

Stability Analysis of Multi-Machine System using STATCOM

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Abstract: This paper presents the improvement of transient stability of a multi-machine power system with a STATCOM. Transient stability improvement is essential from the view point of maintaining system security that is the incidence of a fault should not lead to tripping of generating unit due to loss of synchronism. Static synchronous compensator is widely used in power system to control power by injecting appropriate reactive power into the system. STATCOM has the capability of improving stability and damping by dynamically controlling its reactive power output. The STATCOM is modeled by a voltage source connected to the system through a coupling transformer. The transient stability improvement of the multi-machine power system at different fault condition is investigated in this work. To illustrate the performance of the FACTS controller (STATCOM), a three machine, ninebus Western System Coordinating Council (WSCC) Multi-Machine power System has been considered. The proposed system is also analyzed for different fault clearing times.

I. Introduction

The power system today are complicated networks with hundreds of generating stations and load centers being interconnected through power transmission lines. An electric power system can be subdivided into four stages: i) generation, ii) transmission iii) distribution and iv) utilization (load). The basic structure of a power system is as shown in Fig.1.1. It is composed of generating plants, a transmission system and distribution system.

These subsystems are interconnected through transformers T1, T2 and T3.

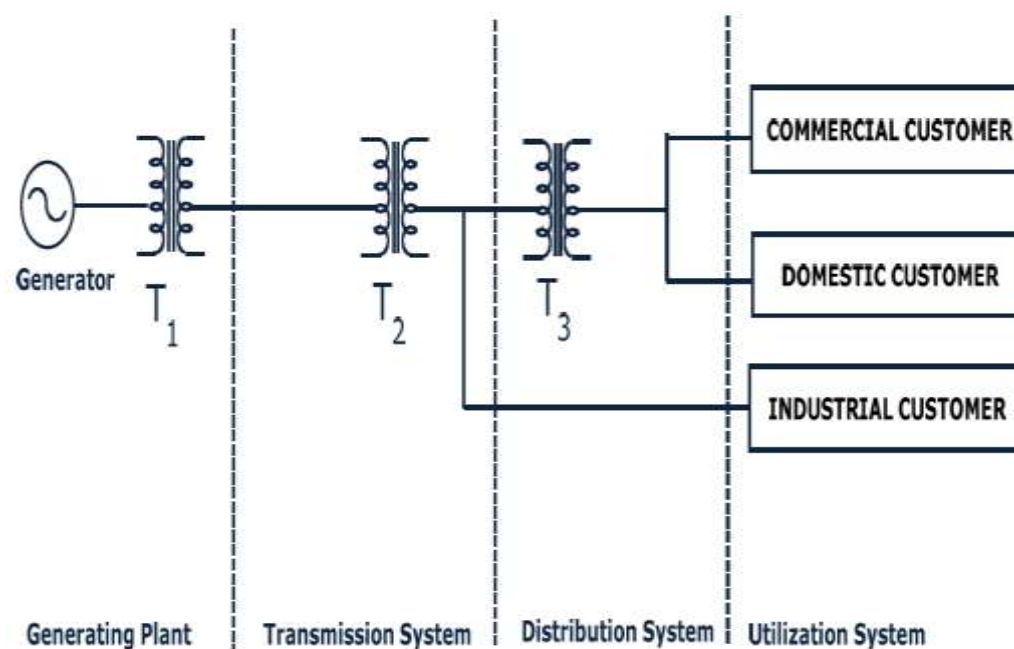


Fig. 1.1 Typical power systems

The power system is a highly nonlinear system that operates in a constantly changing environment; loads, generator outputs, topology, and key operating parameters change continually. When subjected to a transient disturbance, the stability of the system depends on the nature of the disturbance as well as the initial operating condition. The disturbance may be small or large. Small disturbances in the form of load changes occur continually, and the system adjusts to the changing conditions. The system must be able to operate satisfactorily under these conditions and successfully meet the load demand. It must also be able to survive numerous disturbances of a severe nature, such as a short-circuit on a transmission line or loss of a large generator.

