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Control of Synchronous Generator Excitation and Rotor Angle Stability by using Static Synchronous Compensator (STATCOM) with Reference Voltage Compensation (RVC) Simulation Method

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ABSTRACT: The static synchronous compensator (STATCOM) is one type of FACTS devices which resembles in many respects a rotating synchronous condenser used for voltage control and reactive power compensation. The STATCOM can increase transmission capacity, damping low frequency oscillation, and improving transient stability. This paper investigated for the transient stability improvement by using static synchronous compensator (STATCOM). The MATLAB software model is used for simulation of test system. Control scheme for STATCOM (PID controller) and generator excitation to achieve transient stability, damping oscillation is controlled by power system (PSS) and voltage regulation enhancement of power systems is presented. First, the model of STATCOM in a power system is derived. Then, the nonlinearities of the generator and the STATCOM model are alleviated. With the help of robust control theory, the fluctuation of system structure, the parameter uncertainties and the interconnection between the generator and STATCOM are taken into consideration in the controller design. The results present the system performance with all operating conditions. It is shown that the proposed control can provide better stability, voltage control and damping of rotor angle than other schemes.

Keywords: Transient stability, FACTS, STATCOM, PSS, damping and voltage regulation.

1. INTRODUCTION

The relatively recent development and use of FACTS controllers in power transmission systems has many applications of these controllers to improve the stability of power system networks. Several FACTS equipment is available or still under development, based on the solid state switch with conventional thyristors and on the voltage source inverter with GTO switches [1,2]. All these equipment provide controllability to the AC transmission system by adjusting the reactive power, the series impedance of transmission line, or the active and reactive power system. The STATCOM was proposed by several researchers to compensate the reactive current from or to the power system. This function is identical to the synchronous condenser with
rotating mass, but its response time is extremely faster than of the synchronous condenser. This is very effective to increase transient stability, to enhance voltage support, and to damping low frequency oscillation for the transmission system. In this paper a MATLAB software package are performed to verify the transient stability and compensation of reactive power of AC transmission system. Under these conditions, transmission networks are called upon to operate at high transmission levels, and thus power engineers have had to confront some major operating problems such as transient stability, damping of oscillations and voltage regulation, etc. While generator excitation controllers are helpful in achieving rotor angle stability or voltage regulation enhancement, with only excitation control, the system stability may not be maintained if a large fault occurs close to the generator terminal, or simultaneous transient stability and voltage regulation enhancement may be difficult to achieve. Researchers have found that the performance of power systems can be further improved by applying the recently developed FACT device [1].

FACTS (flexible AC transmission systems) controllers. Among the FACTS family, the static synchronous compensator (STATCOM) is a device which can provide smooth and fast reactive power compensation to power systems, and therefore can be used to provide voltage support, increase transient stability and improve damping oscillation. Its ability for energy storage is not a rigid necessity but is only required for system imbalance or harmonic absorption. As a consequence, the not-so-strict requirement for a large energy storage device makes STATCOM more robust and also enhances the response speed.

Traditionally, the generator excitation controller (e.g. PSS/AVR) and STATCOM controller are designed separately without considering their interactions, which is mainly due to the difficulty of getting control signals from these geographically distributed pieces of equipment. While generator excitation controllers are helpful in achieving rotor angle stability or voltage regulation maintenance, with only excitation control, the system stability may not be maintained if a large fault occurs close to the generator terminal, or simultaneous transient stability and voltage regulation enhancement may be difficult to achieve. Researchers have found that the performance of power systems can be further improved by applying the recently developed FACTS (flexible AC transmission systems) controllers.

II. POWER SYSTEM STABILIZERS (PSS)

Power system stabilizers (PSS) have been extensively used as supplementary excitation controllers to damping out the low frequency oscillations and enhance the overall power system stability. Fixed structure power system stabilizers have practical applications and generally provide acceptable dynamic performance [4]. There have been arguments that these controllers, being tuned for one nominal operating condition and provide optimal performance when there are variations in the system connected load. There are two main approaches to stabilize a power system over a wide range of operating conditions, namely multi band and generic mode operation for controlling damping oscillation.

