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Analysis of Power System Stability of IEEE 9 Bus System with TCSC and STATCOM

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Abstract: **- In this paper series FACTS device TCSC and shunt FACTS device STATCOM is used to improve the stability of IEEE 9 bus system under fault condition. STATCOM is used to compensate the reactive power and TCSC is used to enhance the power transfer capability of the system. The IEEE 9 bus system is designed in MATLAB SIMULINK software by using the standard data. The system is first tested without any device and then the devices are connected one by one and the results are obtained. The analysis of results shows that without the FACTS device under fault condition there are a lot of oscillation in the system and it takes much time for the system to become stable whereas with FACTS device connected the system oscillations are reduced and also the system becomes stable in less time.**

Key Words**: IEEE 9 bus system, Static Synchronous Compensator (STATCOM), Thyristor controlled series capacitor (TCSC), Power system stabilizer (PSS).**

I. INTRODUCTION

The existing power systems are big and are extensive and complex. As the demand is increasing the burden or the load on the transmission lines is also increasing. . Some of the parameters involve which are affected are the rotor speed, bus voltage, power flow and other system variables. Power system stability is the ability of the power system to maintain synchronism among generators under small disturbances. Earlier power system instability problem was used to appear as oscillations among generator rotors within the same plant while this was solved using the power system stabilizer. Later on as the size of the system increased low frequency oscillations are encountered due to the grid connections. such types of problems can be solved using the Flexible AC Transmission System (FACTS) devices.

II. POWER SYSTEM STABILIZER

Power system (PSS) is a device use to measure the improvements in system stability when added to a generator's automatic voltage regulator (AVR) and improves the power system stability. PSS detects the change in generator output power and controls the excitation value and reduces the power swing rapidly. PSS is mainly use to damp the rotor oscillations. There are two types of stabilizer 1)

Generic power system stabilizer which is model using the acceleration power (P_a= difference between mechanical power P_m and output electrical power P_{eo}) and 2) Multi-band power system stabilizer modelled using the speed deviation (dw). In this paper Generic power system stabilizer is used which consists of general gain, low-pass filter, a washout high-pass filter, phase-compensation system, and an output limiter. The input to the power system stabilizer is the synchronous machine speed deviation with respect to nominal (dw in pu) or the acceleration power (P_a=P_m-P_e in pu). The output of pss is the stabilization voltage in pu which is connected as input to the excitation system. Fig 1 shows the block diagram of PSS. It consists of a sensor block, overall gain, washout, lead lag filter 1 and 2 and a limiter. PSS gain is important factor as the damping provided by PSS is directly proportional to the gain up to certain gain value after that the damping begins to decrease.

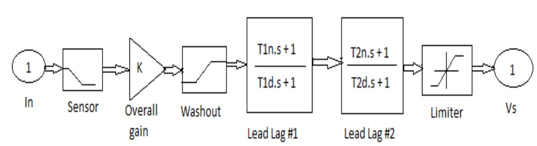

Fig 1: Power system stabilizer

III. STATCOM

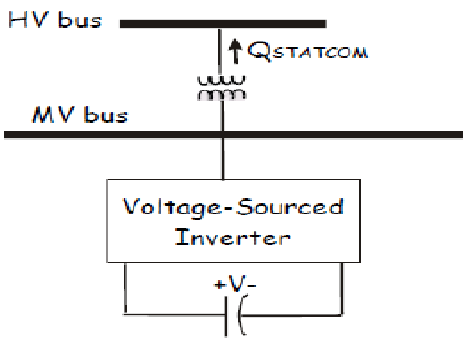

Fig -2: Schematic Diagram of Basic STATCOM

STATCOM is a static synchronous compensator, it is a shunt controller which is used to inject the current and control the voltage. It is connected to the transmission line through a coupling transformer. The shunt controller is use only to consume or to supply the reactive power. STATCOM consists of a voltage source inverter, used to convert dc voltage at its input terminal into three phase ac voltage. STATCOM can be applied with two basic controls which includes (a) control of dc voltage across dc capacitor and (b) regulation of the ac voltage of power system at the bus bar, where STATCOM is installed. The basic principle of STATCOM involves the generation of controllable alternating current voltage source behind a transformer leakage reactance with a voltage source converter connected to a DC storage capacitor. The difference in voltage across the reactance produces active and reactive power exchanges between the STATCOM and the power system.