Now-a-days it is becoming very difficult to fully utilize the existing transmission system assets due to various reasons, such as environmental legislation, capital investment, rights of ways issues, construction cost of new lines, deregulation policies, etc. Electric utilities are now forced to operate their system in such a way that makes better utilization of existing transmission facilities. Flexible AC Transmission System (FACTS) controllers, based on the rapid development of power electronics technology, have been proposed in recent years for better utilization of existing transmission facilities. With the development of FACTS technique, it becomes possible to increase the power flow controllability and enhance power system's stability. Recently, Flexible Alternative Current Transmission System (FACTS) controllers have been proposed to enhance the transient or dynamic stability of power systems.

During the last decade, a number of control devices under the term FACTS technology have been proposed and implemented. Application of FACTS devices in power systems, leads to better performance of system in many aspects. Voltage stability, voltage regulation and power system stability, damping can be improved by using these devices and their proper control. There are various forms of FACTS devices, some of which are connected in series with a line and the others are connected in shunt or a combination of series and shunt. The FACTS technology is not a single high power controller but rather a collection of controllers which can be applied individually or in coordination with other to control one or more of the inter related system parameters like voltage, current, impedance, phase angle and damping of oscillations at various frequencies below the rated frequency. Among all FACTS devices, static synchronous compensators (STATCOM) plays much more important role in reactive power compensation and voltage support because of its attractive steady state performance and operating characteristics. The fundamental principle of a STATCOM installed in a power system is the generation ac voltage source by a voltage source inverter (VSI) connected to a dc capacitor. The active and reactive power transfer between the power system and the STATCOM is caused by the voltage difference across the reactance. The STATCOM can also increase transmission capacity, damping low frequency oscillation, and improving transient stability. The STATCOM is represented by a voltage source, which is connected to the system through a coupling transformer. The voltage of the source is in phase with the ac system voltage at the point of connection, and the magnitude of the voltage is controllable. The current from the source is limited to a maximum value by adjusting the voltage.

2. BASIC TYPES OF FACTS CONTROLLERS

In general, FACTS Controllers can be divided into four categories:

- Series Controllers
- Shunt Controllers
- Combined series-series Controllers
- Combined series-shunt Controllers

2.1 Series Controllers: The series Controller could be a variable impedance, such as capacitor, reactor, etc., or a power electronics based variable source of main frequency, sub synchronous and harmonic frequencies (or a combination) to serve the desired need. All the series Controllers inject voltage in series with line. Even a variable impedance is multiplied by the current flow through it, represents an injected series voltage in the line. As long as the voltage is in phase quadrature with the line current, the variable reactive power is being supplied or consumed by the series controller. Any other means of phase relationship will involve handling of real power as well.

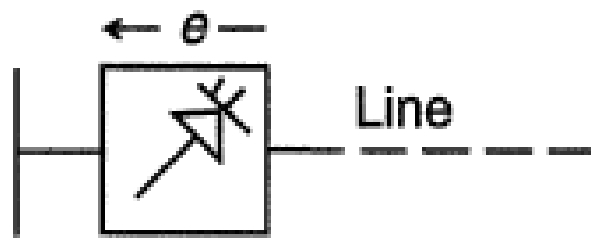


Fig 2.1: Series Controllers:

2.2 Shunt Controllers: As in the case of series Controllers, the shunt Controllers may be variable impedance, variable source, or a combination of above these. All the shunt Controllers inject current into the system at the point of connection. Even a variable shunt impedance is also being connected to the line voltage causes a variable current flow and hence represents injection of current into the line. As long as them injected current is in phase quadrature with the line voltage, the variable reactive power is basically supplied or consumed by the shunt controller. Any other means of phase relationship will involve handling of real power as well.