Show fig.1 a generation unit consisting of a synchronous generator, a turbine a governor and an excitation system an automatic voltage regulator (AVR) and a PSS [3].

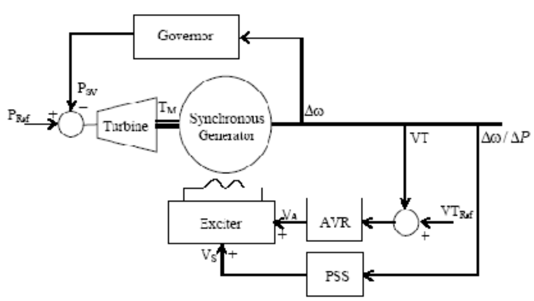

Fig. 1. Generation unit diagram.

Next, a transient model of a synchronous machine is considered and its mechanical parts are modeled by;

$$\Delta\omega(t) = \frac{1}{2H}\int_0^t (T_M - T_E)dt - K_d\Delta\omega(t) \quad (1)$$

$$\omega(t) = \Delta\omega(t) + \omega_0 \quad (2)$$

Where, **ωΔ** is speed variation, **ω** is mechanical speed of rotor, **H** is the inertia constant, $\mathbf{T_M}$ **/** $\mathbf{T_E}$ *are* mechanical / electrical torque respectively and $\mathbf{K_d}$ is a damping factor. Electrical parts of synchronous machine can be described by a sixth order state space model.

III. STATCOM

(Static synchronous compensator) The STATCOM generates a balanced 3-phase voltage whose magnitude and phase can be adjusted rapidly by using semiconductor switches. The STATCOM is composed of a voltage source inverter with a dc capacitor, signal generation and control circuit [2].

A STATCOM is a controlled reactive-power source. It provides the desired reactive-power generation and absorption entirely by means of electronic processing of the voltage and current waveforms in a voltage source converter (VSC). A single line STATCOM power circuit is shown in Fig. 1(a), where a VSC is connected to a bus through magnetic coupling. In Fig. 1(b), a STATCOM is an adjustable voltage source behind a reactance meaning that capacitor banks and shunt reactors are not needed for reactive-power generation and absorption, thereby giving a STATCOM a compact design, as well as low noise and low magnetic impact. The exchange of reactive power between the converter and the ac system can be controlled by varying the amplitude of the 3-phase output voltage, Es**,** of the converter, as illustrated in Fig. 1(c).

That is, if the amplitude of the output voltage is increased above that of the bus voltage, Et**,** then a current flows through the reactance from the converter to the ac system and the converter generates capacitive-reactive power for the ac system. If the amplitude of the output voltage is decreased below the bus voltage, then the current flows from the ac system to the converter and the converter absorbs inductive-reactive power.

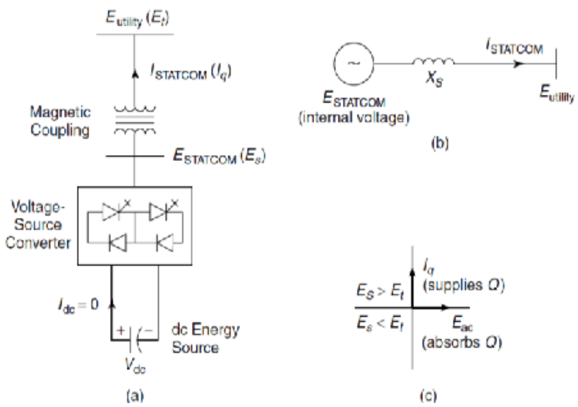

Fig. 2. The STATCOM principle diagram: (a) a power circuit; (b) an equivalent circuit; and (c) a power exchange from the ac system.

