# Improving Power System Stability by Using Series FACTS Devices

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***Abstract*—The power system have been growing continuously due to increase demand of loads. It's becoming more and more difficult to provide stability and control to the system. In this study, series FACTS devices namely, static series synchronous compensator (SSSC) and thyristor-controlled series compensator (TCSC), have been demonstrated to increase the power capacity flow in an electric power network. The primarily aim to increase the load capability of the system to maintain system stability after a transient fault. Therefore, series FACTS devices SSSC and TCSC have been implemented to maintain stability after a fault transient. This paper presents modeling and simulation of SSSC and TCSC in MATLAB/Simulink to maintain transient stability.**

***Keywords*-- FACTS, Power flow, Two Area network, TCSC Model.**

## I. INTRODUCTION

Owing to the growing power demand, expanding power transmission capability in electric power lines is vital. Moreover, electric power network stability in planning and operation has recently received close attention. Numerous blackouts have been experienced in many countries because of voltage stability issues, which may be attributed to the scarcity of the reactive power capacity during disturbances. New expansions in present transmission systems are confined because of financial problems, environmental concerns, and health hazards due to electric and magnetic fields [1]. Hence, electric power network is possibly conserved in voltage permissible condition by assuring suitable reactive power backup by the reactive power sources. The traditional sources of reactive power do not provide fast response rate necessary for reactive power of the power network. Alternatively, using flexible AC transmission system (FACTS) devices for the enhancement of power capacity of transmission system directed from modern components of power electronics is a valuable option [2]. Until recently, FACTS devices have been broadly employed for the enhancement of power flow capability of electric power lines and increase of network governability, consequently minimizing power losses in transmission systems[3--5]. Among different types of FACTS devices, series devices, namely, static series synchronous compensator (SSSC) and thyristor control series compensator (TCSC) have become popular because of their simple design of their controllers, which affect current and power flow. A given MVA size of series controllers is considerably more powerful than shunt controllers for controlling power flow and damped oscillations [6].

Consequently, varying series compensation is considerably useful in governing stability and power flow in transmission lines. SSSC and TCSC are the major static series compensators. These compensators are more powerful compared with simple series capacitor because full compensation voltage can be supplied to transmission lines irrespective of the SSSC line current. SSSC is a voltage source converter (VSC) linked in series with the power line. It can accurately control power transfer in a line through this connection. The SSSC control parameters, angle, and voltage degree of the series converters are shown as independent variables in [7], and their values are determined by the iterative procedure of conventional load flow. Therefore, SSSC controls a wide range of power through transmission line. The basic construction of an SSSC is denoted in Fig. 1.

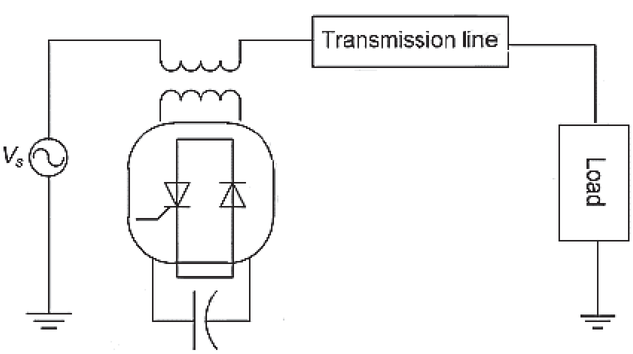



Fig. 1. Schematic of an SSSC.

The TCSC provides series compensation for transmission line impedance in a stable, manageable, and rapid way. The TCSC is also linked in series with transmission lines [8]. TCSC can possibly be a single and big unit or may comprise several similar or various size small capacitors to provide excellent performance [9]. Determining a suitable placement for this device in a power network to gain maximal merits is beneficial due to the high cost of TCSC involved [7]. Furthermore, TCSC has considerable potential for expanding available transfer capability through the transmission line. TCSC also has an automatic control similar to thyristor. Thus, the TCSC is employed to reinforce transient stability, neglect SSR, and damp power oscillations. Fig. 2 shows a schematic diagram of a TCSC, in which a TCR is connected in parallel to a fixed series capacitor.

