Stability Improvement of Power System Using Thyristor Controlled Series Capacitor (TCSC)

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Abstract**-- TCSC are used to improve power handling capability and reduce line losses in power systems. An additional feature of TCSC is its dynamic performance of power oscillation damping by varying the power flow in accordance with power oscillations. This behavior can be used to improve the stability of the system following a disturbance. In this paper eigenvalue-based methods for analysis have been studied and the stability improvement-steady state as well as transient stability of the system is improved using TCSC.**

Index Term**-- Eigen-values, Power system oscillations, Steady-State Stability, TCSC, Transient Stability.**

I. INTRODUCTION

With the increase in electrical equipment worldwide, the electric supply industry is undergoing remarkable transformation. Transmission systems are becoming more heavily loaded and are being operated in ways not originally anticipated. Transmission systems must be flexible to react to more diverse generation and load patterns. For industrialized countries economic utilization of transmission systems assets is necessary to compete, whereas for developing countries optimum use of these assets is essential to meet the rapid increase in generation demand.

An increased demand of generation requires an increase power transfer through lines which is limited by the thermal, voltage and stability of lines [1]. As the lines are operated near to their critical limits of power angles or voltage limits; any disturbance in such a system can result in instability like power system oscillation [2] and may lead to generator outages and ultimately blackout. A solution is to develop new lines, but this requires a high system cost, complexity of protection system design, time requirements and environmental issues etc. These restrictions on the construction of new transmission lines have persuaded the power system designers to look for some alternative solutions to increase the power system stability and efficiently transmit power over the transmission lines. All these problems of environmental and regulatory concerns, and reliability and stability issues are mitigated by a new class of Power electronic devices named as Flexible AC Transmission Systems which brings us to the second option and that is implementation of FACTS devices. The economical prospective of FACTS device has been discussed in [3]. Although there is an another option to use the traditional compensation techniques but FACTS not only increase the power transfer capability [4] but its dynamic features act to reduce power oscillations, increasing angular and voltage stability [5],[6] and thus the reliability of the entire system.

Transmission compensation can be series or shunt. Both types of compensation have been further categorized and discussed in [7]. Since we are studying TCSC which is in fact a series FACTS device so we shall only high-lighten the effects of series compensation. The steady state advantage of TCSC is to provide series compensation which acts to reduce the electrical length of the line and hence increases the power transfer capability of the line by decreasing impedance and losses as is clear from the following relation (1).

$$P = \frac{E_G \times E_M}{X_T} \sin\delta \qquad (1)\ \ [8]$$

An excellent study of various stages /phases for the deployment of FACTS devices in system has been discussed in [9].

AT the same time,one of the things to be taken care of while applying these devices in the system is the determination of optimal location so to extract maximum ou of them.There have been various algorithms proposed to determine optimal location of Facts devices [10],[11],[12].

II. TCSC

The dynamic applications of TCSCs, various control techniques and designs have been proposed for damping power oscillations to improve system dynamic response, whereas **for steady state control**, the main interest of users and researchers has been the use of the this controller for power flow control in transmission lines, usually considering optimal scheduling.

A typical TCSC module consists of a fixed series capacitor (FC) in parallel with a thyristor controlled reactor (TCR). It is connected in series with the transmission line and is used to control the real power flow by controlling the electrical length of transmission line along with providing increased SSR stability. There may be one or more TCSC modules in series in a practical TCSC construction.

1) TCR

A TCR consists of a fixed reactor in series with a bidirectional thyristor controlled switch which is fired with a phase angle α ranging between 90º and 180º with respect to the voltage.

