Transient Stability Study in IEEE9 Bus System and Compensating Using TCSC

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Abstract – Power system engineers are currently facing challenges to increase the power transfer capabilities of existing transmission system. This is where the Flexible AC Transmission Systems (FACTS) technology comes into effect. With relatively low investment, compared to new transmission or generation facilities, the FACTS technology allows the industries to better utilize the existing transmission and generation reserves, while enhancing the power system performance. Moreover, the current trend of deregulated electricity market also favors the FACTS controller sin many ways. FACTS controllers in the deregulated electricity market allow the system to be used in more flexible way with increase in various stability margins. FACTS controllers are products of FACTS technology; a group of power electronics controllers expected to revolutionize the power transmission and distribution system in many ways. The FACTS controllers clearly enhance power system performance, improve quality of supply and also provide an optimal utilization of the existing resources. Thyristor Controlled Series Compensator (TCSC) is a key FACTS controller and is widely recognized as an effective and economical means to.

Index Terms – Transient stablity, Facts devices, 9bus system, Matlab/ Simpower system.

1. INTRODUCTION

Static VAR compensated FACTS device are the most important device and have been used for a number of years to improve voltage and power flow through the transmission line by resolving dynamic voltage problems. SVC is shunt connected static generator/absorber. Utilities of SVC controller in transmission line are many:

a) Provides high performance in steady-state and transient voltage stability control.

b) Dampen power swing.

c) Reduce system loss.

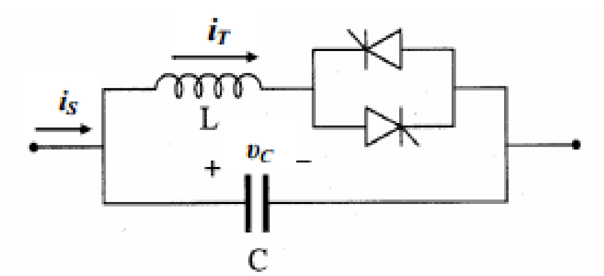
d) Control real and reactive power flow.

In such an environment, application of the Flexible AC Transmission System (known as FACTS) in power systems has become an issue of great concern. FACTS technology is becoming more and more popular due to improvement in Power Electronics technology and reduction in costs. The term FACTS coverts number of devices which may be working in isolation or in coordination with a few other devices. Several FACTS controllers for shunt, series or both shunt and series compensation are now operating in power systems around the world. By controlling impedance or phase angle or series injection of appropriate voltage a FACTS Controller can control the power flow as required.

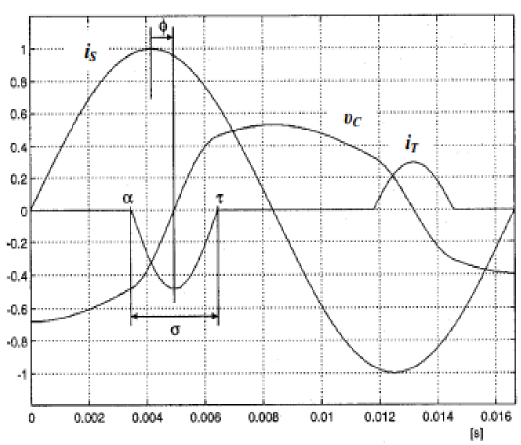
The FACTS facilitates power flow control, increased power transfer capability, and enhances the security and stability of power systems without expanding transmission and generation utilities. Excellent applications of FACTS controllers, such as the unified power flow controller (UPFC), and the Static Synchronous Compensator (STATCOM), have yielded successful results. It has been shown in recent case studies that FACTS can provide a more flexible stability margin to power systems and also improve power transfer limit in either shunt or series compensation. TCSC module which consists of a series capacitor bank in parallel with a Thyristor Controlled Reactor (TCR). The controlling element is the thyristor controller, shown as a bidirectional thyristor valve. Thyristor Controlled Series Capacitor (TCSC) is the series FACTS devices. It consists of the capacitor bank reactor bank and thyristor. The thyristors control the reactance that dictate the power flow through a line. The TCSC can be applied for improving transient stability of power system. The evaluation of Critical Clearing Time (CCT) of power system is one of the most important research areas for power engineers because it indicates the robustness of the faulted power system. The rotor angle of the synchronous generator determines the stability of power system. Although the stability of the synchronous machine is used to represent the stability of the power system, all of the power system components such as transmission line and transformer affect the stability of the power system. This study will investigate the capability of the TCSC on transient stability of the IEEE 9 Bus system. The concept of two-port network is applied to simplify the mathematical model of the power system. The sample system consist the practical short transmission line is used to investigate in this study. The proposed method is tested for worst fault condition.