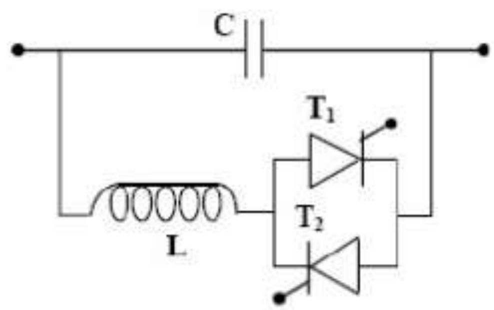



Fig. 2 Block diagram of TCSC.

Controllable series line compensation is the foundation of FACTS technology. These compensators can be used for the complete utilization of transmission resources, particularly in controlling power flow in transmission lines, restraining loop flows, and diminishing the effects of system disruptions. Through this method, the SSR issues can also be terminated by representing the device in an inductive–resistive mode. Self-commutating switches, such as GTO and IGBT, are employed in switching converter for these series controllers.

## II. CONTROL SCHEME BLOCK DIAGRAM OF SSSC AND TCSC

The control design denoted in Fig. 3 shows the following:

- $V_d$_conv represents the series component of injected voltage $V_d$ provides for the losses of transformer and voltage source converter by charging the DC link capacitor.
- Vq_conv represents quadrature component of the implanted voltage. Vq compensation can be varied by controlling the magnitude of this component. VSC uses
- GTO-based square-wave inverters. A total of four three-level inverters are considered to create a 48-step voltage waveform. • Peculiar connection of transformers is realized for the nullification of involved harmonics in square waves developed by specific inverters.

In such a voltage source converter, the essential voltage component V corresponds to DC voltage (Vdc). Hence, Vdc changes to regulate the implant voltage. The control scheme of SSSC denoted in Fig. 3 comprises the following:

- Phase-locked loop (PLL) The output of PLL is considered to determine the dq-axis components of three phase AC voltages and currents (designated as Vd, Vq, and Id, Iq on Fig. 3).
- Measuring system This system measures the components of AC and DC voltage.
- Voltage regulators these regulators calculate Vd and Vq. Required DC voltage and Vqref are obtained by using these components. The Vq voltage regulator is reinforced by a feed-forward regulator, which anticipates the $V_d$_conv voltage from the $I_d$ current measurement.

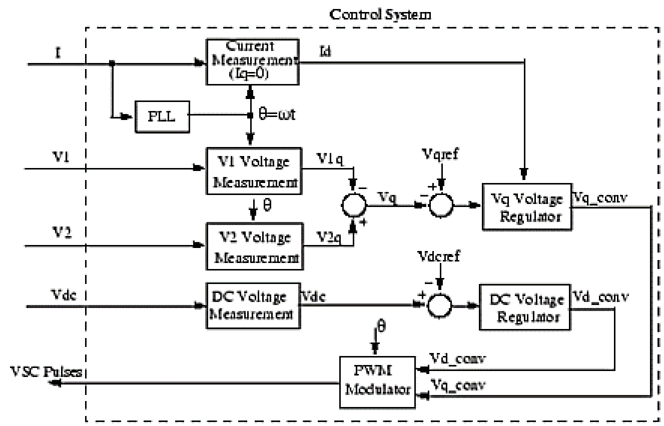



Fig. 3 Control Scheme of SSSC.

A layered structure in the controller is used to achieve different control objectives. The control scheme of TCSC denoted in Fig. 4 comprises the following control approaches:

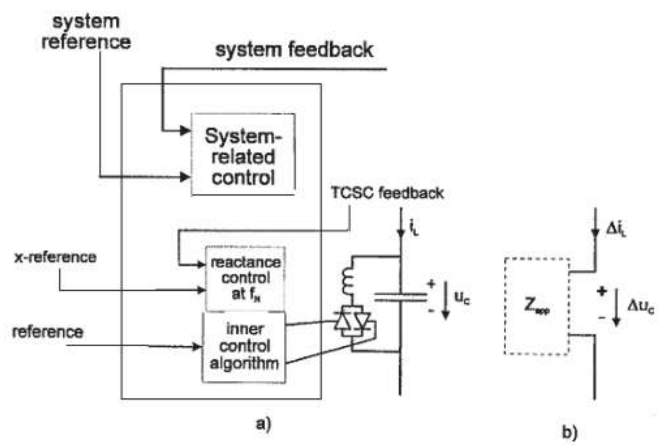



Fig. 4. Control Scheme of TCSC

## III. MODE OF OPERATION OF SSSC AND TCSC

### A. *Thyristor Controlled series capacitor*

TCSC can be governed to perform in both capacitive and inductive fashions averting steady state resonance [10], as shown in Fig.5. The TCSC impedance characteristics represent inductive and capacitive zones are feasible by changing the firing angle α. In inductive mode the inductance increases from a minimum value to a maximum value of infinity at resonance. Similarly, in the capacitive mode, capacitance decreases from infinity to a minimum value.