STATCOM in this paper consists of a gate pulse generator circuit which is use to generate the gate pulses for the firing of the IGBT/Diode of the voltage source inverter. VSI is used to produce the output voltage. To the gate pulse generator input is given as a three phase current which is then converted to d-q frame of reference by parks transformation then its value is compared with the reference voltage by the PI controller and again it is converted to three phase i_a, i_b and i_c current which is feed to three separated PI controllers. Here it is compared with the triangular wave and if the given condition is satisfied then pulses are generated which are the input to the VSI. Voltage Source Inverter has filters and IGBT/Diode which is use to generate the output voltage.

IV. IEEE 9–BUS POWER SYSTEM WITH STATCOM

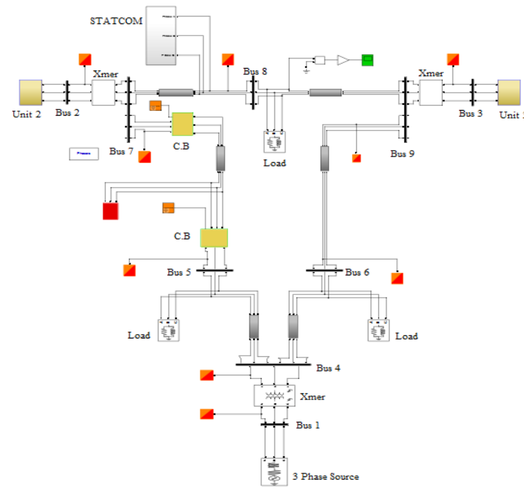

Fig 3: IEEE 9–bus power system with STATCOM

The above figure shows IEEE 9 bus power system where the shunt FACTS device STATCOM is connected between bus no. 7 and buses no 8. This model is prepared in the MATLAB SIMULINK software by using the standard data of the 9 bus system [1].

V. THYRISTOR COTROL SERIES CAPICITOR

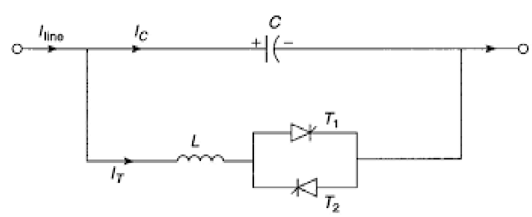

Fig 4: Schematic diagram of TCSC

TCSC is a series FACTS device it consists of a fixed series capacitor in parallel with the thyristor controlled reactor TCR is formed by a reactor which is in series with a bi-directional thyristor valve that is fired with a phase angle in the range of 90^0 and 180^0 with respect to the capacitor voltage. In a TCSC, there are two main operational blocks i.e., an external control and an internal control. The external control operates the controller to accomplish specified compensation objectives; this control directly relies on the measured systems variables to define the particular reference for the internal control, which is usually the value of the controller reactance. The internal control provides appropriate gate signals for the thyristor valve to produce the desired compensating reactance. The basic function of a TCSC is power flow control, which is accomplished either automatically with a "slow" PI controller or manually through direct operator intervention. TCSC consists of a control system block which is used to switch the mode of operation i.e capacitive or inductive the input to this block is the current and voltage in TCSC I_{TCSC} and V_{TCSC}. These control system block produces the firing angle α which is the input to the impedance block. Using this impedance and the controlled voltage source TCSC produces the desired output voltage.

VI. IEEE 9–BUS POWER SYSTEM WITH TCSC

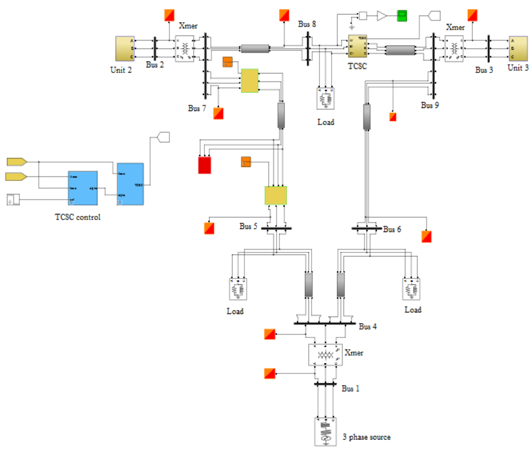

Fig 5: IEEE 9–bus power system with TCSC

The above fig shows the IEEE 9 bus system with the series FACTS device TCSC which is connected to the bus no. 7.