IV. THE V-I CHARACTERISTIC

A typical *V-I* characteristic of a STATCOM is depicted in Fig. 3. As can be seen, the STATCOM can supply both the capacitive and the inductive compensation and is able to independently control its output current over the rated maximum capacitive or inductive range irrespective of the amount of ac system voltage.

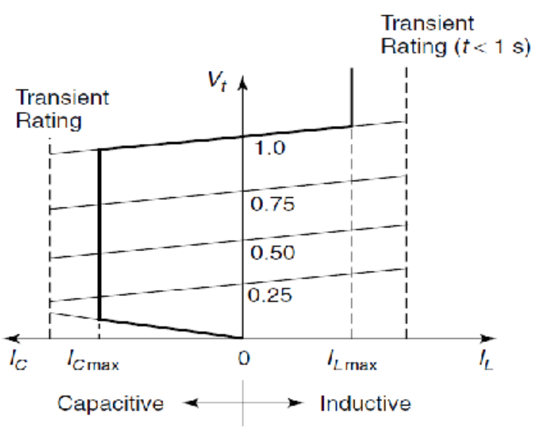

Fig. 3. The *V-I* characteristic of the STATCOM.

That is, the STATCOM can provide full capacitive-reactive power at any system voltage even as low as 0.15 pu. The characteristic of a STATCOM reveals strength of this technology: that it is capable of yielding the full output of capacitive generation almost independently of the system voltage (constant-current output at lower voltages). This capability is particularly useful for situations in which the STATCOM is needed to support the system voltage during and after faults where voltage collapse would otherwise be a limiting factor [2].

Power circle diagram of STATCOM absorbs and deliver reactive power in power system. Shown in fig.4

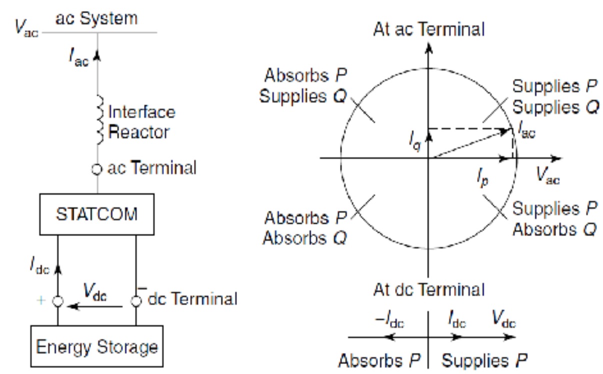

Fig. 4. The power exchange between the STATCOM and the ac system.

V. MODEL OF STATCOM IN POWER SYSTEMS

Show the fig. of power system model single line three bus systems with transmission line fault occurs.

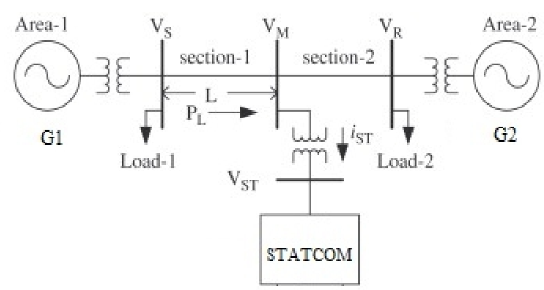

Fig. 5. Single line diagram infinite bus with fault.

The STATCOM generates a balanced 3-phase voltage whose magnitude and phase can be adjusted rapidly by using semiconductor switches. The STATCOM is composed of a voltage source inverter with a dc capacitor, coupling transformer [5], and signal generation and control circuit Assuming balanced, fundamental frequency voltages, the controller can he accurately represented in transient stability studies using the basic model shown in fig.5 Without losing generality, a STATCOM system is employed to derive the model. It resembles the case where power is transmitted through an electrical transmission line connecting various generators and loads at its sending and receiving end. It should be noted that except the STATCOM parameters, all the transmission network parameters are not known in practice [5].

