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Power flow improvement using Static Synchronous Series Compensator (SSSC)

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ABSTRACT:

This paper demonstrates SSSC; it is belonging to FACTS family. In SSSC, the voltage source convertor (VSC) connected in series with the transmission line injects the voltage in quadrature with the line current. SSSC used to enhance voltage stability and power flow. This paper also includes the control circuit of PWM controlled SSSC. The controller ensures effectiveness on the dynamic and transient operation of the system. Simulation results have been presented in MATLAB/Simulink environment.

Keywords: *SSSC, FACTS, Real and reactive power flow, PWM control and Power oscillation damping controller (POD).*

I.INTRODUCTION

Now-a-days with the current expansion of electric utilities, new technologies are required for reliable and secure operation of power system. FACTS devices are introduced in power system for obtaining operational reliability. Introduction of FACTS controllers in power system improves the quality of power supply. The FACTS devices deliver the electrical power more economically when compare to existing transmission lines. FACTS are designed based on power electronic equipment [1]. These controllers operates very fast, they extend the safe operating limits of a transmission system without risking stability [2].

For Series compensation in transmission line the SSSC is most important FACTS device. It is a power electronic based VSC that generates nearly sinusoidal three phase voltage which is in quadrature with the line current [3].

A Novel control scheme for dynamic operation of STATCOM and SSSC are presented in [4]. In this method reactive power compensation and voltage stabilization using decoupled current control strategy method was implemented. The basic SSSC features regarding power flow control in the system were explained on the basis of mathematical model [5]. A multi control functional model of SSSC for power flow analysis was proposedin [6].

II. PRINCIPLE OF OPERATIONA OF SSSC

Generally the SSSC connected in series with the transmission line. SSSC consists of coupling transformer, voltage source converter (VSC) and a DC capacitor. The SSSC block diagram is shown in figure 2.1.

One side of VSC is connected to the DC bus. The DC capacitor is used to maintain DC voltage level on the DC bus. The DC capacitor is selected to meet harmonics and environment criteria of the SSSC and the power system.

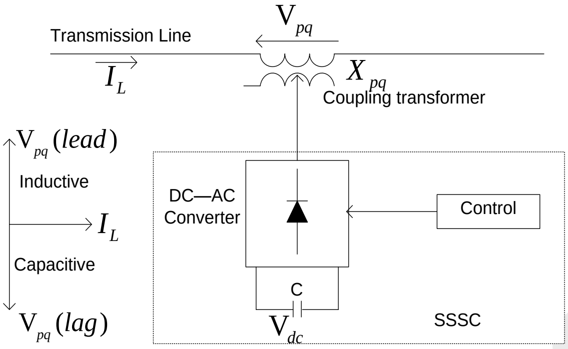

Fig.2.1: static synchronous series compensator

If the SSSC voltage V_{pq} lags the line current I_L by 90°, capacitive series compensation is obtained and if V_{pq} leads I_L by 90°, inductive series compensationis obtained. By controlling the voltage magnitude the amount of series compensation can be adjusted[3].

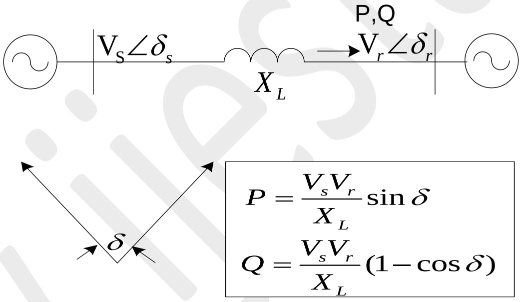

Fig.2.2: Elementary power transmission system

Fig.2.2 shows the single transmission line with inductive reactance X_L is connected in between the sending end voltage V_S and receiving end voltage V_R. Here δ_s and δ_R are the phase angles of the sending end and receiving end voltage sources. If $V = V_s\angle\delta_s = V_R\angle\delta_R$. Difference between the phase angles is $\delta = \delta_S - \delta_R$. At the receiving end side the real and reactive power equations P and Q are as follows.

$$P = \frac{V_S V_R}{X_L}\sin(\delta_S - \delta_R) = \frac{V^2}{X_L}\sin\delta \text{.......1(a)}$$

$$Q = \frac{V_S V_R}{X_L}(1-\cos(\delta_S - \delta_R))$$

$$= \frac{V^2}{X_L}(1-\cos\delta) \text{ ....1(b)}$$

When SSSC is connected in the transmission line, the power flow equations 1(a)&1(b) can be written as 2(a)&2(b).Where X_{eff} is the effective reactance of the transmission line which includes line reactanceX_L and reactance of SSSC X_q.

$$P_q = \frac{V^2}{X_{eff}}\sin\delta = \frac{V^2}{X_L(1-\frac{X_q}{X_L})}\sin\delta \text{............2(a)}$$

$$Q_q = \frac{V^2}{X_{eff}}(1-\cos\delta) = \frac{V^2}{X_L(1-\frac{X_q}{X_L})}(1-\cos\delta).\text{2(b)}$$

When the reactance is inductive the power flow P_q and Q_q decreases and X_{eff}increases, it means compensating reactance is negative. When the reactance is capacitive the power flow P_q and $Q_Q$increases and X_{eff} decreases, it means compensative reactance is positive.