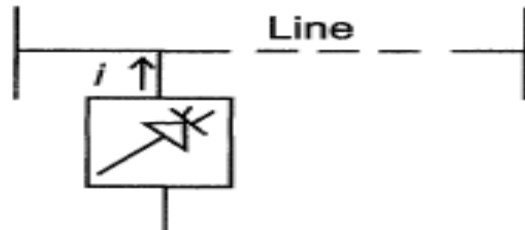


Fig 2.2: Shunt Controllers

2.3 Combined series-series Controllers: This could be a combination of separate series controllers, which are being controlled in a proper manner, in a transmission system of multiline. Or it could be a unified Controller, in which series Controllers provide reactive compensation for each line but also transfer real power among the lines via the power link.

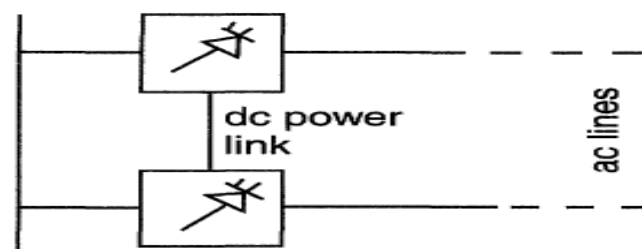


Fig 2.3: Combined series-series Controllers

2.4 Combined series-shunt Controllers: This could be a combination of separate shunt and series Controllers, which are controlled in a proper manner, or a Unified Power Flow Controller with series and shunt elements. Combined shunt and series Controllers inject current into the system with the shunt part of the Controller and voltage in series in the line with the series part of the Controller. However, when the shunt and series Controllers are unified there can be a real power exchange between the series and shunt Controllers via the power link.

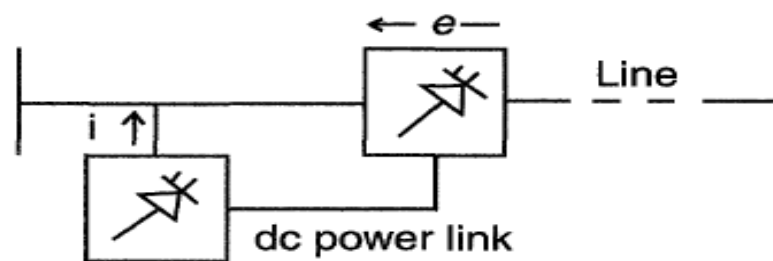


Fig 2.4: Combined series-shunt Controllers

3. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

In general, STATCOM use to generate or absorb reactive power. The active power generation or absorption capability of the STATCOM is normally used under special circumstances such as to enhance the steady state and transient voltage control, to improve the sag elimination capability.

3.1 BASIC OPERATION

The basic electronic block of the STATCOM is the voltage sourced inverter that converts an input dc voltage into a three phase output voltage at fundamental frequency. In its simplest form, the STATCOM is made up of a coupling transformer, a voltage-sourced inverter and a dc capacitor. In this arrangement, the steady-state power exchange between the device and the ac system is mainly reactive. A functional model of the STATCOM is shown in fig.2

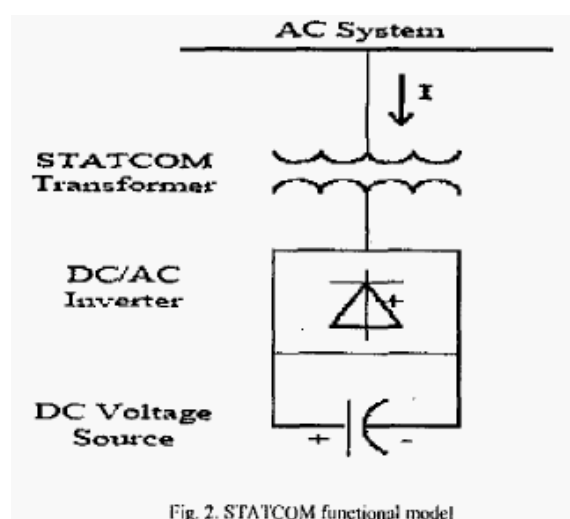


Fig. 2. STATCOM functional model

Regulating the amplitude of the STATCOM output voltage controls the reactive power exchange of the STATCOM with the ac system. If the amplitudes of the STATCOM output voltage and the ac system voltage are equal, the reactive current is zero and the STATCOM does not generate absorb reactive power. If the amplitude of the STATCOM output

