model against SVC Control Model Performance Analyses Technique by Matlab

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Abstract: Principal objective of this paper is to investigate the behavior of STATCOM against SVC controller by setting up new control parameters. Essentially, STATCOM, and SVC linear operating ranges of the V-I and V-Q as well as their functional compensation capabilities have been addressed to meet operational requirement with certain degree of sustainability and reliability. Hereby, the other operating parameters likewise transient stability, response time, capability to exchange real Power and Power Losses have also been addressed in STATCOM against SVC control models. In addition to that, STATCOM-Controller's pragmatic response has been identified and determined reliability level to maintain full capacitive output current at low system voltage. Therefore, it indicates that STATCOM device has more effectiveness than the SVC in improving transient stability (first swing).

Key words:

FACTS Devices - Matlab, Measuring Transfer Function - Control Transfer Functions – STATCOM

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 of 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. The STATCOM has been defined as per CIGRE/IEEE with following three operating structural components. 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:** provided with reactive compensation.[1],[2]

In this paper following areas have been addressed

1. Generation of reactive power compensation
2. Typical SVC Functionality
3. Typical STATCOM Functionality
4. SVC versus STATCOM characteristics (V-I and V-Q)
5. Transient stability characteristic OF STATCOM against SVC:
6. Voltage stability by
7. STATCOM Power system applications
8. STATCOM Versus SVC voltage stability
9. STATCOM losses
10. Combined compensator characteristics
11. STATCOM Voltage control model analysis
12. SVC Voltage control modeling analysis
13. STATCOM Performance comparison with other devices

1. Generation of reactive power compensation

A. *First Generation; Mechanically switched devices are:*

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

B. *Second Generation; Thyristor-based devices are:*

- 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)

C. *Third Generation; Converter-based devices*

- Static synchronous compensator (SATECOM)
- Static Synchronous Series compensator (SSSC)
- Unified power flow controller (UPFC)
- Interline power flow controller (IPFC)
- Self commutated compensator (SCC)

2. Typical SVC Functionality

Figure no.1 is demonstrating its operations to maintain required compensation. On the Left hand side functional control blocks for the TSC-TCR type var generator is shown. On the right hand side the function block is relatively simple. The input current reference from power system representing the magnitude of the requested output current is divided by the (scaled) amplitude of the TSC branch would draw at the given amplitude of the AC system.[3],[4],[5]

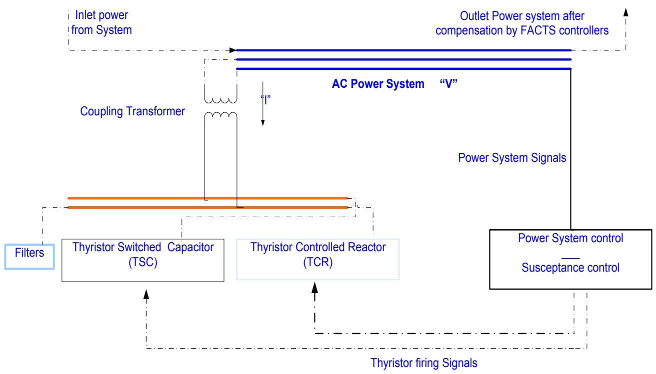

Fig. 1. Typical SVC Compensator

3. Typical STATCOM Functionality

Figure no. 2 is indicating simple operational approach of STATCOM, herein a static compensator functional capability to handle dynamic system conditions, such as transient stability and power oscillation damping in addition to providing voltage regulation.

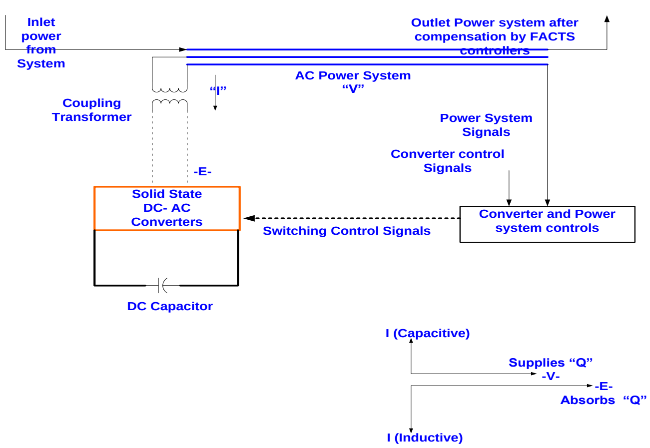

Fig. 2. Typical STATCOM Compensator

4. STATCOM Versus SVC Characteristics

Figure No.3 (a) and 4(a) illustrate the characteristics of STATCOM against SVC. In these figures the STATCOM may, depending on power semiconductors used. Which control an increased transient rating in both the inductive and capacitive operating regions. [6],[7]