VI. TRANSIENT STABILITY

The double machine three bus systems qualitatively exhibits important characteristics of the behavior of machine system, it is extremely useful to describe the general concepts of power systems stability and is relatively simple to study [1]. Shown in Fig.6 is thus used to show the effect of STATCOM in improving system transient stability [2]. The compensation capacitor is omitted during this investigation. During the fault the transmitted electrical power decreases significantly while mechanical input power to generator remains constant, as a result, the generator continuously accelerates as can be seen in the generator speed and power angle shown in Fig.6 (With STATCOM) respectively. When the fault is cleared, the speed is continuously increasing and system is not able to retain stability due to the lack of damping. During the fault, the generator terminal experiences voltage sag of more than 90% without the STATCOM as shown in Fig.6. This voltage is not recovered after the fault clearance due to the lack of reactive power support, the shaft sections of the turbine generator set are subjected to high torsional oscillations and force as seen in the electromechanical torques [6].

When the STATCOM is connected to the midpoint terminals, reactive power controller adapts the value of the inverter firing angle according to system requirements. As shown in Fig.6. STATCOM firing angle, the firing angle should remain zero at normal operating conditions and there is no reactive power exchange between the system and the STATCOM. When the fault occurs, the firing angle is changed instantly and the reactive power is supplied by the STATCOM to the system. When the fault is cleared, the firing angle is reduced to zero again and the STATCOM back to the idle condition [6]. The impact of reactive power modulation using STATCOM on system performance can be seen in Fig.6 Connecting the STATCOM to the midpoint terminals will maintain the rotor speed and the power angle at their nominal values even during the fault. The voltage sag at the generator terminals will be reduced substantially. The shaft oscillations and torsion forces will be reduced to almost the normal steady state condition [7,8,9].

VII. EXPERIMENTAL TEST MODEL

For the purpose of studying the transient phenomena and obtaining more practical results, the proposed MATLAB/SIMULINK control scheme in computer hardware and software designed specifically for the solution of power system electromagnetic transients. Because real time operation can be achieved, it can be applied in areas traditionally reserved for analogue simulators, and Testing of system controller. Double machine three bus models are power system for evaluating the proposed design method is considered. Using this model, we consider a typical two 1000MVA, 11KV, 50Hz synchronous generator to connect with a 1000MVA, 11/400KV two transformers and two transmission lines operating voltage label are 400KV and 300KM length connected to three buses. MATLAB/ SIMULINK model are shown in fig.6

Generator:
S=1000MVA, V=11 kV, ω_0= 314.159rad/s, D=5.0 pu., H= 4.0s, X_d= 1.863 pu, X'_d = 0.657pu, X''_d=0.245pu, T'_{d0} = 6.9s T''_{d0}= 0 .03s , X_q= 0.657 pu. , X_q'' = 0.27pu, T''_{d0}= 0.06s, X_{ad}=1.712pu, k_c= 1, and Max [Ef(t)] = 6.Opu.

Transformer:
S = 1000 MVA, winding 1(Y) = 11 kV, winding 2(Δ) = 400 kV, and X_T= 0.227 pu.

Transmission line:
Length =300km, X_{L1} = X_{L2} = 0.24265 pu, R_{L1}= RL2 = 0.016pu and f= 50Hz

STATCOM:
220MVAR, R_s=0.01 pu., L=0.1 pu, C_{dc}= 100OpF, snubber circuit: Rb = 5000 Ω, and *C*, = 0.05 µF.

Test system controllability and observe ability is shown under fig.

