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Transient Stability Enhancement of Power System Using STATCOM

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Abstract: The increased demands on transmission, absence of long term planning and need to provide open access to generating companies and customers have together created tendency towards less security and reduced quality of supply. Essentially, FACTS opens up new opportunities for controlling power and enhancing the usable capacity. The development of FACTS controllers has followed 2 distinctly different technical approaches, both resulting in a compressive group of controllers able to address targeted transmission problems. The first group employs reactive impedances or a tap-changing transformer with thyristor switches as controlled-elements; the second group uses self-commutated static converters as controlled voltage sources. The Static Synchronous Compensator (STATCOM), based on the voltage source inverter is a widely used FACTS device. This study deals with the basic simulation of STATCOM and demonstration of transient stability enhancement using STATCOM through MATLAB/ SIMULINK.

Key words: FACTS, STATCOM modeling, transient stability, synchronism, voltage control

INTRODUCTION

Increased use of transmission facilities due to higher industrial output and deregulation of the power supply industry have provided the momentum for exploring new ways of maximizing power transfers in existing transmission facilities while, at the same time, maintaining acceptable levels of network reliability and stability. In this environment, high performance control of the power network is mandatory. The possibility of controlling power flow in an electric power system without generation rescheduling or topology changes can improve the power system performance. By use of controllable components, the line flows can be changed in such a way that thermal limits are not exceeded, losses minimized, stability margins increased, contractual requirement fulfilled, etc. without violating the economic generation dispatch.

Recent break-throughs in power electronics technology have enabled the development of a variety of sophisticated controllers used to solve long-standing technical and economical problems found in electrical power systems at both the transmission and distribution levels. These emerging controllers are grouped under the headings FACTS and custom power technology, respectively. FACTS is 1 aspect of the power electronics revolution that is taking place in all areas of electric energy. A variety of powerful semiconductor devices not only offer the advantage of high speed and reliability of switching but, more importantly, the opportunity offered by a variety of innovative circuit concepts based on these power devices enhance the value of electric energy. The use FACTS devices in a power system can potentially overcome limitations of the present mechanically controlled transmission systems. By facilitating the bulk power transfers, these interconnected networks minimize the need to enlarge power plants and enable neighboring utilities and regions to exchange power. The stature of FACTS devices within bulk power system will continually increase as the industry moves toward a more competitive posture in which power as bought and sold as a commodity. As power wheeling becomes increasingly prevalent, power electronic devices will be utilized more frequently to insure system reliability and stability and to increase maximum power transmission along various transmission corridors.

The basic operating requirements of an ac power system are that the synchronous generators must remain in synchronism and the voltages must be kept close to their rated values (Padiyar, 2002). The capability of a power system to meet these requirements in the face of possible disturbances (line faults, generator and line outages, load switchings, etc.) is characterized by its transient, dynamic and voltage stability. The stability requirements usually determine the maximum transmittable power at a stipulated system security level.

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In this study, a 2-machine power system has been considered for describing the impact of STATCOM in enhancing the transient stability of the power system in the event of a 3-phase fault near a bus (Canizares *et al.*, 2003; Tan, 1999; Padiyar, 2008; Yang *et al.*, 2000; Yang *et al.*, 2001). This study investigates the changes in terminal voltages of the 2 machines, machines speeds and rotor angle difference between the 2 machines with and without STATCOM, when the fault occurs. Simulation results for the case study conducted on the 2 machine system are also presented.

PRINCIPLE OF STATCOM

Static var generators generate or absorb controllable reactive power by synchronously switching capacitor and reactor banks 'in' and 'out' of the network. The aim of this approach is to produce variable reactive shunt impedance that can be adjusted to meet the compensation requirements of the transmission network. The possibility of generating controllable reactive power directly, without the use of ac capacitors or reactors, by various switching power converters was disclosed by Narain *et al.* (2001). These converters are operated as voltage and current sources and they produce reactive power essentially without reactive energy source components by circulating alternating current among the phases of the system. Functionally, from the standpoint of reactive compensation, their operation is similar to that of an ideal synchronous machine whose reactive power output is varied by excitation control. Like the mechanically powered machine, they can also exchange real power with the ac system if supplied from an appropriate, usually dc source. Because of these similarities with a rotating synchronous generator, they are termed Static Synchronous Generators (SSG). When an SSG is operated without an energy source and with appropriate controls to function as a shunt-connected reactive compensator, it is termed as Static Synchronous Compensator or STATCOM.