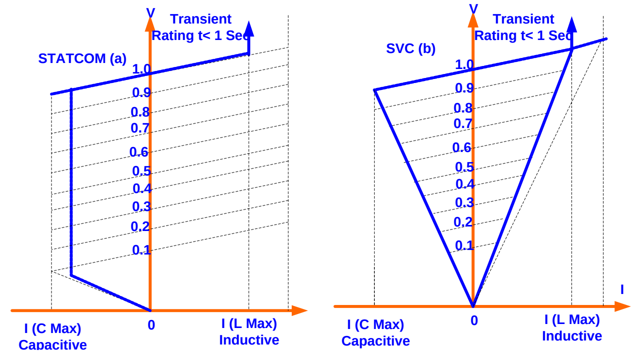

Fig. 3. V-I Characteristics of STATCOM versus SVC

Figure No.3 (b) and 3(b) illustrate the characteristics of SVC, which is indicating the SVC being composed of (TCR + TSC), becomes a fixed capacitive admittance at full output. In SVC operations the maximum attainable compensating current of the SVC decreases linearly with ac system voltage, and maximum var output decreases with square of the voltage.[10]

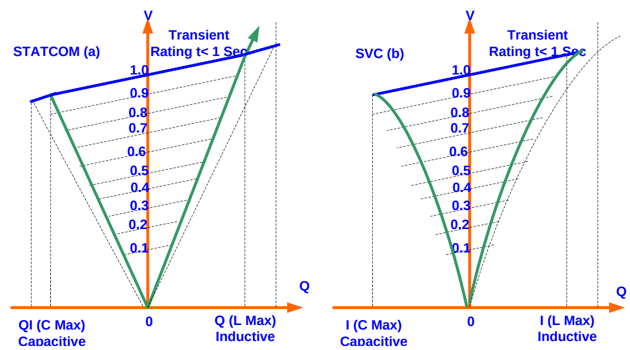

Fig. 4. V-Q Characteristics of STATCOM versus SVC

5. Transient stability characteristic OF STATCOM against SVC:

Figure No. 5 illustrates the STATCOM and figure 6 illustrates the SVC operations to provide stability during transient. It is assumed that the system transmitting steady state power P1 at angle $\delta 1$, is subjected to the fault period of time during which P1 becomes zero. In fault condition the machine will accelerate at sending end and absorbing kinetic energy represented by the shaded area below the constant P1 line. When the original system restored after clearing the fault the transmitting power becomes much higher than the P1 due to large transmission angle δc. As a result the sending-end machine starts to decelerate, but δ increase further until the machine loses all the kinetic energy it gained during the fault. Thus, the recovered energy is represented by the shaded area between P versus δ curve and the constant power line P1.[8],[9] STATCOM against SVC stability Margin