III. PWM TECHNIQUE OF SSSC

It is one of the most used techniques. Using this PWM control technique of SSSC both magnitude and angle of the injected voltage can be controlled. It hasa simple closed loop block diagram presented in Fig.3.1.

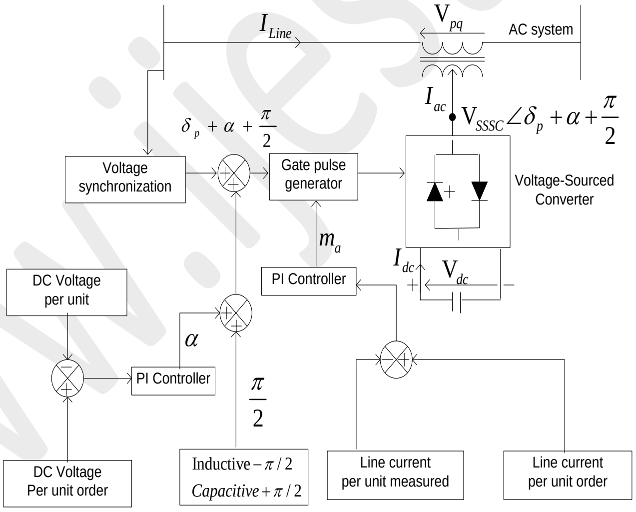

Fig.3.1: Functional Control diagram for PWM Controlled SSSC

The technique depends on two control loops. They are current control loop and voltage control loop.Based on this current and voltage control loops the magnitude and phase angles of the injected voltage can be maintained.In voltage control loop the difference of per unit values of measured line voltage and reference voltages are passed through PI controller.

In current control loop the measured per unit values of line current and reference line currents are passed through the PI controller. The output of the PI controller is givento gate pulse generator. Gate pulse generator will generate the pulses to the VSC [4].

IV. TEST SYSTEM

In test system the grid consists of two generating stations. It is a two machine four bus system. In that four buses are connected to each other through the following transmission lines. The line L1having length of 320 KM long, line L2 split in to two segments length of 180 KM each in order to simulate the fault, line L3 also split into two segments length of 180 KM each, and line L4having the length of 50 KM. The single line diagram of test system is shown Fig.4.1.

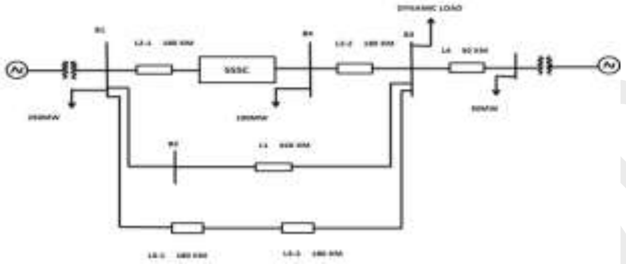

Fig.4.1: Single Line Diagram

The Simulink diagram of test system is shown in Fig.4.2.

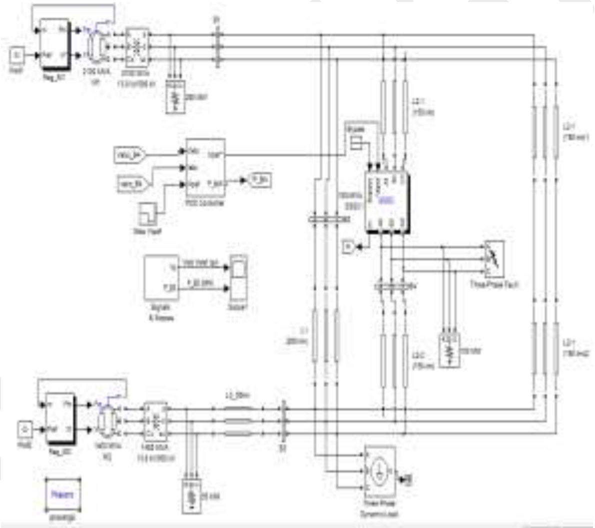

Fig.4.2: Static Synchronous Series Compensator (SSSC) used for Power Oscillation Damping

Device	**Rating**
Generating station M1	2100 MVA
Generating station M2	1400MVA
Dynamic load	2200MW
SSSC	100 MVA

The SSSC is located at bus4 and simulated for different type of faultsituations at bus4.SSSC is utilized to control the active and reactive power and also for improving the stability of the system.