VII. DATA SHEET OF 9 BUS SYSTEM

The system consists of three generators, three transmission lines, three transformers and three loads. Synchronous machine are associated with the generator 2 and generator 3. Also the power system stabilizer is connected to the synchronous machine of generator 2 and 3. Bus 1 is the source bus, Bus 2 and 3 are the generator or the voltage bus as the generators are directly connected to these buses, and bus 4,5,6,7 8 and 9 are the load buses. The system base is chosen to be 100 MVA and all the impedance values are taken corresponding to this base. Table 1 shows the equivalent shunt admittance for the load and the corresponding Y matrix is given in [1]. Table 2 gives the generator data were generator 1 is hydro and generator 2 and 3 are steam generator. The transmission line is having π connections.

Table I
PREFAULT NETWORK ADMITTANCE INCLUDING LOAD EQUIVALENTS

	BUS No	Impedance		Admittance	
		R	X	G	D
Generator					
No 1	1-4	0	0.1184	0	-8.4459
No 2	2-7	0	0.1823	0	-5.4855
No 3	3-9	0	0.2399	0	-4.1684
Transmission Line					
	4-5	0.0100	0.0850	1.3652	-11.6041
	4-6	0.0170	0.0920	1.9422	-10.5107
	5-7	0.0320	0.1610	1.1876	-5.9751
	6-9	0.0390	0.1700	1.2820	-5.5882
	7-8	0.0085	0.0720	1.6171	-13.6980
	8-9	0.0119	0.1008	1.1551	-9.7843
Shunt Admittance					
Load A	5-0			1.2610	-0.2634
Load B	6-0			0.8777	-0.0346
Load C	8-0			0.9690	-0.1601
	4-0				0.1670
	7-0				0.2275
	9-0				0.2835

Table II
GENERATOR DATA

Generator	1	2	3
Rated MVA	247.5	192.0	128.0
KV	16.5	18.0	13.8
Power Factor	1.0	0.85	0.85
Type	Hydro	Steam	Steam
Speed	180 r/min	3600r/min	3600 r/min
X_d	0.1460	0.8958	1.3125
$X_{d'}$	0.0608	0.1198	0.1813
X_q	0.0969	0.8645	1.2578
$X_{q'}$	0.0969	0.1969	0.25
X_l (leakage)	0.336	0.0521	0.0742
$T_{d0'}$	8.96	6.00	5.89
$T_{q0'}$	0	0.535	0.600
Stored Energy at rated speed	2364 MW/s	640 MW/s	301 MW/s

The generator internal voltage and their initial angles are given in pu by

$$E_1\angle\delta_{10} = 1.0566\angle 2.2717$$
$$E_2\angle\delta_{20} = 1.0502\angle 19.7315$$
$$E_3\angle\delta_{30} = 1.0170\angle 13.1752$$

VIII. SIMULATION RESULTS

The system is first tested without any device connected and then the results are taken with STATCOM and TCSC connected one by one.