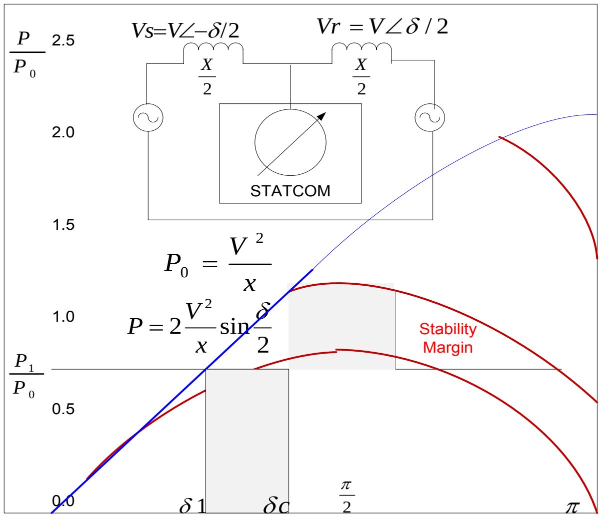

Fig. 5. STATCOM stability margin at mid point

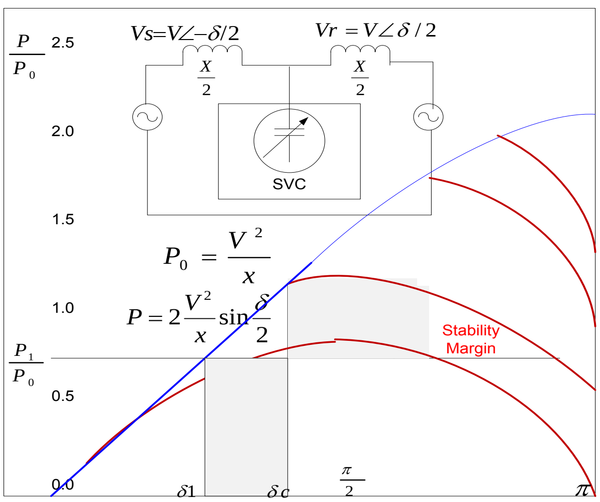

Fig. 6. SVC stability margin at mid point

Hence, it has been observed, the transient stability margin obtained with STATCOM is significantly greater than that attainable with the SVC of identical var rating. [5],[6]

6. Voltage stability by STATCOM vs SVC:

For transmission system the best location for var compensation is in the middle, whereas for a radial feed to a load the best location is at the load end. The line no.1 indicates no compensation, line no.2 indicates MSC in operations, line no. 3 indicates SVC or STATCOM in operations, line no. 4 indicates SVC out of control, and similarly line no. 5 indicates STATCOM out of control.[11]

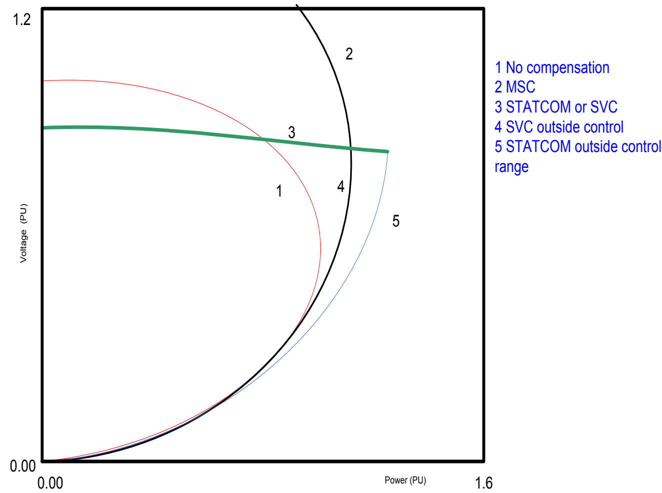

Fig. 7. Impact of compensation for voltage stability

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7. Applications of STATCOM

The STATCOM has the following applications in controlling power system dynamics.

- 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)[4],[5],[9]

8. STATCOM Operational Losses:

Figure no. 11 indicates total losses of the STATCOM during normal operations. Equation 2 & 3 are used to calculate the total STATCOM losses, both equation abbreviations are defined in table #2.

Loss $_{\text{total}} =$ (Loss $_{\text{MG}}$ + Loss $_{\text{CONVT}}$) (1)

- Converters losses are due to conduction and switching losses accompany by “snubber” losses.

Loss $_{\text{TMG}} =$ (Loss $_{\text{TARNFOREMR}}$ + Loss $_{\text{INTERFACE}}$) (2)

- Transformer losses are due to high voltage applications
- Interface magnetic losses are due to overall converter structure and operating mode of operations.