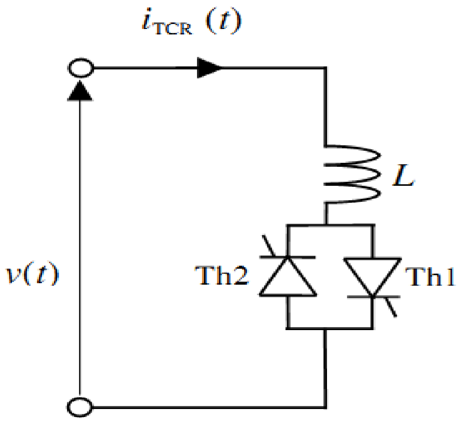

Fig. 1. Thyristor controlled reactor [13]

The overall action of the thyristor controller on the linear reactor is to enable the reactor to act as a controllable susceptance, in the inductive sense, which is a function of the firing angle. However, this action is not trouble free, since the TCR achieves its fundamental frequency steady-state operating point at the expense of generating harmonic distortion, except for the condition of full conduction.

First, consider the condition when no harmonic distortion is generated by the TCR, which takes place when the thyristors are gated into conduction, precisely at the peaks of the supply voltage. The reactor conducts fully, and one could think of the thyristor controller as being short-circuited. The reactor contains little resistance and the current is essentially sinusoidal and inductive, lagging the voltage by almost 90 (p/2) [13].

2) TCSC Impedance

A TCSC is a parallel combination of TCR and a fixed capacitor. The TCR reactance as a function of firing angle is given by (2)

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin 2\alpha} \qquad (2)$$

(2) [14]

As this variable reactance comes in parallel with the fixed capacitor so in the equivalent circuit, the capacitance can be considered to be variable as well [14].

The steady state fundamental impedance of the TCSC is given by (3)

$$X_{TCSC} = \frac{X_C \bullet X_L(\alpha)}{X_C - X_L(\alpha)} \qquad (3)$$

Therefore by varying the conduction angle the fundamental reactance of the TCSC can be controlled and can be made either inductive or capacitive.

Putting the value of $X_{L(\alpha)}$ in the above relation (3), the following result equation (4) is obtained.

$$\begin{aligned} X_{TCSC}(\alpha) = & -X_C + C_1(2(\pi-\alpha)+\sin(2(\pi-\alpha))) \\ & -C_2\cos^2(\pi-\alpha)(\overline{w}\tan(\overline{w}(\pi-\alpha)) \\ & -\tan(\pi-\alpha)) \end{aligned}$$

(4)

where,

$$X_{LC} = \frac{X_C X_L}{X_C - X_L}$$

$$C_1 = \frac{X_C + X_L}{\pi} \quad [14]$$

$$C_2 = 4\frac{X_{LC}^{\ 2}}{\pi X_L}$$

$$\overline{w} = \sqrt{\frac{X_C}{X_L}}$$

For the range of 0 to 90 of α, $X_L(\alpha)$ start vary from actual reactance XL to infinity. This controlled reactor is connected across the series capacitor, so that the variable capacitive reactance is possible across the TCSC to modify the transmission line impedance.

The impedance characteristic is shown in Fig. 2.

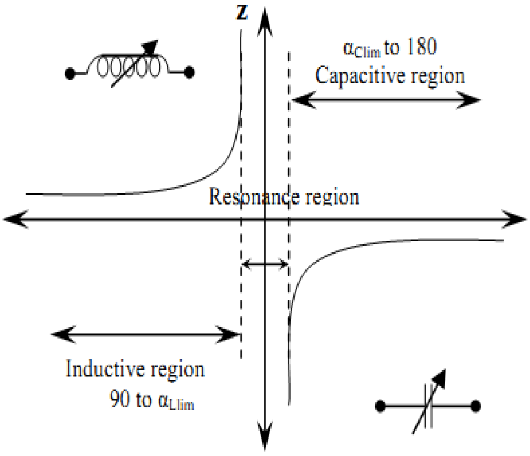

Fig. 2. Impedance diagram of TCSC [14]

3) Stability Analysis

The system considered for study is the IEEE 14 bus system. The system is modified by adding Automatic voltage regulators to all generators. The test system as seen in PSAT is shown in Fig3.

