Multi-machine system with Series FACTS device: Static synchronous series compensator

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Abstract - *This paper presents the importance of SSSC and shows the comparative study of effect of transmission lines with SSSC and without SSSC considering the different cases :- I)Normal load condition II) with the increasing 8% load connected in area2 and III) with the L-L-L-G fault in area 2 . The model is simulated with MATLAB to demonstrate system behavior with static synchronous series compensator.*

***Key Words*: Power system, FACTS, VSC, SSSC, Transient stability.**

1. INTRODUCTION

Day-by-day demand for electricity goes on increasing. To meet with that demanded power it is not possible to replace existing power system. So some technology has to be added with existing power system to increase the capacity of the system. The FACTS controllers are one of the best devices for compensation of this problem.

Generally, the FACTS controller can be divided into two groups i.e. I) Non-converter based FACTS controller which includes Static Var compensator and Thyristor-controlled series capacitor have the advantages of generating as well as absorbing reactive power without the use of ac capacitor and reactor. II) Converter based FACTS controller which consist of STATCOM, SSSC, UPFC and IPFC which has the capability of individually control the active and reactive power flow in transmission lines [1]. The series FACTS devices are used for power flow control in transmission lines and for damping the power system oscillations present in the system. Static synchronous series compensator (SSSC) has the ability to inject voltages or absorb voltages from transmission line where it is connected. SSSC can be participated in the power system inter-area oscillation damping by changing the compensated reactance of the transmission line [3]. Synchronous voltage source and gate turn-off thyristor (GTO) based voltage sourced inverter provides controllable series compensation to the transmission line. SSSC provides controllable compensating voltage independently of the magnitude of the transmission line current. External dc power supply compensates the voltage drop of transmission line across the resistive component of the line impedance [4]. Multi-pulse and multilevel inverter topology for high power applications has been proposed in [5]. Harmonic neutralization phase shifting transformer is used for multilevel inverter. This multilevel inverter produces sinusoidal voltage waves to controls the power flow in transmission lines.

The SSSC is a series compensation FACTS device based on the voltage source converter (VSC) which controls the power flow in transmission lines, damps the oscillations present in system and improve the transient stability of the system .The SSSC controls the power flow by controlling the magnitude of injected voltage (V_q) and also the phase angle of injected voltage (Ψ) in series with the transmission line where it is connected as shown in fig.1. It consist of three basic components - I) voltage source converter which is a main component II) transformer for coupling the SSSC to the transmission line and III) energy source to provides the dc voltages across capacitor and compensate against device losses.

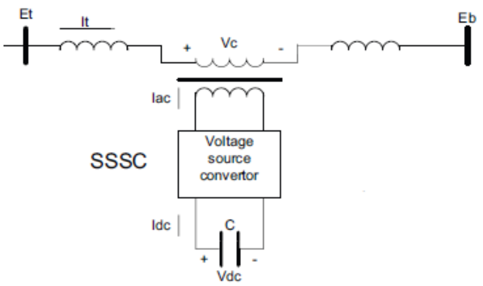

Fig-1: Static synchronous series compensator

This paper investigates the static synchronous series compensator in terms of power flow improvements and transient stability improvements of the multi-machine system.

1.1 MATHEMATICAL MODELLING OF SSSC

SSSC injects the voltages (V_q) in series with the transmission line where it is connected. Controller of SSSC sets the limit for injection of voltages in transmission line.

Hence, the system shows the effects with changing control signals.

The generator rotor motion can be represented as-

$$\delta = \omega_i - \omega_{0j}$$
$$\omega = \omega_{0j} / M' (P'_m - D'/\omega_{0j} (\omega_i - \omega_{0j}) - P'_e) \quad (1)$$

Let excitation of system is neglected [6]. At this conditions voltage equation becomes

$$E_{q1} = V_{q'} + V_{ssscq'} + I_{d'} x_{d'\Sigma}$$
$$0 = V_{d'} + V_{ssscd'} + I_{q'} x_{q\Sigma} \quad (2)$$

Where,

δ – Generator rotor motion angle
ω – Rotational speed
M' – Moment of inertia
D' – Coefficient of damping
P'_e – Electromagnetic power
P'_m – Mechanical power
$V_{ssscd'}$ - d axis voltage component of SSSC
$V_{ssscq'}$ - q axis voltage component of SSSC
$V_{d'}$ - d axis voltage component of infinite bus
$V_{q'}$ - q axis voltage component of infinite bus
$I_{d'}$ - d axis current component of transmission line
$I_{q'}$ - q axis current component of transmission line

$$X_{id'\Sigma} = x_{id'} + x_{t'} + x_{l'}$$
$$X_{iq'\Sigma} = x_{iq} + x_{t'} + x_{l'} \quad (3)$$

equation (3) shows the total d axis and q axis impedance of the system.