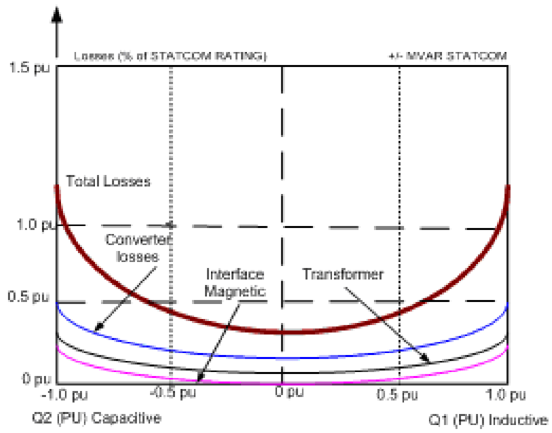


Fig. 8. Losses at various operational scenarios

9. Combined compensator Characteristics

Figure 12 is demonstrating STATCOM and SVC parallel operation accompany by power absorbing and generating trends.

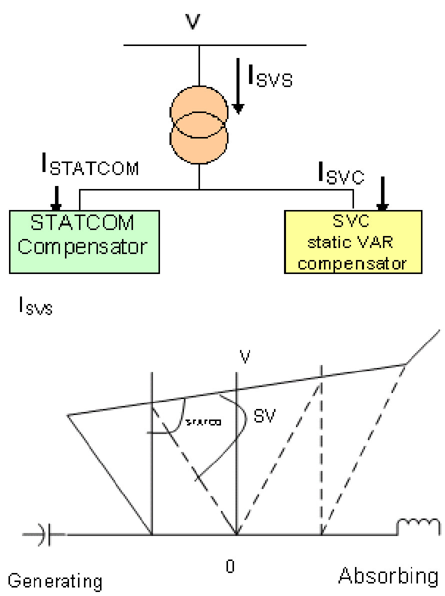


Fig. 9. SATCOM & SVC operations

A. *STATCOM Voltage control model*

In the linear operating range of the STATCOM compensator, the AC system terminal voltage can be denoted from figure 13 in terms of the internal voltage V and reference voltage V_{Ref} as given in the equation 3 and its parameters are also defined in table 2.[12]

$$V_T = V\frac{1}{1+G_1G_2HX} + V_{Ref}\frac{G_1G_2X}{1+G_1G_2HX} \qquad (3)$$

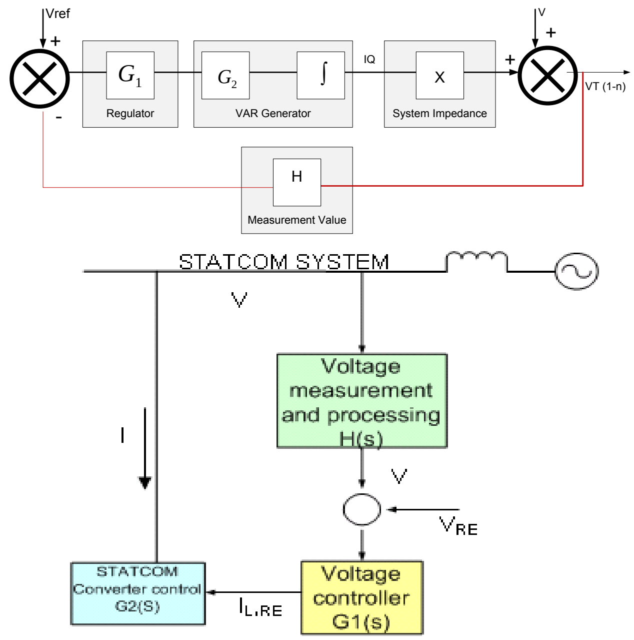


Fig. 10. STATCOM voltage regulators and control loop

STATCOM control model has been simulated and developed to analyze its possible performance barriers. Thus, mathematical simulation has been demonstrated into stepwise has listed below.