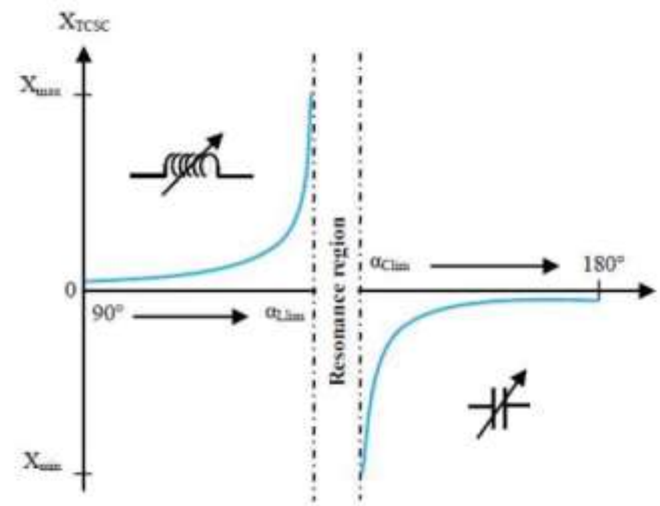



Fig. 5. Impedance Diagram of TCSC.

*Modes of operations*

TCSC has three fashions of operation.

- Blocking mode In this mode, the thyristors are not gated and thus can be operated as a fixed capacitor. In this fashion, αL lim and αC lim.
- Thyristor valve by pass mode In this fashion, thyristors are gated for full conduction such that TCSC reactance is in parallel combination of a fixed capacitor and inductor. This condition is called inductive operation zone.
- Vernier control mode (capacitive zone) The thyristors are continuously gated to run in capacitive zone operation. In this fashion, angles vary from αL lim to 180°.

### B. *Static synchronous series compensator (SSSC)*

The SSSC implants a voltage in series with the line regardless of the line current. The SSSC can yield inductive and capacitive compensating voltage regardless of the equality of power line current to the rated current of the line. In voltage compensation zone, the SSSC can keep the rated capacitive and inductive compensating voltage irrespective of the varying line current. The capacitive and inductive zones of operations are shown in Fig. 6.

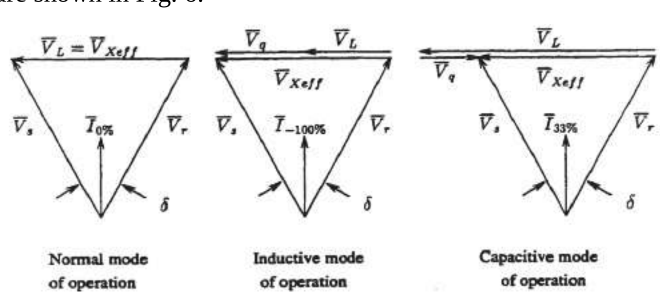



Fig. 6. SSSC modes of operation

- When the mirror reactance is capacitive, the active and reactive flow of power increase and the active reactance reduces as the reactance compensation increases in the positive direction.
- When the mirror reactance is inductive, the active and reactive transfer of power decrease and the active reactance increases as the reactance compensation increase in the negative direction

## IV. MODELLING AND SIMULATION

A 1000 MW hydraulic generation plant (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 MVA plant and a local generation of 5000 MVA (plant M2)

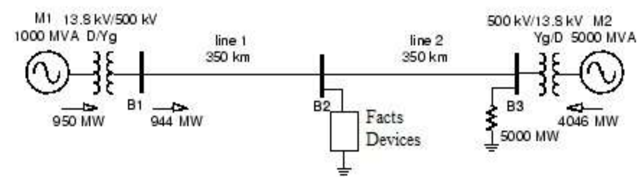



Fig 8 single line diagram of two area power system using facts devices.

A load flow has been performed on this system with plant M1 generating 950 MW so that plant M2 produces 4046 MW. The line carries 944 MW which is close to its surge impedance loading (SIL = 977 MW). To maintain system stability after faults, the transmission line is series compensated at its center.