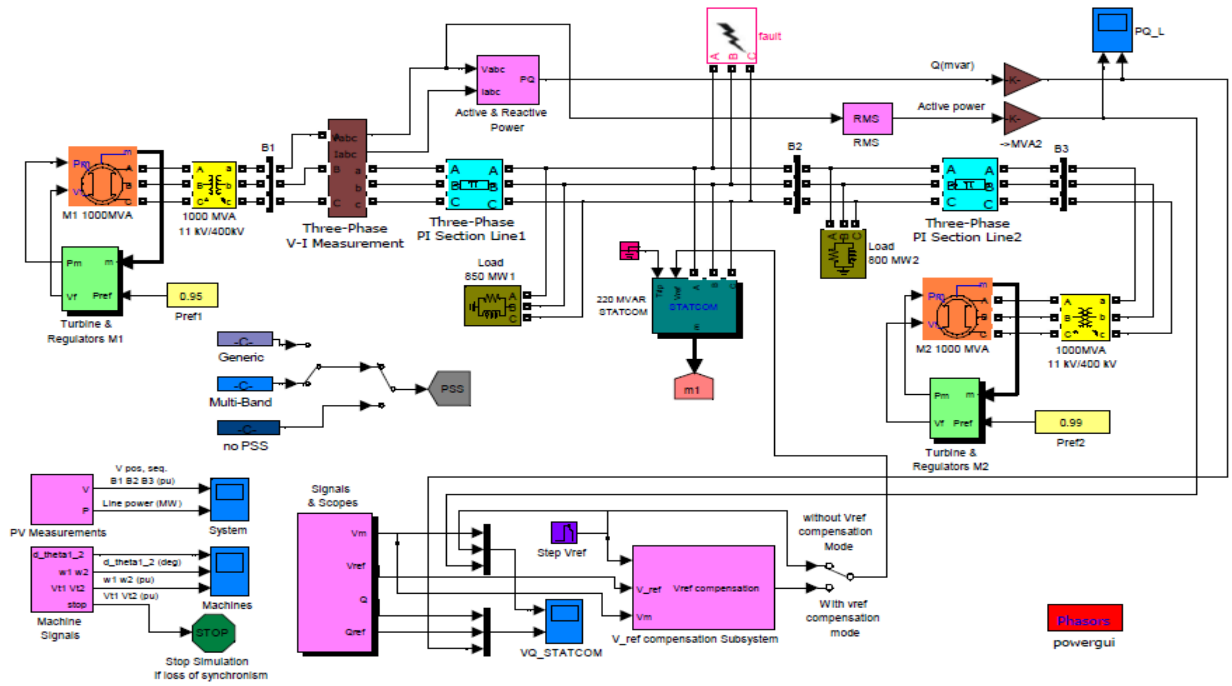

Fig. 6. MATLAB experiment model for transient stability test system.

VIII. SIMULATION AND RESULTS

In this model, performance of controller is evaluated conventional PSS multiband operation from IEEE standard. The simulations carried out using MATLAB/ SIMULINK environment for power system Fig.7 for evaluating robustness of proposed PSS stabilizations of these PSS is simulated of disturbances.

1. Without STATCOM- Shows d_theta angle instability of synchronous generator, angular velocity ω1 and ω2 and terminal voltage unstable due to occurs single phase fault. When no compensation allows-

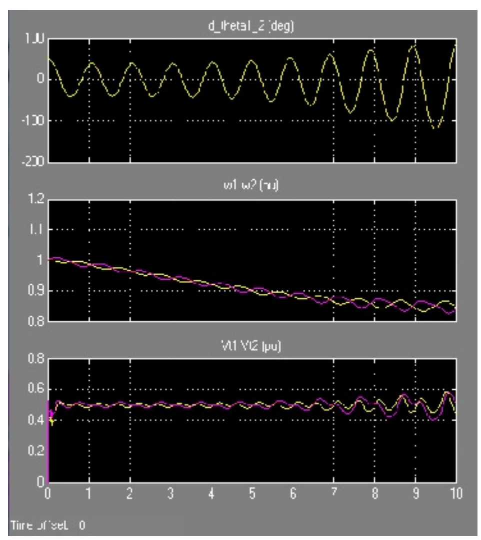

Fig. 7. d_theta angle of without STATCOM.