1) *In Step one, STATCOM control transfer function (G_1)*

$$G_{1(s)} = \frac{K_D}{1+T_1 s} \qquad (4)$$

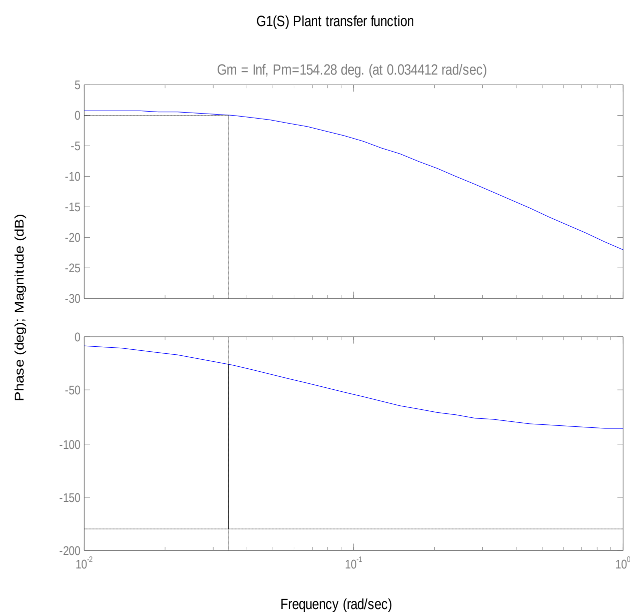


Fig. 11. G1 control response

2) *In step two, STATCOM control Transfer Function (G_2)*

$$G_{2(S)} = e^{-T_2 S} \tag{5}$$

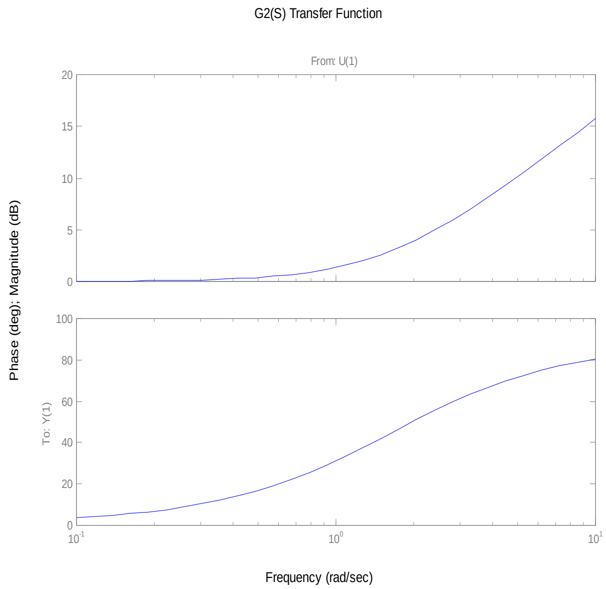


Fig. 12. Demonstrating $H_{(S)\ response}$

3) *In Step three, STATCOM final control block:*

Which is demonstrating in the figure: 16 after combining the transfer function of G1 and G2 and the results were achieved very much promising accompany by an excellent stability margin to maintain secure power system operations without any process ambiguity.

$$\frac{\Delta V}{\Delta E_s} = \frac{1}{1 + G_1(s) G_2(s) H(s) X_s} \tag{6}$$

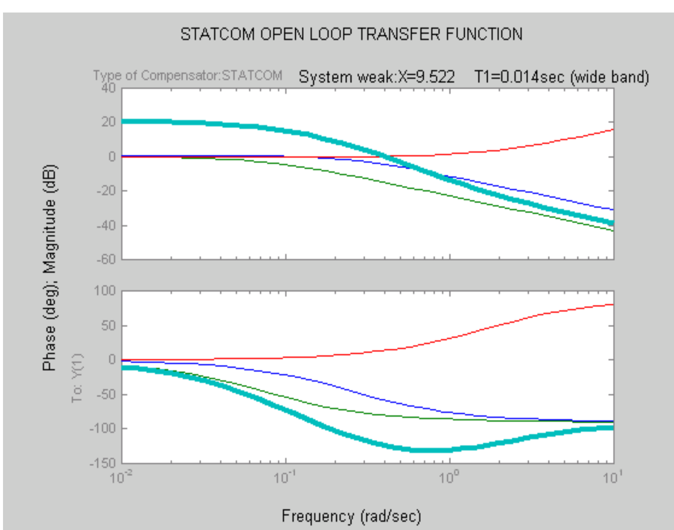
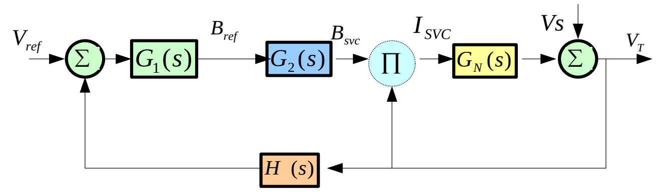


Fig. 13. STATCOM final control function

In the figure 16 the linear operating range of the STATCOM compensator demonstrated, as a result the terminal voltage has been maintained in terms of the internal voltage V and the reference voltage.