V. SIMULATION RESULTS

Fault is initiated at 0.3 sec with the duration of 0.2sec. The simulation results are divided into 4 sections. (A) Discussion of healthy system results, (B) Discussion of the faulted system results, (C) Discussion of LG fault results with and without SSSC, (D)Summarization.

A. Healthy system

The proposed system without SSSC and without fault can be treated as healthy system.For healthy system the maximum voltage, active and reactive powers of the proposed system are shown in below table5.1.

Table5.1: Voltage profiles and power flows of healthy system

Bus No	Voltage(p.u)	Active power(MW)	Reactive power(MVAR)
1	1.0322	1400	-651.25
2	1.0322	542	645.7
3	1.0409	1055.5	-251.73
4	1.0608	424.55	-37.44

B. Faulted system

The proposed system without SSSC and with LG fault can be treated as faulted system.The maximum values of voltage, active power and reactive powers of proposed system are as shown in below table5.2.

Table5.2: Voltage profiles and power flows of faulted system

Bus No	Voltage(p.u)	Active power(MW)	Reactive power(MVAR)
1	1.062	1622	-311.28
2	1.062	628.734	645.7
3	1.0716	1304.7	-57.4
4	1.2966	492.8	40

C. Simulation results of LG fault

In proposed system the LG fault is applied at bus4.With the fault and Without SSSC the system results the less amount power flow and the voltage injection takes place after clearing the fault. It is clearly shown in Fig.5.c.1&5.c.2

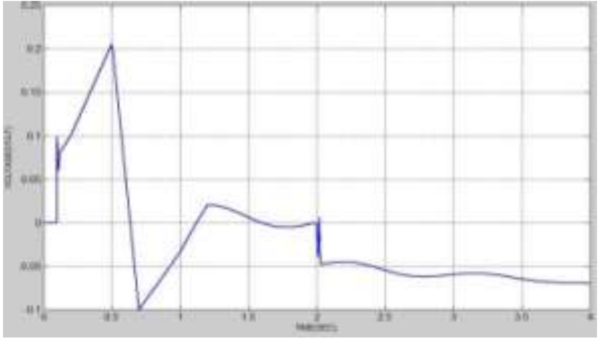

Fig.5.c.1: Voltage of bus4 without SSSC

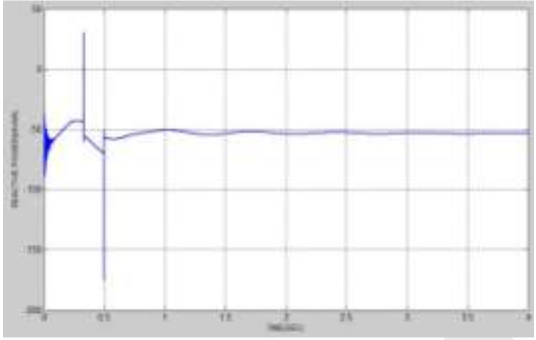

Fig.5.c.2: Reactive power of bus4 without SSSC

The proposed system with SSSC with fault will improve the power flow and also the voltage injection takes place before clearing the fault when compare to without SSSC case. It is clearly shown in Fig.5.c.3&5.c.4