Therefore $I_{d'}$ and $I_{q'}$ becomes-

$$I_{d'} = (E_{q1} - V_{q'} - V_{ssscq'}) / x_{id'\Sigma}$$
$$I_{q'} = (V_{d'} + V_{ssscd'}) / x_{iq\Sigma} \quad (4)$$

The electromagnetic power of generator can be

$$P'_e = E_{q1} I_{q'} + (x_{q'} - x_{d'}) I_{d'} I_{q'} \quad (5)$$

The system consists of two areas in which two salient pole type generators are connected. These two areas are connected together with the help of two parallel lines. Facts device SSSC connected in one transmission line as shown in fig. 2.

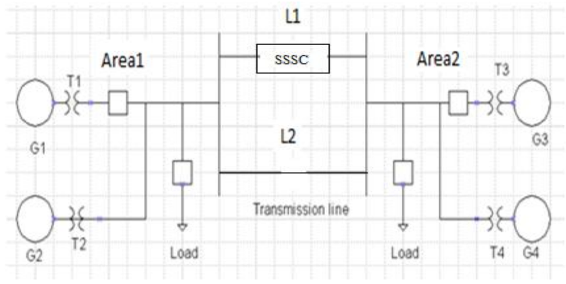

Fig-2: System with SSSC

The multi-machine system is demonstrated in MATLAB environment with SSSC connected in one transmission line and without SSSC considering the cases that are I) normal load condition II) with the increasing 8% load and III) with the fault condition. Under these various conditions power flowing through bus 1 to bus 2 is calculated and compare with system connecting with SSSC and without SSSC.

2. SIMULATION RESULTS

Different cases which are considered for MATLAB simulation are as follows-

Case 1 :- Normal load condition

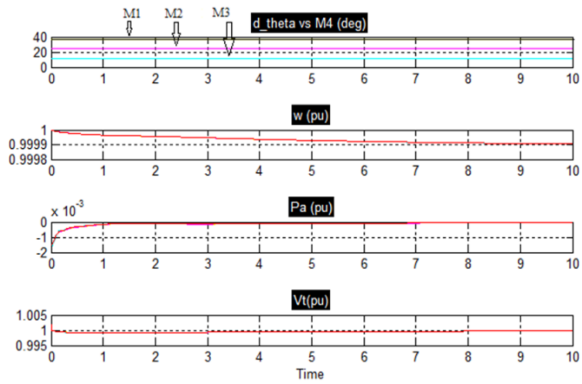

Fig-3: Machine parameters without SSSC

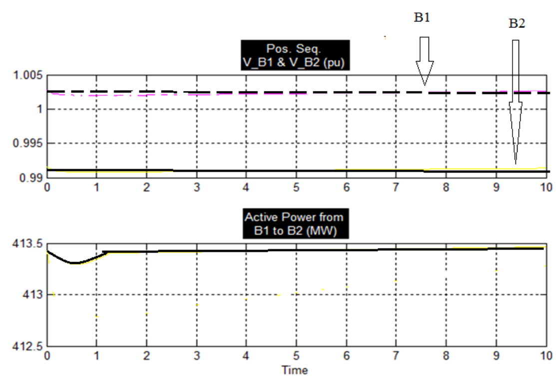

Fig-4: System parameters without SSSC.

Under normal load condition power flowing through the system is 413.5 MW as shown in fig.4.

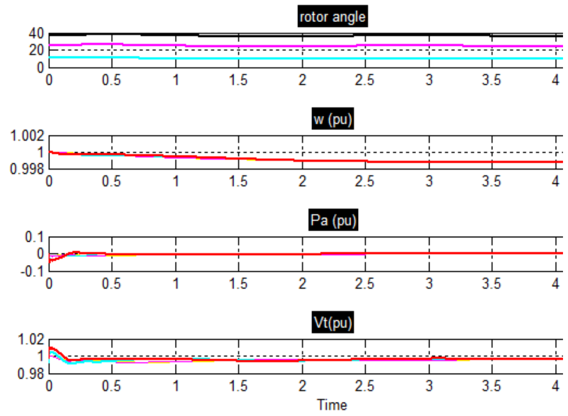

Fig-5: Machine parameters with SSSC.

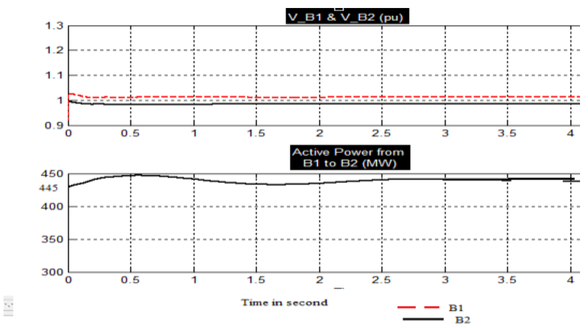

Fig-6: System parameters with one SSSC.

SSSC connected in transmission line L1 and simulation is done. Power flowing through the system is near to 445 MW i.e power flowing is increased by 8%.