B. SVC Voltage Control Model

In the second form of operations a SVC model has been developed to produce the results as per defined as mathematical model. The control transfer functions which have been verified to maintain it operational credibility which has been formulated in control as given below.[8],[9]



A. In Step one, SVC Control Function (G1)

$$G_{1(s)} = \frac{K_D}{1 + T_1 s} \tag{7}$$

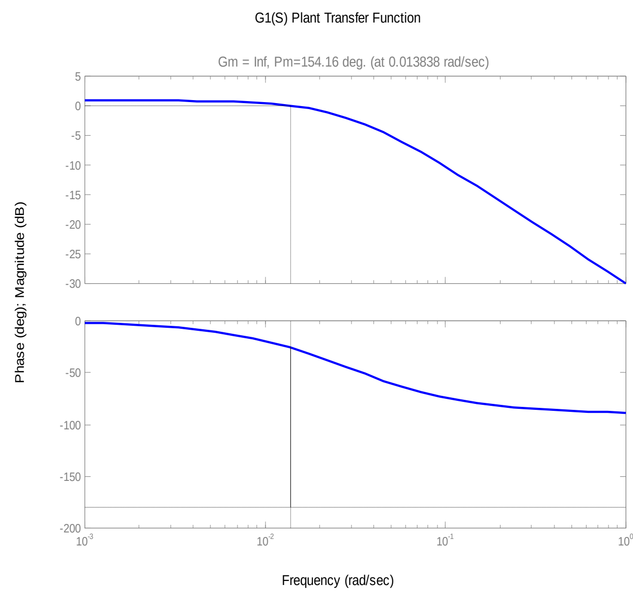


Fig. 14. Regulator control function

B. In step two, SVC Control function (G2)

$$G_{2(S)} = e^{-T_2 S} \tag{8}$$

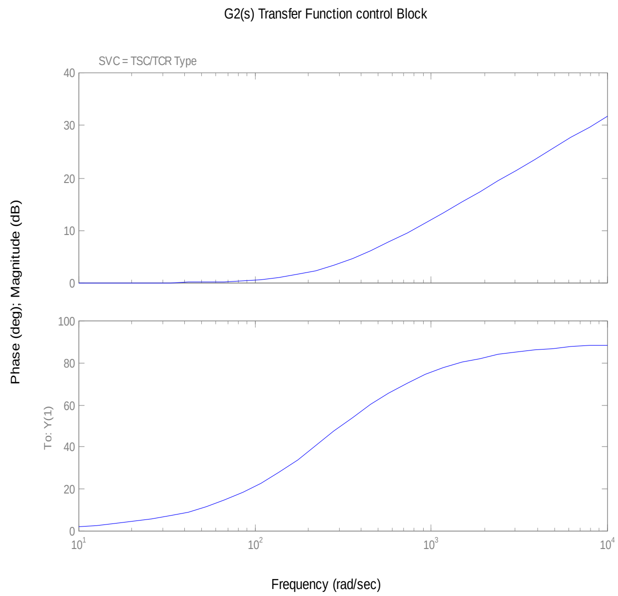


Fig. 15. VAR regulator control function

C. In step three, SVC Control Transfer Function (H)

$$H_{(s)} = \frac{1}{1+T_H s} \tag{9}$$

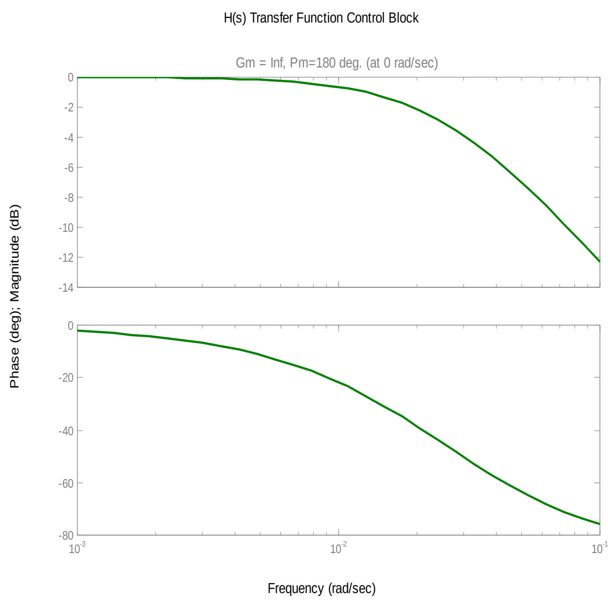


Fig. 16. Feedback control function

D. In Step four, SVC final control transfer function

$$\frac{\Delta V}{\Delta E_s} = \frac{1}{1+G_1(s)G_2(s)H(s)X_s} \tag{10}$$

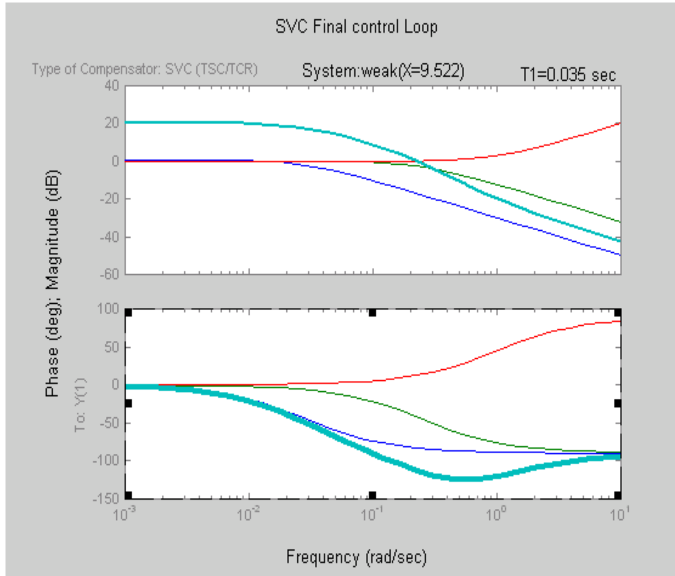


Fig. 17. SVC final control function

The figure 20 indicates the linear operating range of the SVC compensator demonstrated; as a result the terminal voltage has been maintained in terms of the internal voltage V and the reference voltage.

Table. I. SVC and STATCOM Operating parameters

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

Table. II. SVC and STATCOM measured parameters

Symbol	Description
V_T	AC system terminal voltage
V	Internal voltage
V_{Ref}	Reference voltage
T_1	Time constant of the PI controller (10-50) ms depending on the VAR generator transport lag
T_2	Amplitude measuring circuit time constant (8-16)ms
Td	Transport lag of the VAR generator (2.5 ms for TCR, 5.0ms for TSC and 0.2-0.3 ms for convertor)
X	Z (reactive part of the system impedance)
K	Regulation of slope (1-5%)

S	Laplace operator
G1	Regulator