A 300 MVA SSSC is connected at the center of power transmission line to manage network stability after the faults. In this network, machines are equipped with hydraulic turbine and governor, power system stabilizer (PSS), and excitation system. The following two kinds of stabilizers can be used: power accelerated (PA) PSS, which employs acceleration power, and multi-band (MB) PSS, which employs speed diversion. Stabilizers can be elected by establishing any value (1 = Pa PSS, 2 = dw MB-PSS, or 0 = No PSS) from the constant block of PSS.

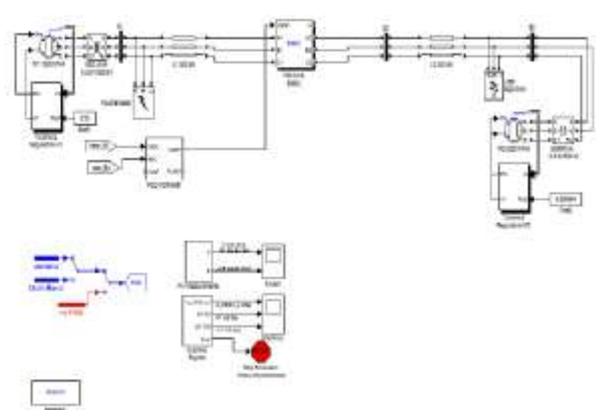
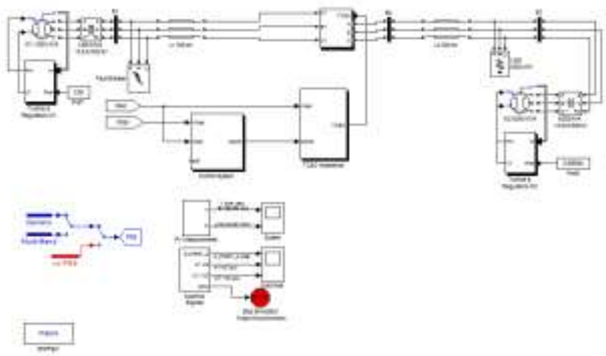


Fig 9 simulation model by using SSSC



. Fig 10 simulation model by using TCSC

## V. SIMULATION RESULT

The results obtained from the simulation of the proposed systems are presented in this section. For transient stability analysis, a single-phase line-to-ground (L-G) fault is applied at bus number 1 and simulated for both operations, that is, with and without SSSC and TCSC in operation.

The X-axis of graphs represents the simulation time, and the Y-axis represents the machine characteristics, which include rotor angle, machine angular speed, and terminal voltages. Oscillations are observed in Figures but the post-fault condition is stable with PSS.

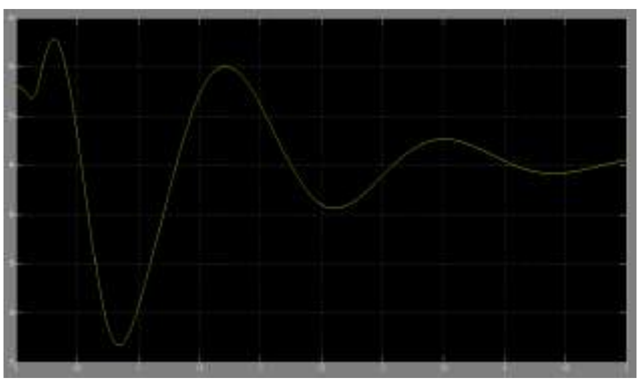


Fig. 11 Variation of generator rotor angle of the two-area power system with SSSC

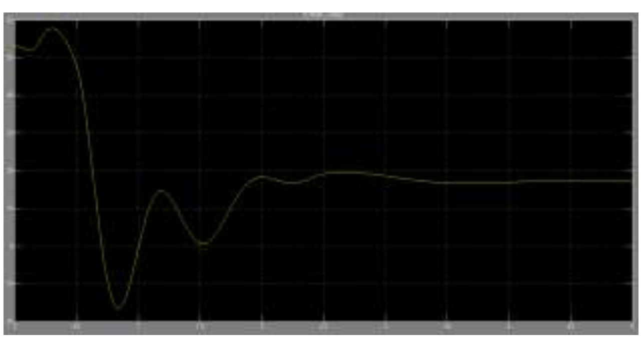


Fig. 12 Variation of generator rotor angle of the two-area power system with TCSC.