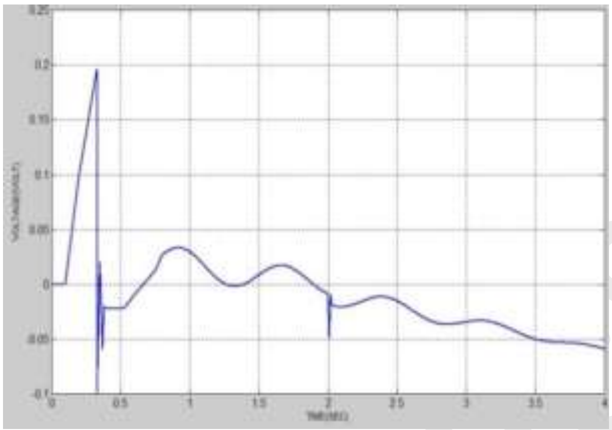

Fig.5.c.3: Voltage of bus4 with SSSC

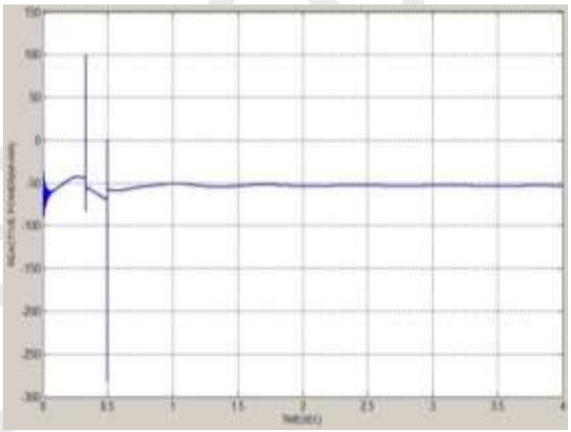

Fig.5.c.4: Reactive power of bus4 with SSSC

Comparison betweenthe voltage and power at different buses with and without SSSC is shown in table 5.3.

Table.5.3: voltage profiles and power flows of faulted system at bus4

Bus no	**Voltage (PU)**		**Active power(MW)**		**Reactive power (MVAR)**	
	With out	**With**	**With out**	**With**	**With out**	**With**
1	**1.0602**	**1.0603**	**1686.61**	**1687.5**	**-307.7**	**-306.55**
2	**1.0602**	**1.0603**	**624.68**	**616.5**	**700**	**600**
3	**1.0694**	**1.0695**	**1335**	**1335.36**	**-60**	**-82.9**
4	**1.2686**	**1.2682**	**403.263**	**566.82**	**30**	**100**

According to the results oftest system with and without SSSC case, the power flow across the bus4 increases also the maximum values compared to other buses. It concluded that where SSSC located the maximum power will improve at that near bus compare to other buses.

D.SUMMERIZATION

(1)*LLG fault:*

Faulted system:

Proposed system without SSSC and with LLG fault can be treated as faulted system. The maximum values of voltage, active power and reactive powers of proposed system are as shown in below table5.4.

Table5.4: Voltage profiles and power flows of faulted system

Bus No	Voltage(p.u)	Active power(MW)	Reactive power(MVAR)
1	1.1427	2373.16	-229.422
2	1.1427	919.6	645.7
3	1.1531	2118.3	119.8
4	1.8952	721.33	72.94

The comparison between the voltages and powers at different buses with and without SSSC is shown in below table. In that SSSC improve the maximum power across the bus4 compare to other buses.

Table.5.5: voltage profiles and power flows of faulted system at bus4

Bus no	Voltage (PU)		Active power(MW)		Reactive power (MVAR)	
	With out	With	With out	With	With out	With
1	1.142	1.1415	2491	2500.8	-212.87	300
2	1.142	1.1415	8929	603.59	700	600
3	1.151	1.1512	214.4	2157.7	1192.2	-90
4	1.8	1.8062	513.5	1352.3	65	429

(2) Three phase fault

Faulted system:
The proposed system without SSSC and with fault can be treated as faulted system.The maximum values of the voltage, active power and reactive powers of proposed system are as shown in below table5.2.

Table5.6: Voltage profiles and power flows of faulted system

Bus No	Voltage(p.u)	Active power(MW)	Reactive power(MVAR)
1	1.191	3314.5	598.46
2	1.191	1136	645.7
3	1.2021	3138.73	343.26
4	2.6104	1008.5	125

When compared the results of test system with and without SSSC, the power flow was improved across the bus4 compared to another buses.

Table5.7: Voltage profiles and power flows of faulted system when SSSC at bus 4

Bus no	Voltage (PU)		Active power(MW)		Reactive power(MVAR)	
	With out	With	With out	With	With out	With
1	1.105	1.1865	1717.6	3445.5	1015.25	1040.4
2	1.105	1.1865	5139.1	642.15	666.5	599.5
3	1.193	1.2	2727.2	3138.9	392.4	510.8
4	2.42	2.45	-222.06	2267.8	710.14	930.1

Comparing all the fault results, it is concluded as the SSSC is capable of controlling the power flow at a desired point in the transmission line. It is also observed that after installing the SSSC, the power flows are improved compared to without SSSC.

VI. CONCLUSION

The SSSC with the voltage source converter was injected the voltage in series with the transmission line. The series controller emulates inductive and capacitive reactance in series with the transmission line thus enhancing the power flow of the system.

According to the obtained results of bus4 the FACTS Controller device SSSC increased the maximum power across various buses in Line to Ground and Double Line to Ground faults. From the resultant waveforms it is clear that the maximum power flow has been increased at various buses when SSSC connected in the system when compared to the system without SSSC.

So the SSSC controller can be placed in different power system locations for different faults to improve the power transfer in the system.

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