G2	VAR generator
Loss $_{total}$	Total STATCOM losses
Loss $_{MG}$	Total magnetic losses during STATCOM operations
Loss $_{CONVT}$	Total converter losses during STATCOM normal operations
Loss $_{TRANSFORMER}$	Coupling transformer losses
Loss $_{INTERFACE}$	Converter structure losses

Table. III. 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 improvemen t	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
Instantaneou s 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			

10. Results:

Various optimum controls parameters have been selected on trial basis as given above in the tables 1 &2. Both models (SVC and STATCOM) have been mathematically simulated by Matlab by putting its operational barriers into considerations. In this connection, very promising results have been achieved. The basic operational difference (voltage source versus reactive admittance) accounts for the STATCOM's overall superior functional characteristics better performance and greater application flexibility than those attainable with the SVC at high accuracy level of both FACTS devices.

11. Conclusion:-

The controlled static compensator is configured to regulate the terminal voltage with certain degree of accuracy. Herein it has been also observed that the transient stability can be increased by maintaining the transmission voltage at midpoint. This can be further enhanced by temporarily increasing the voltage above the regulation reference.

The SVC will reciprocate with same features but limited transient stability, which also depend SVC operational components. The instrumental approach to regulate the voltage and system stability were exceptional by using STATCOM and SVC controllers, which are showing how voltage control would improve the power system quality..

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