Static synchronous compensator (STATCOM) is a FACTS controller based on voltage-sourced converters. This device is shunt connected to a power system. Through injecting or absorbing reactive current, STATCOM can regulate the voltage at its location (Narain *et al.*, 2001). Consequently, the voltage stability, transient stability, or loadability can be greatly improved. If a storage device such as a large capacitor, battery source or flywheel, a STATCOM can provide real power compensation too.

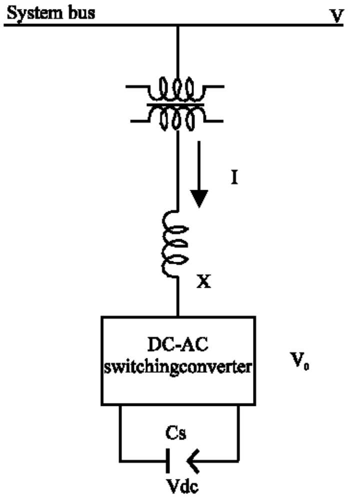


Fig. 1: Reactive power generation by voltage-sourced switching converter

The basic voltage-sourced converter scheme for reactive power generation shown schematically, in the form of single-line diagram in Fig. 1. From a DC voltage source, provided by the charged capacitor C_s, the converter produces a set of controllable 3-phase output voltages with the frequency of the ac power system. Each output voltage is in phase with and coupled to the corresponding ac system voltage via a relatively small tie reactance (which in practice is provided by the per phase leakage inductance of the coupling transformer). By varying the output voltage produced, the reactive power exchange between the converter and the ac system can be controlled in a manner similar to that of the rotating synchronous machine. That is, if the amplitude of the output voltage is increased above that of the ac system voltage, then the current flows through the tie reactance from the converter to the ac system and the converter generates reactive power for the ac system. If the amplitude of the output voltage is decreased below that of the ac system, then the reactive current flows from the system to the converter and the converter absorbs reactive power. If the amplitude of the output voltage is equal to that of the ac system voltage, the reactive power exchange is zero.

STATCOM MODELLING

Several distinct models have been proposed to represent FACTS in static and dynamic analyses. These models are based on the energy balance criterion used in the modeling and simulation of voltage-sourced converter based controller (Narain *et al.*, 2001; Padiyar, 2008).

The basic structure of a STATCOM with PWM-based voltage control is depicted in Fig. 2.

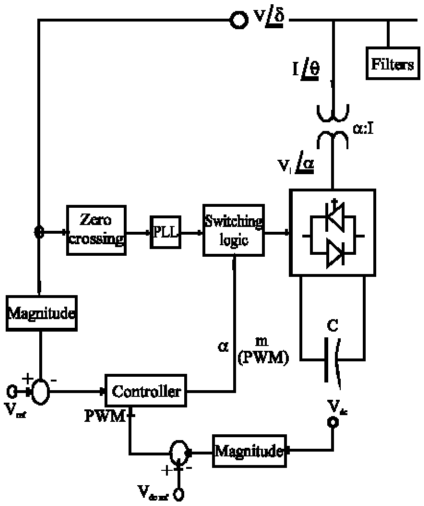


Fig. 2: Block diagram of a STATCOM with PWM voltage control

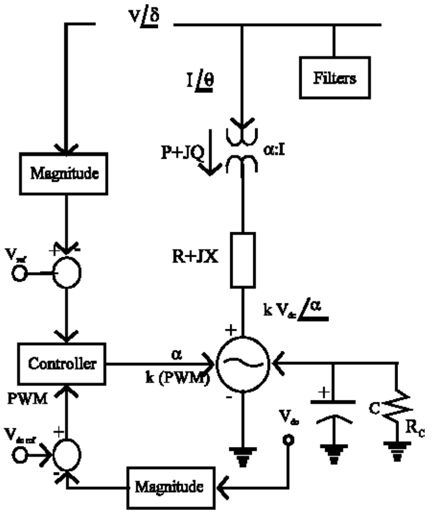


Fig. 3: Transient stability model of a STATCOM with PWM voltage control

The STATCOM models proposed here are based on the power balance equation:

$$P = P_{dc} + P_{loss} \tag{1}$$

which basically represents the balance between the controller's ac power P and DC power P_{dc} under balanced operation at fundamental frequency (these are the basic assumptions on which steady state and transient stability studies of power systems are based). For the models to be accurate, it is important to represent the losses of the controllers (P_{loss}).