Case 2:- With the increasing 8% load

The load connected in area 2 is increased by 8%. Earlier it was 1767 MW now it is increased up to 1908 MW.

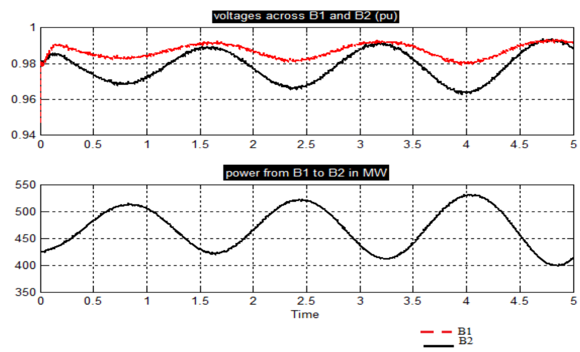

Fig-7: System parameters without SSSC

From fig 7. it is cleared that as load demand is increases the voltages across each buses decreases and disturbances occurs in system.

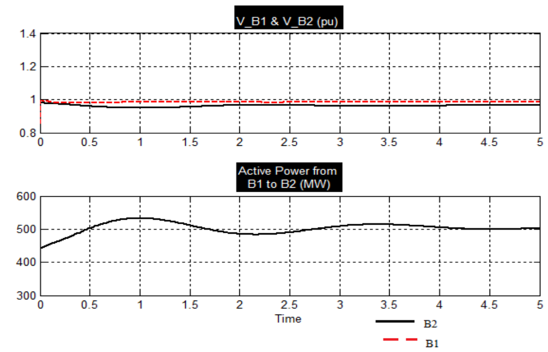

Fig-8: System parameters with one SSSC.

When SSSC is connected to the transmission line, the voltages across each bus are improved and disturbances occur due to increased load condition decreases. The power flowing from bus B1 to bus B2 is increased up to 500 MW as load is increased.

Case 3:- With fault in area 2

L-L-L-G fault occurred in area2 for duration 0.2 second which occurs at 1 second and clear at 1.2 second.

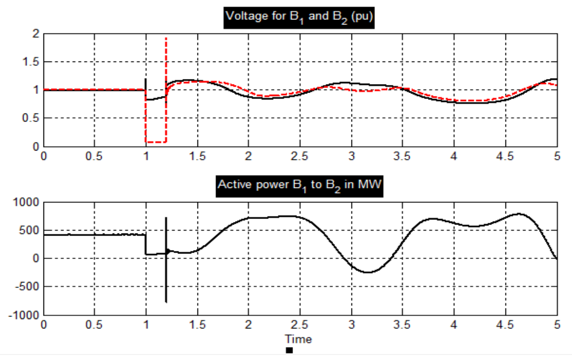

Fig-9: System parameters without SSSC

After fault clearing system takes large time to settle down to their original condition as shown in fig. 9.

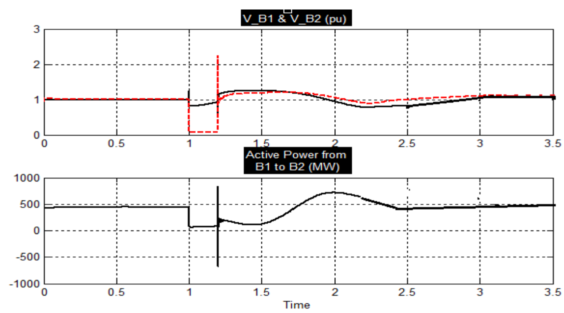

Fig-10: System parameters with SSSC

Under fault condition the FACTS device SSSC improves the power flowing from B1 to B2 as shown in fig 10 and settles the system to their original condition within small period.

3. CONCLUSIONS

FACTS devices help in meeting the increased demand. SSSC is a series connected device and control the power flow in transmission line by controlling magnitude and phase angle of injected voltages.

By using SSSC the power flowing from bus B1 to B2 is increased by 8% .The system operates stably with SSSC and improves the power flowing through transmission lines. Also it damps the oscillation occurred in system due to disturbances.

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Table1:-

System data

Area1	Transmission line	Area2
G1=G2= 900MVA, F=60Hz	L1=L2= 220km,	G3=G4= 900MVA, F=60Hz
Vrms=20kv	V=230kv	Vrms=20kv
X_d=1.8 pu, X_d'=0.3pu, X_d"=0.25pu		X_d=1.8 pu, X_d'=0.3 pu, X_d"=0.25pu
X_q=1.7pu, X_q'=0.55pu, X_q"=0.25 pu		X_q=1.7pu, X_q'=0.55pu, X_q"=0.25 pu
T1=T2= 900 MVA , 20kv/230kv		T1=T2= 900 MVA , 20kv/230kv
Load=967MW, 100MVAR, -187MVAR& -200MVAR		Load=1767MW 100MVAR, -187MVAR, -350MVAR