2. BASIC OPERATION OF TCSC

Fig. shows the circuit diagram of single phase TCSC. The system is composed of a fixed capacitor in parallel with a Thyristor Control Reactor (TCR). The switching element of the TCR consist of two anti- parallel thyristors, which alternate their switching at the supply frequency .The system is controlled by varying the firing angle of the thyristor firing pulses relative to the zero crossing of some reference waveform .The effect of such variation can be interpreted as a variation in the value of the capacitive, inductive reactance at the fundamental frequency. In our analysis, the thyristors will be ideal, so that nonlinearities due to the thyristor turn on and turn off are neglected. Also, the line current is is essentially assumed sinusoidal, and take it to be the reference waveform for the synchronization of the firing pulses. A slight modification for analysis is needed if the synchronization is instead done with the capacitor voltage Vc.



Basic diagram of proposed system



TCSC behaves at fundamental system frequency like continuously variable reactive impedance, controllable by thyristor firing angle α and the parallel LC circuit determines the steady-state impedance of the TCSC. The LC circuit consists of a fixed series capacitor and variable inductive impedance as shown in figure 1.1

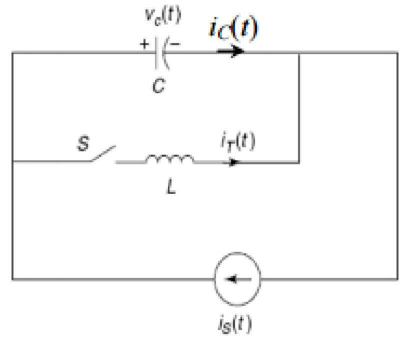


Fig. 1.1: Variable Impedance of TCSC

Power Transfer Capability of Transmission Line:

The power transfer between two ends of uncompensated transmission line is given by

$$P = \frac{V_S \cdot V_R}{X_L} \sin \delta$$

Where V_S and V_R are sending end and receiving end voltages, respectively, XL is transmission line reactance (losses is neglected) and δ is power angle. The compensating effect results from the voltage drop across the series impedance of TCSC caused by line current as shown in figure 1.1. The power transfer through transmission line with series compensated by using TCSC is

$$P = \frac{V_S . V_R}{X_L + X_{TCSC}(\alpha)} \sin \delta$$

3.1 System **Model**

The model systems used for simulation of the transient stability study is IEEE 9 bus system is shown below.