Transient stability model: The transient stability indicates the capability of the power system to recover following a major disturbance. A major disturbance, for example a severe fault on a heavily loaded line, can result in a large step-like decrease in transmitted electric power while the generators feeding the line receive constant mechanical input power. The difference between mechanical input and electrical output power causes the machines to accelerate. The transient stability at a given power level and fault clearing time is primarily determined by the P versus δ characteristic of the post-fault system that controls the electric power transmission and there by the rate of energy absorption from the machine (Padiyar, 2002).

Assuming balanced, fundamental frequency voltages, the controller can be accurately represented in transient stability studies using the basic model shown in Fig. 3 (Narain *et al.*, 2001).

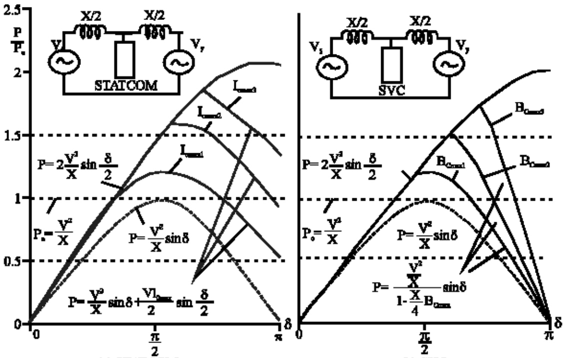
The p.u. differential-algebraic equations (DAE) corresponding to this model can be readily written as follows:

$$\begin{aligned}
&\begin{bmatrix} \dot{x}_c \\ \dot{\alpha} \\ \dot{m} \end{bmatrix} = f_c(x_c, \alpha, m, V, V_{dc}, V_{ref}, V_{dcref}) \\
&\dot{V}_{dc} = \frac{VI}{CV_{dc}}\cos(\delta-\theta) - \frac{G_c}{C}V_{dc} - \frac{RI^2}{CV_{dc}} \\
&0 = \begin{bmatrix} P - VI\cos(\delta-\theta) \\ Q - VI\sin(\delta-\theta) \\ P - V^2G + kV_{dc}VG\cos(\delta-\alpha) \\ +kV_{dc}VB\sin(\delta-\alpha) \\ Q + VB - kV_{dc}VB\cos(\delta-\alpha) \\ +kV_{dc}VGin(\delta-\alpha) \end{bmatrix}
\end{aligned} \tag{2}$$

Where most of the variables are explained on Fig. 3. The admittance $G+jB = (R+jX)^{-1}$ is used to represent the transformer impedance and any ac series filters (e.g., smoothing reactors), whereas G_c is used to model the switching inertia of the converter due to the electronic switches and their associated snubber circuits, which have a direct effect on the capacitor voltage dynamics. The constant $k = \sqrt{3/8}m$ is directly proportional to the modulation index m.

The variables x_c and functions $f_c(x_c, \alpha, m, V, V_{dc}, V_{dcref})$ in (2) stand for the internal control system variables and equations, respectively and hence vary depending on whether a PWM or phase control technique is used in the controller. For example, in the simple PWM voltage controller shown in Fig. 3, the variables and differential equations associated with the various control blocks directly define x_c and $f_c(x_c, \alpha, m, V, V_{dc}, V_{dcref})$. Observe that in this PWM controller, the ac bus voltage magnitude is controlled through the modulation index m, as this has a direct effect on the VSC voltage magnitude, whereas the phase angle δ, which basically determines the active power P flowing into the controller and hence the charging and discharging on the capacitor, is used to directly control the DC voltage magnitude. Note also that the controllers have a bias, which corresponds to the steady state value of the modulation index m_0 for the voltage magnitude controller and to the phase angle ä of the output voltage of the STATCOM for the DC voltage controller (this value changes as the system variables change during the simulation). Although, the latter complicates the simulation, it is needed to guarantee a direct control of the charging and discharging of the capacitor, which basically depends on the power flow between the VSC and the ac bus, i.e. it depends on $(\delta - \alpha)$. This can be simplified by setting the bias of the DC voltage control to the constant value $\delta_0 = \delta_0$, where ä$_0$ stands for the bus voltage phase-shift when the STATCOM is not connected. Typically, the modulation index control would be faster than the phase angle control, as there is a significant charging and discharging inertia of the capacitor due to its relative large value, whereas the modulation index has an immediate effect on the output voltage of the controller.