voltage is increased above the amplitude of the ac system voltage, the current flows through the transformer reactance from the STATCOM to the ac system, and the device generates reactive power (capacitive). If the amplitude of the STATCOM output voltage is decreased to a level below that of the ac system, then the current flows from the ac system to the STATCOM, resulting in the device absorbing reactive power (inductive). Since the STATCOM is generating/ absorbing only reactive power, the output voltage and the ac system voltage are in phase, when neglecting circuit losses. The current drawn from the STATCOM is 90°- shifted with respect to the ac system voltage, and it can be leading (generates reactive power) or lagging (absorbs reactive power). A capacitor is used to maintain dc voltage to the inverter. An uncontrolled rectifier based six diodes used to keep the Capacitor charged to the required levels.

3.2 PRINCIPLE OF REACTIVE POWER CONTROL

The principle of control reactive power via STATCOM is well known that the amount of type (capacitive or inductive) of reactive power exchange between the STATCOM and the system can be adjusted by controlling the magnitude of STATCOM output voltage with respect to that of system voltage. The reactive power supplied by the STATCOM is given as:

$$Q = \frac{V_{STATCOM} - V_s}{X} V_s$$

Where:

Q is the reactive power.

V_{STATCOM} the magnitude of STATCOM output voltage.

V_s is the magnitude of system voltage.

X is the equivalent impedance between STATCOM and the system.

When Q is positive the STATCOM supplies reactive power to the system. Otherwise, the STATCOM absorbs reactive power from the system.

4. Modelling of multimachine machine system using STATCOM:

The popular Western System Coordinated Council (WSCC) 3-machines 9-bus practical power system is a widely used one and found very frequently in the relevant literature shows a 3-machines 9-bus WSCC system. Here the loads have been assumed to be represented by constant impedance model.

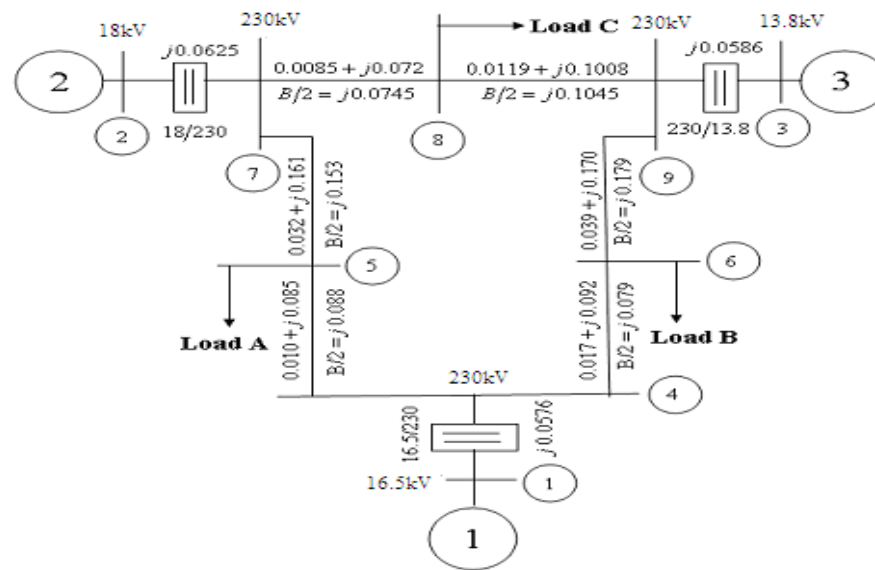
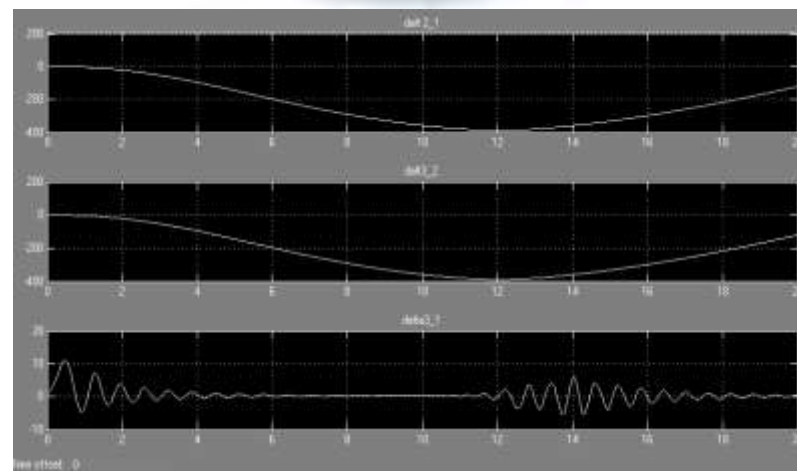