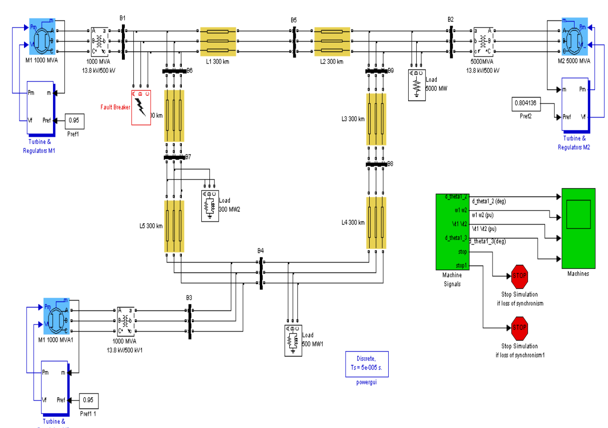
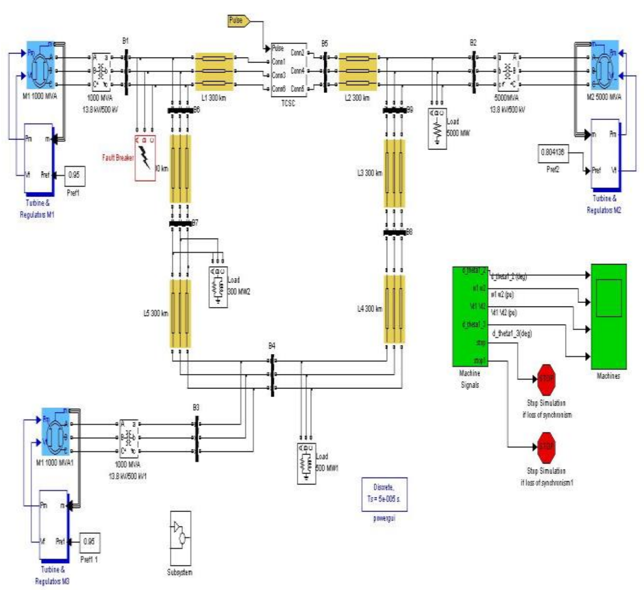


Fig. 3.2: IEEE 9 Bus System (Uncompensated)

This model consists of nine buses consist of three machine at which the simulation results were obtained. Two machines are of 1000 MVA & one machine is of 5000 MVA. The primary voltage generated by the machines is of 13.8 kV. All machines are connected to a ring system of nine buses operating at 500 kV through step up transformers of 13.8 kV/500 kV. Each line section is of 300 km. The loads are added to the system at three locations at different buses. The fault near the generator terminal has been created to generate the disturbance. The fault is considered as L-L-L-G fault.

Fig 3.3 IEEE 9 Bus System (TCSC compensated)

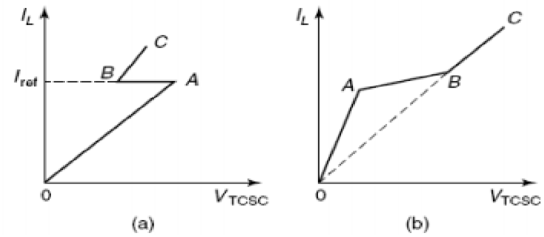


In the above figure 3.1 IEEE 9 Bus system with TCSC compensation has been shown. TCSC has been connected in line segment L4. TCSC can vary the impedance continuously to levels below and above to the lines' natural impedance. Once installed, it will respond to rapidly to control signals to increase or decrease the capacitance or inductance thereby damping those dominant oscillation frequencies that would otherwise breed instabilities or unacceptable dynamic conditions during or after disturbance.

The performance of the system prior to compensation after the compensation is planned to be analyzed. Simulation is done using

MATLAB/SIMULINK. TCSC control Strategy

There are two types of control (either closed-loop or open-loop) can be used to control over TCSC. Open-loop control is used to generate an output according to a predefined transfer function and no response measuring is required, while closed-loop control is implies the classical feedback system.



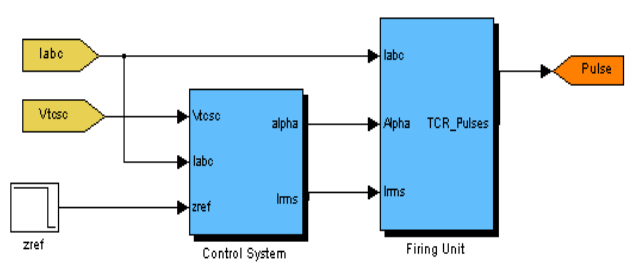
TCSC Control Characteristics (a) Constant Current Mode (b) Constant Angle Mode

For the proposed study, the second type is employed and both of load current and voltage are traced as a feedback, where the ratio of compensator current to the voltage error determines the slope of voltage/current characteristic. The system stability and response are determined by total loop gain and time constants. Conventionally, reactive power compensator controllers are based on one of the following modes; Constant Current (CC) Mode, Constant Angle (CA) Mode and Constant Power Mode (CP).