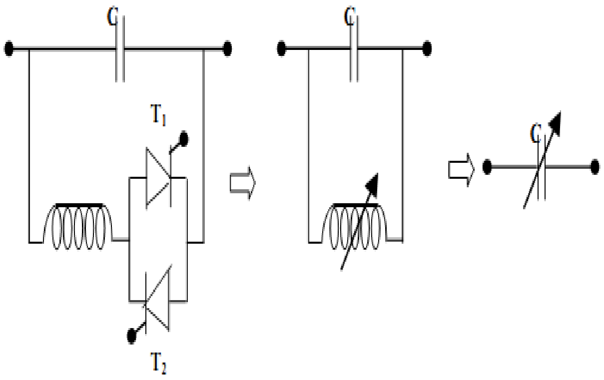

Fig. 3. Equivalent circuit as variable capacitor

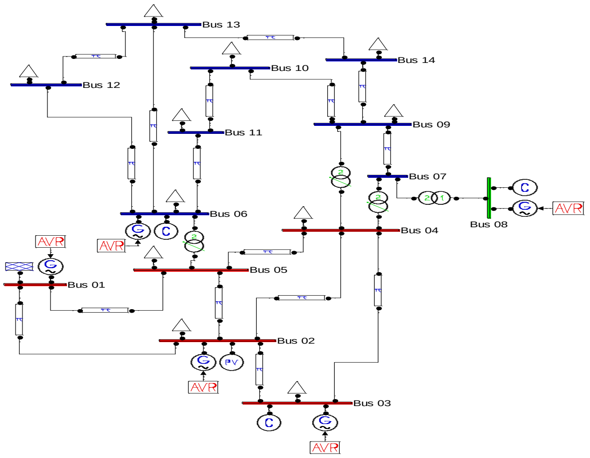

Fig. 4. IEEE 14 bus modified system for study [15]

The Steady state analysis of the system is performed using the eigen-value analysis available in PSAT. The obtained results show two positive eigen-values which are of the generator 1 excitation system hence the system is steady state unstable. An analysis of generator speeds, power and voltage profile shows that the generator 1 is contributing the maximum towards power oscillations. The Steady state stability analysis results obtained from PSAT are shown in Fig.5. The positive eigen values are