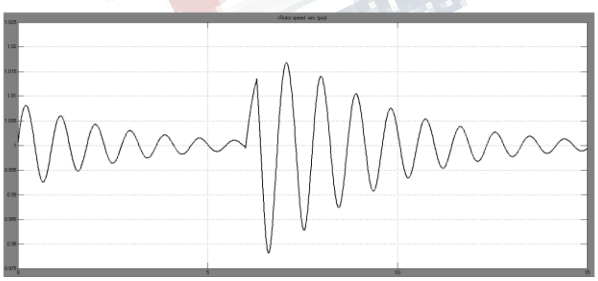

Fig 6: Rotor speed without FACTS device

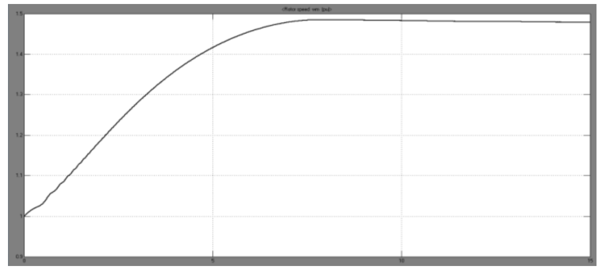

Fig 7: Rotor speed with STATCOM

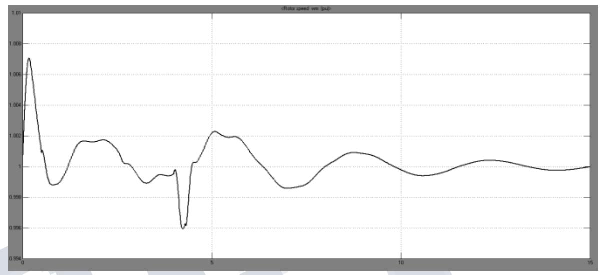

Fig 8: Rotor Speed with TCSC

From fig 6 the result shows that the rotor speed is fluctuate during the fault condition without device and fig 7 shows that STATCOM has improve the rotor speed to the value of almost 1 pu without any fluctuation even during the fault condition. Fig 8 also shows that TCSC has improved the rotor speed to 1 pu after the fault has occurred and hence stabilize the system in less time.

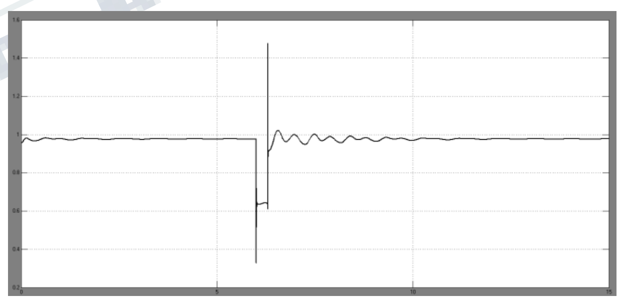

Fig 9: Line Voltage without FACTS device

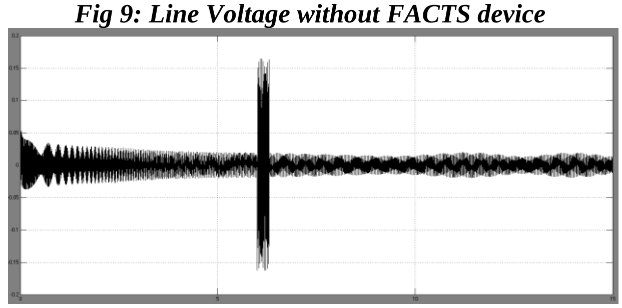

Fig 10: Line Voltage with STATCOM

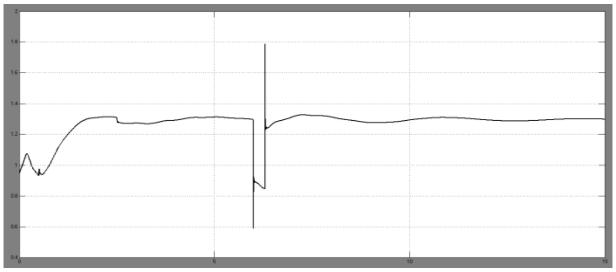

Fig 11: Line Voltage with TCSC

Fig 9 shows the line voltage between bus 8 and 9 without any device the system takes more time to settle whereas fig 10 shows the line voltage with STATCOM because of presence of STATCOM the voltage has settled just after the fault and also the fault magnitude is reduced also fig 11 shows that TCSC has settled the system in less time as compared to the system without FACTS device.

IX. CONCLUSIONS

After observing the results conclusion can be drawn that the FACTS device TCSC and STATCOM has enhanced the power system stability by reducing the settling time of the system. In this paper the simulation of STATCOM and TCSC has verified that the devices has improved the voltage profile and also helps in maintain the rotor speed of both the synchronous machine to almost 1 pu which means the generators remains in synchronism. The best possible locations of the FACTS devices are found to vary with the location of the fault and the operating condition of the devices. Further scope in this project could be to connect these devices to another bus system for example 15 bus system.

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