Steady-state control characteristic of CC mode is divided into three regions OA, AB and BC. Regions OA and BC are represent the minimum and the maximum TCSC reactance limits while region AB represent the control range in which TCSC reactance is varied through firing angle α to maintain a constant specified line current. CP Mode is a combination of employing inner current closed loop and voltage control loop; CP mode is offering an effective method for damping oscillation that may occur during rapid load changing.

Proposed control Strategy

In this project work the close loop control scheme for the TCSC control has been employed. Here, both of interconnected bus current and voltage are traced as a feedback.



When TCSC operates in the constant impedance mode it uses voltage and current feedback for calculating the TCSC impedance. The reference impedance indirectly determines the power level, although an automatic power control mode could also be introduced. The TCSC is maintained in the capacitive mode.

A separate PI controller is used in each operating mode. The capacitive mode also employs a phase lead compensator. Each controller further includes an adaptive control loop to improve performance over a wide operating range. The controller gain scheduling compensates for the gain changes in the system, caused by the variations in the impedance.

Simulation Results:-

- A small signal disturbance has been created in the system by introducing the 3-phase to ground fault imposed in the system.
- Fault has been created at the generator -1 terminal bus at instant 0.05 & cleared at instant 0.22 sec. It means a fault has been imposed for 8.5 cycles.
- Simulation has been carried out for 3 Sec for both systems i.e uncompensated & compensated.
- The rotor angle deviations, stator voltages, rotor speed signals have been monitored.
- Simulation has been incorporated with a STOP facility whenever the rotor angle deviation moves above 180° it will stop.

The simulation results has been discussed in the details below

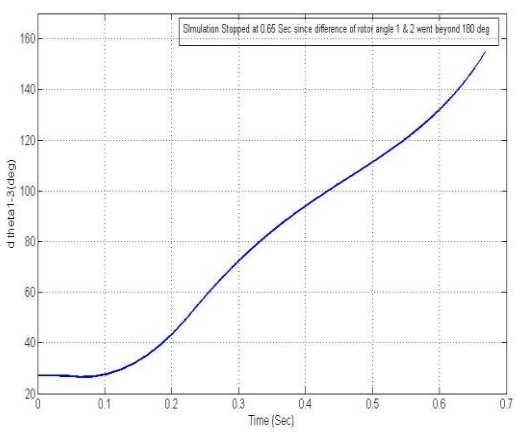


Fig4.1:-Difference of Rotor angle Deviation of Generator 1& 2 (Uncompensated**)**

Conclusion drawn from the simulation results:-

- Fig 4.1 & Fig 4.2 indicate the difference of rotor angle deviation between the generator 1 & 2 with uncompensated system and with TSCS compensated system.
- Since the difference of rotor angle deviation of generator 1 & 2 goes beyond 180 degree in uncompensated system the simulation stops at 0.65 seconds
- On other hand the compensated system with TCSC have maximum difference of rotor angle deviation of 47 to -35 degree so the simulation does not stop and the system gets steady after few seconds.
- Hence it can be seen that the TCSC improves the transient stability of a given system.

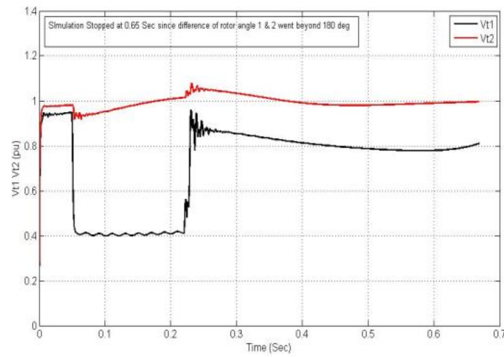


Fig4.3:-Stator voltages of generator 1 & 2 (Uncompensated)