The Eq. (2) is the direct result of applying the power balance Eq. (1) and allows to represent fairly accurately the dynamics of the DC voltage in the controller model. The adequate modeling of the V_{dc} dynamics is important, given the fact that the time constants associated with the dc voltage on the capacitor are in the order of the time constants of interest in stability studies. These dc voltage dynamics are basically defined by the G_c parameter in the proposed model, as its value directly affects the capacitor's charging and discharging time constant.



(a) STATCOM (b) SVC

Fig. 4: Transmitted power versus transmission angle of a 2-machine system with a midpoint STATCOM (a) and a midpoint SVC (b) obtained with different var ratings

ENHANCEMENT OF TRANSIENT STABILITY WITH STATCOM

A STATCOM, controlled to regulate the terminal voltage, can increase the transient stability by maintaining the transmission voltage at the midpoint or some appropriate intermediate point in face of the increased power flow encountered immediately after fault clearing. However, the transient stability can be increased further by temporarily increasing the voltage above the regulation reference for the duration of the first acceleration period of the machine. The voltage increased above its nominal value will increase the electric power transmitted and thus, will increase also the deceleration of the machine. This is illustrated in Fig. 4, where the P versus δ plots of a simple 2-machine system with different midpoint compensations is shown (Narain *et al*., 2001; Padiyar, 2008). The plot marked

$$P = 2\frac{V^2}{X}\sin\frac{\delta}{2}$$

represents the P versus δ plot obtained with an ideal compensator holding the midpoint voltage constant. The plots marked with STATCOM and SVC represent these compensators with a given rating insufficient to maintain constant midpoint voltage over the total range of δ. Thus, the P versus δ plots are identical to that of the ideal compensator up to a specific δ ($\delta = \delta_i$) at which the SVC becomes a fixed capacitor and the STATCOM a constant current source. In the interval between δ_i and π, the P versus δ plots are those which correspond to a fixed midpoint capacitor and a constant reactive current source. The continuations of these plots in the δ_i to zero interval show the P versus δ characteristic of the 2-machine system with the maximum capacitive admittance of the SVC and with the maximum capacitive output current of the STATCOM. That is angles smaller than δ_i the transmission line is overcompensated and for angles greater, it is under-compensated. This overcompensation capability of the compensator can be exploited to enhance the transient stability by increasing the var output to the maximum value after fault clearing. Depending on the rating of the compensator and the allowed voltage increase, the attainable increase in transient stability margin can be significant.