2. With STATCOM- Shows d_theta angle stability of synchronous generator, angular velocity ω1 and ω2 and terminal voltage stable single phase fault on a generator bus. When RVC compensation allows-

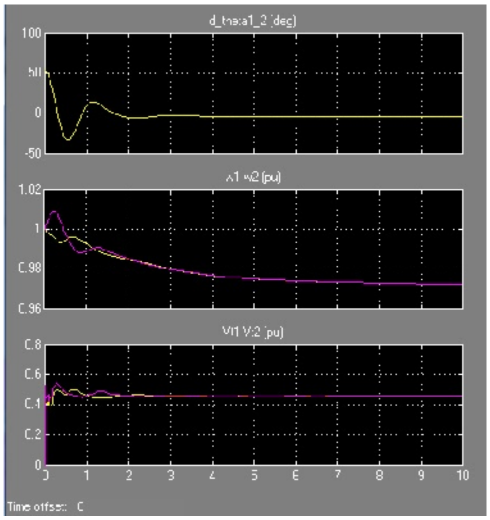

Fig. 8. d_theta angle of with STATCOM.

3. This simulation result shows that line power fluctuation and bus voltage fluctuation Without STATCOM.

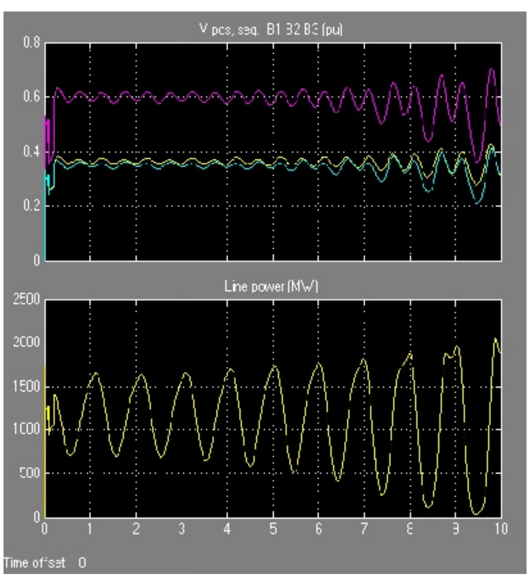

Fig. 9. Line power and bus voltage of without STATCOM.

4. This simulation result shows that line power fluctuation and bus voltage fluctuation With STATCOM.

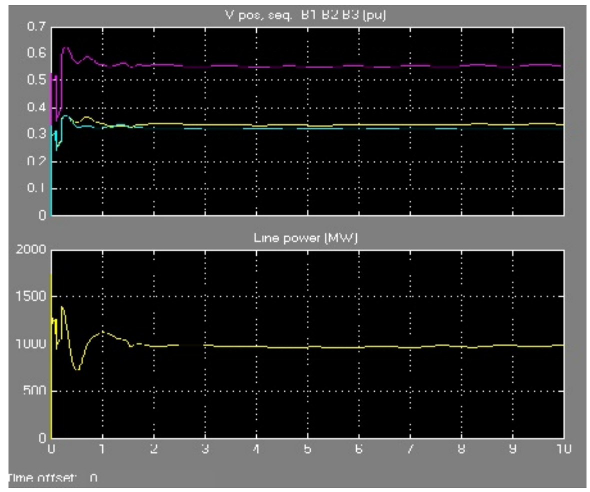

Fig. 10. Line power and bus voltage of with STATCOM.

IX. CONCLUSION

In this paper a control system of the STATCOM was presented for the transient stability enhancement. The test system is two synchronous machine transmission systems. And a simulation model with the MATLAB/SIMULINK was developed to verify the interaction between the STATCOM and AC transmission system. The main circuit configuration of STATCOM was represented by 6 pulse voltage source inverter with gate turn off (GTO) switches in the Power System SIMULINK. Also the signal generation and control circuit were modeled with the SIMULINK toolbox in the SIMULINK/MATLAB model. In this paper MATLAB technique is used for decreasing transient instability of STATCOM output signal parameter. Using STATCOM can improve the transient stability of AC transmission system and it is able to compensating the reactive power. Therefore STATCOM can also increase reliability and capability of AC transmission system.

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