Fig. 4.1 -Machines 9-bus WSCC system

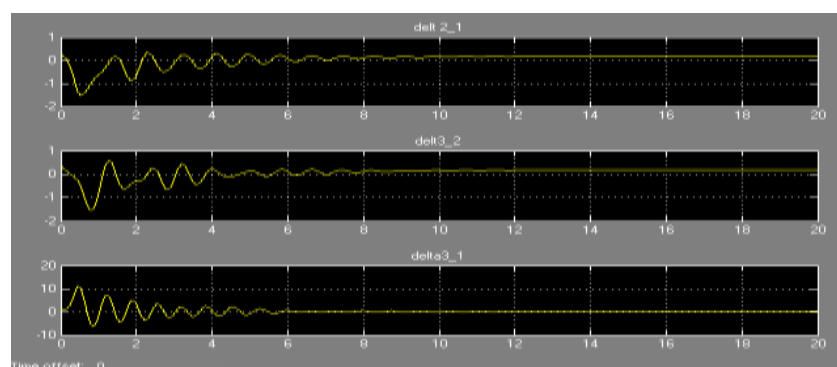
The base MVA of the system is 100, and system frequency is 60 Hz.. All time constants are in seconds. The complete system with all the required components has been modeled by using MATLAB/Simulink blocks.

4.1 RESULTS:

Case1- MATLAB/Simulink model of multi-machine (3-machine 9-bus) WSCC system, is incorporated with a three-phase fault and without STATCOM. For transient Stability studies, the variation of relative angular positions of the generators with time has been analyzed



Case 2- The MATLAB/Simulink model of 3-machine 9-bus WSCC system with a three-phase fault occurring between bus 7 and bus 4 and STATCOM placed between bus 7 and bus 4. For transient stability, the variation of relative angular positions with time is been analyzed. The total simulation time taken is 20 sec.



The location of STATCOM has been varied to study the optimum location of STATCOM in case of a fault in a system and the time taken to attain stability for three relative angular positions δ_{2_1} , δ_{3_2} and δ_{1_3} , for different locations of STATCOM when a three-phase fault occurred between bus 9 and bus 4.

5. CONCLUSION

STATCOM controller injects current in shunt with the line that changes the reactive power which in turn affects the rotor angle and brings back the system into synchronism. The best optimum location of STATCOM can be obtained. When the three-phase fault is occurring between bus 7 and bus 4, STATCOM finds its best location in the mid point of the same line i.e between bus 7 and bus 4. The simulation of single-machine infinite-bus (SMIB) system and multi-machine (3-machine 9-bus).WSCC system with STATCOM FACTS controller has been done using MATLAB/Simulink (7.5 version) software. This simulation can also be extended for Multiple faults system and Complex multi-machine systems.

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