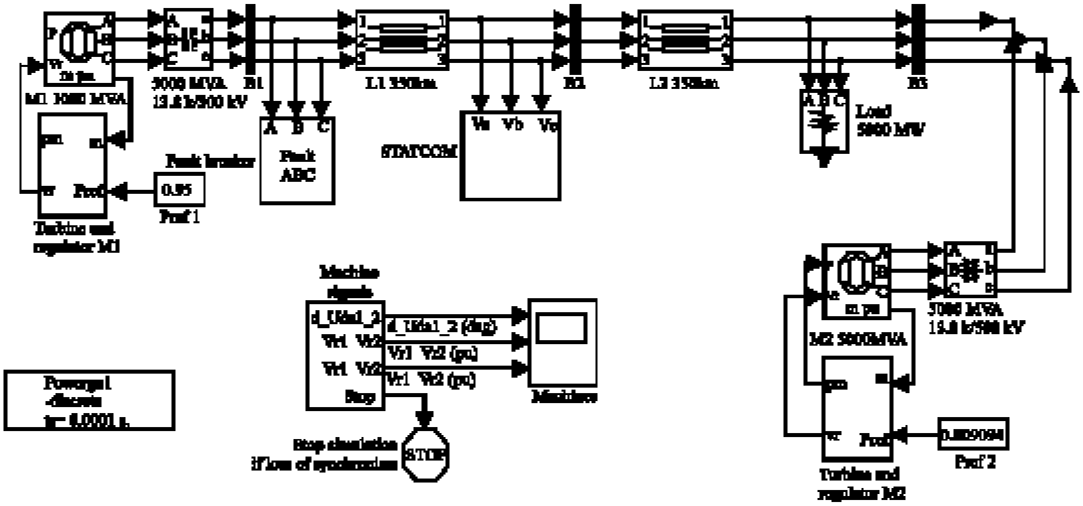


Fig. 5: Transient stability enhancement using STATCOM

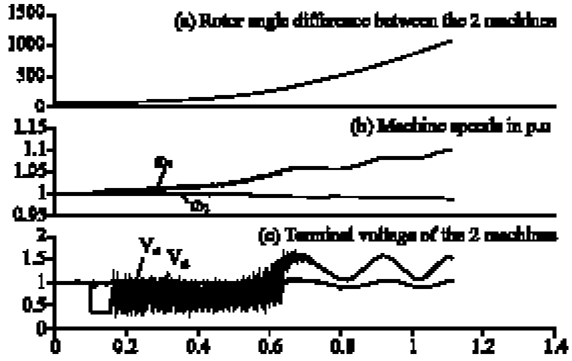


Fig. 6: Simulation results without STATCOM

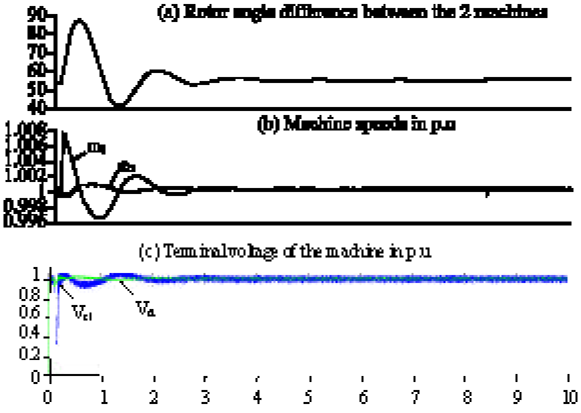


Fig. 7: Simulation results with STATCOM

RESULTS

Circuit description: The multi-machine system used for simulating the transient stability enhancement using STATCOM is described in this study (Claudio *et al*., 2003; Tan, 1999; Padiyar, 2008; Yang *et al*., 2000; Yang *et al*., 2001). A 1000 MW hydraulic generation plant (machine M1) is connected to a load center through a long 500 kV, 700 km transmission line. The load center is modeled by a 5000 MW resistive load. The load is fed by the remote 1000 MW plant and a local generation of 5000 MW (machine M2). The system has been initialized so that the line carries 950 MW which is close to its surge impedance loading (SIL = 977 MW). In order to maintain system stability after faults, the transmission line is shunt compensated at its center by a 200-Mvar STATCOM. The 2 machines are equipped with a Hydraulic Turbine and Governor (HTG), Excitation system. The circuit diagram is as shown in Fig. 5.

Three-phase fault-Impact of STATCOM: A 3-phase fault is applied at the bus B1, i.e., near the machine M1 and observed the impact of STATCOM for stabilizing the network during a severe contingency. If the STATCOM is not connected, the angle between the 2 machines is increased rapidly and the 2 machines fell out of synchronism after fault clearing. This is illustrated in Fig. 6, where as a STATCOM will support the voltage by injecting reactive power on the line when the voltage is lower than the reference voltage. It will increase the transient stability by supporting the voltage. This is illustrated in Fig. 7.

CONCLUSION

Different simulations are carried out in MATLAB/SIMULINK environment. The STATCOM is simulated for the Transient Stability Enhancement on a multi-machine system. The system is simulated by initiating a 3-phase fault near the first machine in the absence of STATCOM. In this case, the difference between the rotor angles of the 2 machines is increased tremendously and ultimately loses its synchronism. But, when the same fault is simulated in the presence of STATCOM, the system becomes stable as the STATCOM provides voltage support at the bus where it is connected. This is illustrated in Fig. 6 and 7. Thus, it is concluded that, using STATCOM, Transient Stability Limit can be enhanced.

REFERENCES

Canizares, C.A., M. Pozzi, S. Corsi and E. Uzunovic, 2003. STATCOM modeling for voltage and angle stability studies. Elec. Power Energy Sys., 25: 1-20.

Narain, G., Hingorani and L. Gyugyi, 2001. Understanding FACTS: Concepts and technology of flexible AC transmission systems. Standard Publishers Distributors. IEEE. Press.

Padiyar, K.R., 2008. FACTS controllers in power transmission and distribution. New Age International Publishers.

Padiyar, K.R., 2002. Power System Dynamics-Stability and Control. 2nd Edn., B.S. Publications.

Tan, Y.L., 1999. Analysis of line compensation by shunt-connected FACTS controllers: A comparison between SVC and STATCOM. Power Eng. Rev. IEEE., 8 (19): 57-58.

Yang, Z., M.L. Crow, C. Shen, L. Zhang, 2000. The steady state characteristics of a STATCOM with energy storage. Power Engin. Soc. Summer Meeting IEEE., 2: 669-674.

Yang, Z., C. Shen, L. Zhang, M.L. Crow, 2001. Integration of a STATCOM and battery energy storage. IEEE. Trans. Power Sys., 2 (16).