Eigen value 1	0.737	8.1012
Eigen value 2	0.737	-8.1012

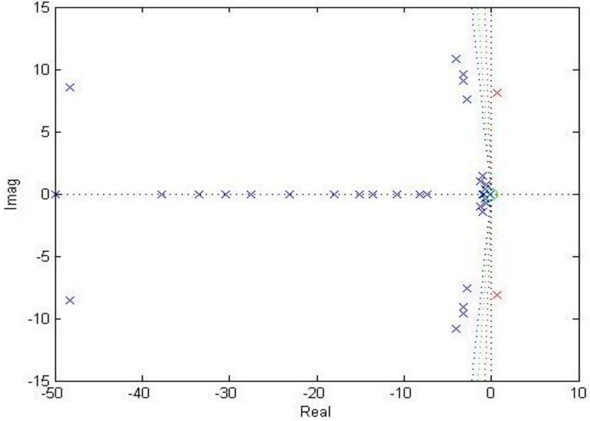

Fig. 5. steady state stability analysis of test system

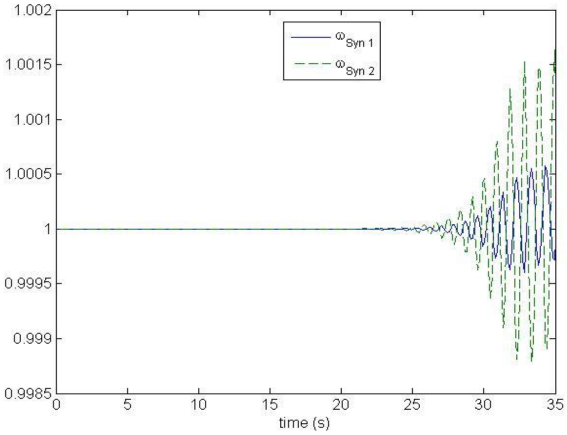

Fig. 6. generator speeds for base case

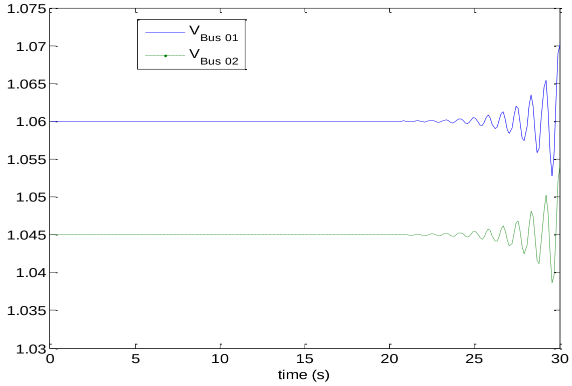

Fig. 7. voltage profiles of bus1 and bus 2 base cases

The steady state stability of the system is improved by adding turbine governor to the generators. The simulations results and eigen value analysis high-lighten this result.

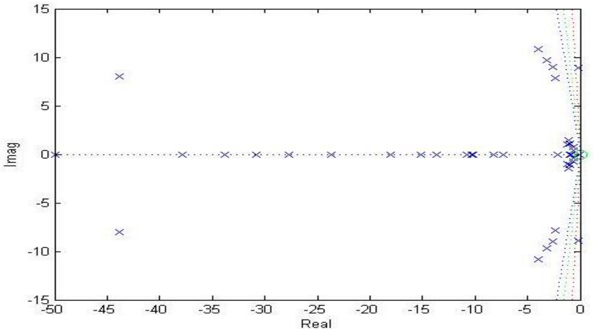

Fig. 8. Steady state stability through Turbine governor

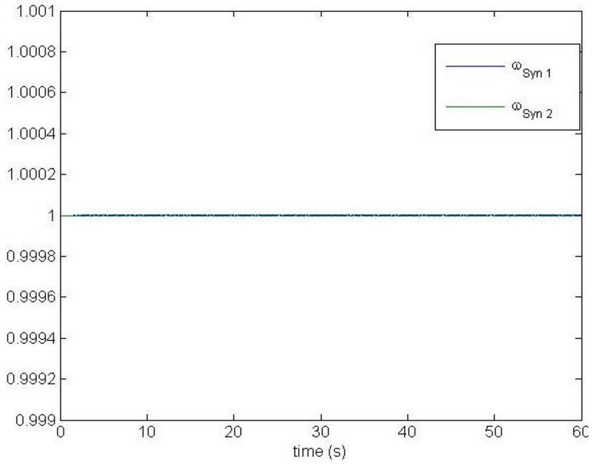

Fig. 9. generator speeds after steady state stability

It is clear from the figure 9 that for the steady state stable systemboth the generators operate at their synchronous speeds and there are no inter area oscillations.

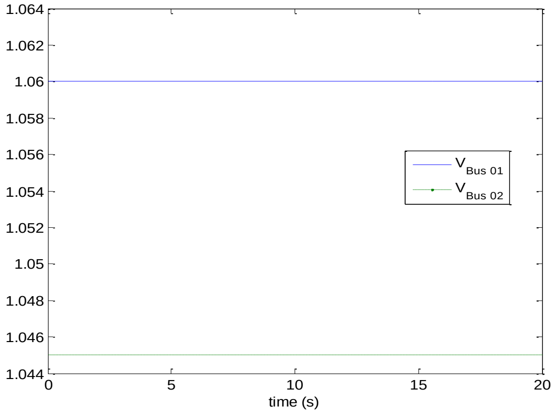

Fig. 10. Voltage profile for steady state stable system.

It is clear from Fig.10 that the turbine governor has restored the steady state stability of the system. However, in this system, for a large disturbance such as the line outage of a critical line like line 2-5, the system is unstable. This transient stability is then improved using TCSC.

III. TRANSIENT STABILITY

Now the line outage 2-5 has been done with the help of circuit breaker at 1sec. From the above eigen value analysis, generator speeds and voltage profile, it can be inferred that the system gets unstable with line outage of 2-5 but as shown in previous figures system was stable with turbine governor. So it is concluded that turbine governor is not able to make the system transiently stable.