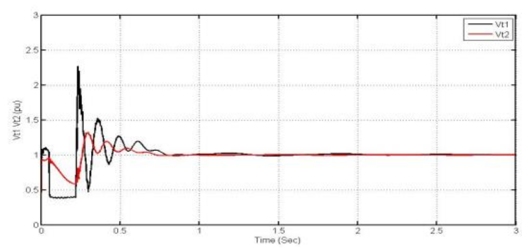
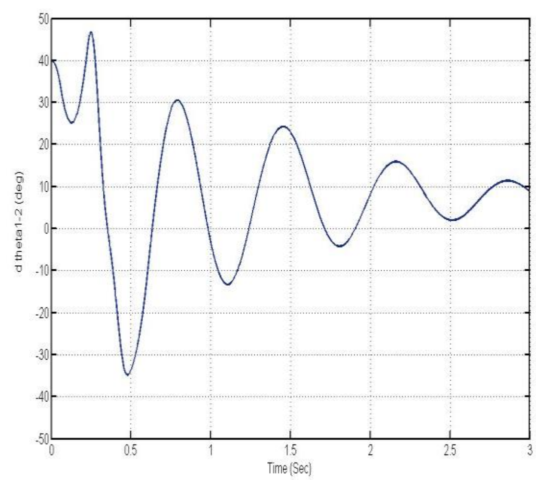


Fig4.4:-Stator voltages of generator 1 & 2 (TCSC Compensated)



- Fig 4.3 & Fig 4.4 indicate the behavior of stator terminal voltage of generator 1 & 2 with uncompensated system and with TSCS compensated system.
- From Fig 4.3 behavior of stator terminal voltage of generator 1 & 2 with uncompensated system, it is observed that as the fault is placed on the generator
- terminal-1 the terminal voltage at generator-1 has collapsed during the fault instant 0.05 to 0.22 sec.
- On other hand the compensated system with TCSC as in Fig 4.4, it can be seen that the voltage oscillated & then tries to settle down to normal value due to compensation provided by the TCSC.

Hence it can be seen that the TCSC improves the transient stability of a given system & avoid the sudden voltage collapse during

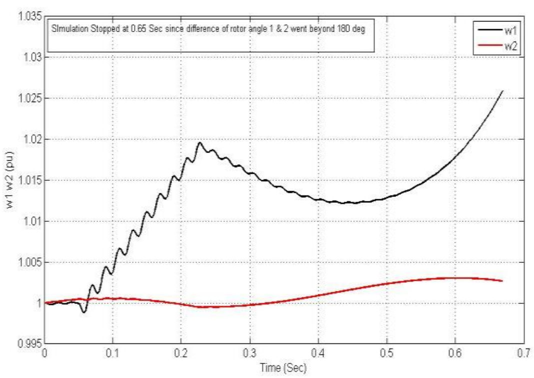


Fig4.5 :-Rotor Speed of generator disturbance.

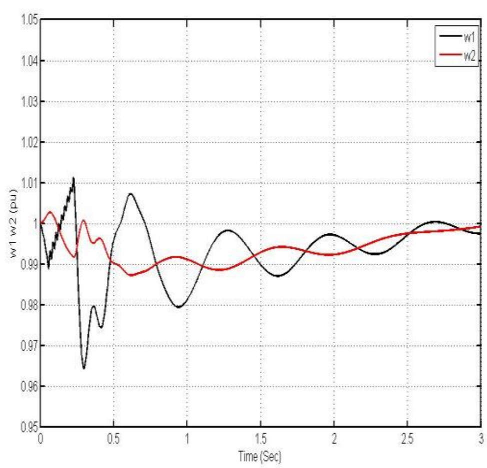


Fig4.6:-Rotor Speed of generator 1 & 2 (TCSC Compensated)

Observations drawn from the simulation results:-

Fig 4.5 & Fig 4.6 indicate the behavior of Rotor Speed of generator 1 & 2 with uncompensated system and with TSCS compensated system.

From Fig 4.5 behavior of rotor speed of generator 1 & 2 with uncompensated system, it is observed that as the fault is placed on the generator terminal-1 the rotor speed at generator-1 has moves aggressively above 1 p.u. during the fault instant 0.05 to 0.22 sec.