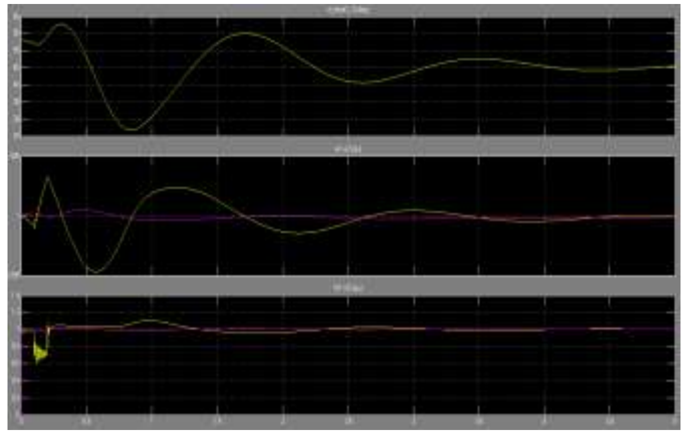


Fig. 13 the system becomes stable as the fault is removed with the application of SSSC.

Figure 13. (a) Change in delta between the two machines for L-G fault SSSC. (b) Speed of machine 1 for three-phase fault SSSC. (c) Voltage of machine 1 for three-phase fault SSSC.

A fault is initiated at 0.1 s and continued for 10 cycles. With the absence of TCSC, the system evidently becomes unstable due to increased inter-area oscillations. Figures 12 (a)–(c) show that these oscillations are sufficiently damped out when TCSC (capacitive mode) is used to stabilize the system.

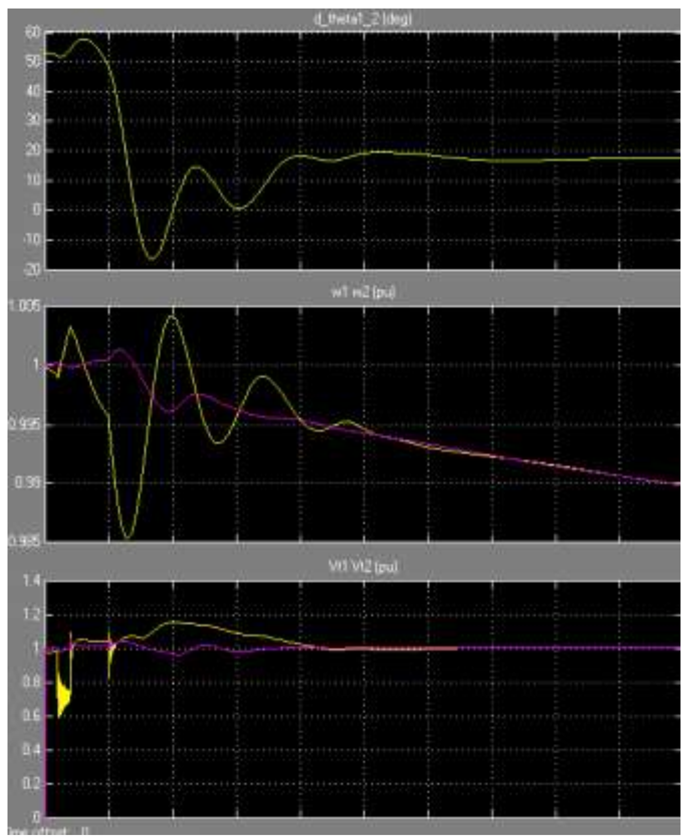



Fig. 14 the system becomes stable as the fault is removed with the application of TCSC.

Figure 14. (a) Change in delta of two machines for three-phase fault TCSC. (b) Speeds of two machines for three-phase fault TCSC. (c) Terminal voltages of machines for three-phase fault TCSC.

## VI. CONCLUSION

Using a Simulink/MATLAB model, a power system with numerous loads associated with distinct buses has been presented. Moreover, transient stability is improved owing to the successful enforcement of SSSC to the power system. The effectiveness of SSSC and TCSC in characterizing machines for stability limit enhancement is verified by comparing the outcomes before and after the implementation of considered controllers. Distinct faults, namely, single-phase L-G faults have been implemented at bus 1 to analyze the instability in the proposed system. The results show that the transient stability of the power network is eminently afflicted by SSSC and TCSC. Thus, the improved transient stability of the electric power network is realized by using SSSC and TCSC. In future, more research is also suggested by implementing the neuro-Fuzzy adaptive control approach based FACTS devices SSSC and TCSC controller. Also comparing their performance with the one proposed in this research paper for better power quality improvements.

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