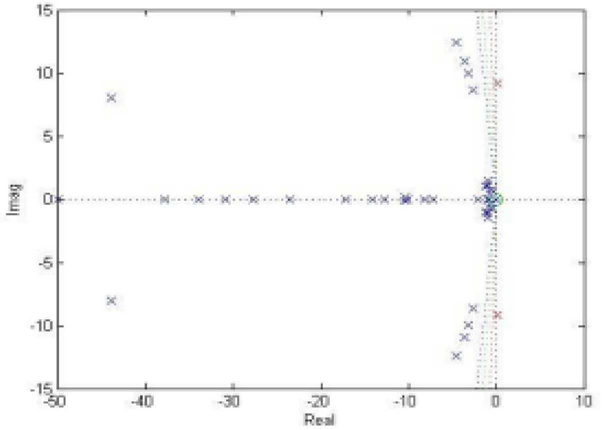

Fig. 11. line 2-5 Outage without TCSC

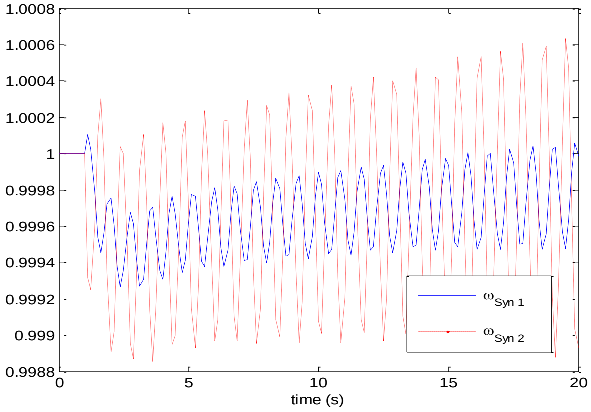

Fig. 12. Generator speeds for line outage

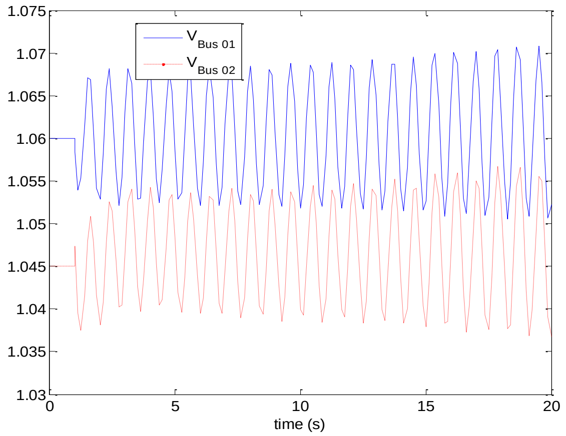

Fig. 13. Voltage profile for Transient stability

Now **TCSC** has been inserted between bus 1 and 5 to improve the transient stability.