On other hand the compensated system with TCSC as in Fig 6.6, it can be seen that the rotor oscillated & then tries to settle down to normal value due to compensation provided by the TCSC.

Hence it can be seen that the TCSC improves the transient stability of a given system & avoid the sudden loading on generator during disturbance.

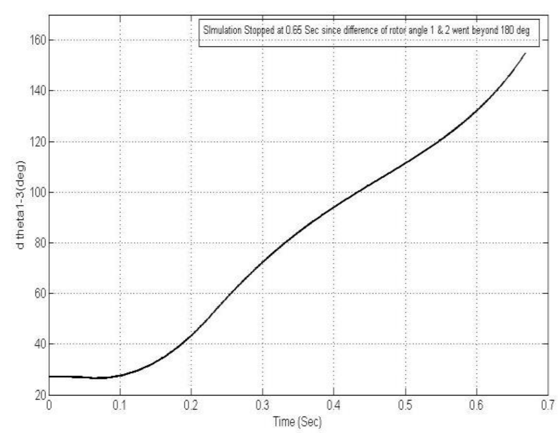


Fig4.7:-Difference of Rotor angle Deviation of Generator 1 & 3(Uncompensated)

Observations drawn from the simulation results:-

Fig 4.6 & Fig 4.7 indicate the difference of rotor angle deviation between the generator 1 & 3 with uncompensated system and with TSCS compensated system.

Since the difference of rotor angle deviation of generator 1 & 3 goes beyond 180 degree in uncompensated system the simulation stops at 0.65 seconds

On other hand the compensated system with TCSC have maximum difference of rotor angle deviation ranging from 47 to -53 degree so the simulation does not stop and the system gets steady after few seconds.

Hence it can be seen that the TCSC improves the transient stability of a given system.

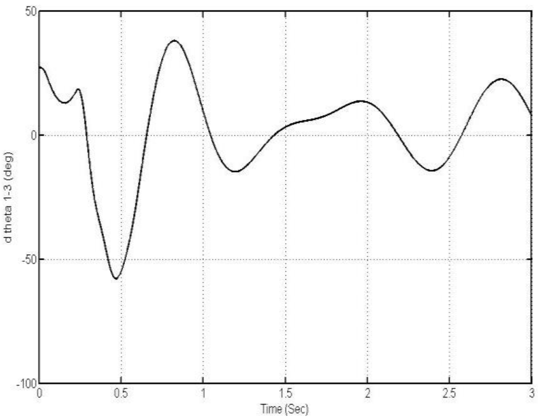


Fig4.8 :-Difference of Rotor angle Deviation of Generator 1& 3 (TCSC Compensated)

The simulation results observations are tabulated as below

Fault Type: - 3 Phase **(**LLLG) Fault

Fault Duration: - 0.05 to 0.22 Sec (8.5 Cycle)

Fault Location: - At the Generator Terminal-1

Table No 4.1:- Parameter Observed With & Without TCSC

Parameter Observed	**Uncompensated System**	**Compensated system**
Rotor angle Deviation of Generator 1& 2	Moves out above 180 degree	Rotor angle deviation of 47 to -35 degree
Stator Voltage at Generator-1 & 2	Collapse of Stator voltage to 0.8 of Gen-1	Voltage spike of 2.2pu observed but settles down after fault clearance
Rotor Speed Generator-1 & 2	Moves aggressively above 1 p.u. during the fault	Rotor oscillated & then tries to settle down to normal
Rotor angle Deviation of Generator 1& 3	Moves out above 180 degree	Rotor angle deviation ranging from 47 to -53 degree

Note: - As worst fault condition has been simulated hence change in the fault type & fault locations study has not been considered part of this project work.

3. CONCLUSION & SUGGESTED FURTHER WORK

From the simulation results it can be seen that the TCSC device can be used for the improvement of the existing transmission system effectively.

TCSC not only improve the transient stability in the system due to disturbances but also helps reducing the cost of modification of the existing system.

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