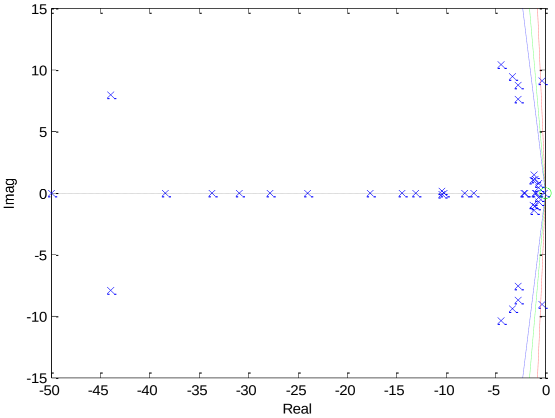

Fig. 14. Transiently stable system with TCSC

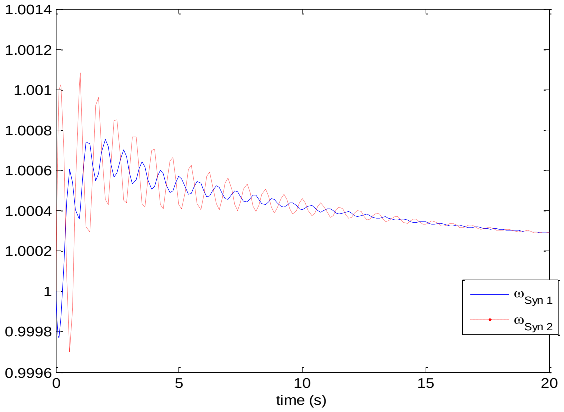

Fig. 15. Generator speeds with TCSC

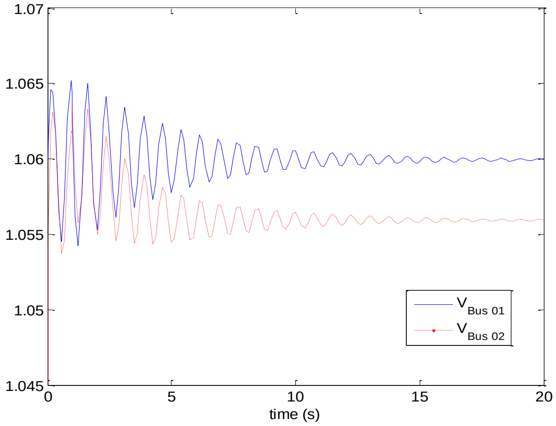

Fig. 16. Voltage profile with TCSC

From the Fig.14, Fig.15 and Fig.16, it is concluded that TCSC between line 1 and 5 has made the system transiently stable in spite of the occurrence of fault at 1sec. There are oscillations in the system when line outage occurs but TCSC damps out these oscillations and make the system stable.

REFERENCES

[1] H.R.Baghae,M.Jannat,,B.Vahidi,S.H Hosseinain,H.Rastegar , “Improvement of Voltage Stability and Reduce Power System Lossess by GA-based allocation of Multi-Type FACTS Devices”, IEEE.

[2] W.Du,H.F.Wang and R.Dunn ,“Power System Oscillation Stability and Control by FACTS and ESS-A Survery” , IEEE

[3] Jospeh Mutale and Goran Strbac , “Trasnmission Network Reinforcement Versus FACTS: An Economic Assessment” , IEEE Transaction on Power System,Vol.15,No.3,August 2000

[4] Ying Xiao,Y.H Song,Chen-Ching Liu and Y.Z.Sun , “Available Transfer Capability Enhancement Using FACTS Devices” ,IEEE Transactions on Power Systems,Vol.18,No.1,February 2003

[5] Cuong Vu The,Khanh La Minh,Tuan Tran Quoc,Nguyen Boi Khue and Lam Du Son, “ FACTS Devices Applications on Power System to Improve the Angle Stability” , 2006 IEEE.

[6] Sandeep Gupta,R.K Tripathi and Rishabv Dev Shukla, “Voltage Stability Improvement in Power Systems Using Facts Controllers:State-of-the-Art Review” , 2010 IEEE

[7] Heinz K.Tyll, Frank Schettler, “Historical Overview on Dynamic reactive power compensation solutions from the begin of AC power transmission towards present applications” , 2009 IEEE.

[8] HADI SAADAT, “Power system analysis”, 2nd Edition, McGraw, Oct 2007.

[9] John J.Paserba , “ How FACTS Controllers Benefit AC Transmission Systems-Phases of Power System Studies”2009 IEEE.

[10] M.M.El Metwally,A.A.E.I Emary,F.M.E.I Bendary and M.I.Mosaad, “Optimal Allocation of FACTS Devices in Power System Using Genetic Algorithms” ,2008 IEEE.

[11] Belkacem Mahdad,Tarek Bouktir and Kamel , “Strategy of Location and Control of FACTS Devices for Enhancing Power Quality” ,2006 IEEE.

[12] Baghaee, H.R Jannati,M.Vahidi,B.Hosseinian,S.H Jazebi, “Optimal Multi-Type FACTS Allocation Using Genetic Algorithm to Improve Power System Security” ,Power System Conference,2008. MEPCON 2008.12th International Middle-East 12-15 March 2000.

[13] Enrique Acha, Claudio R. Fuerte-Esquivel, Hugo Ambriz-Pe´rez, Ce´sar Angeles-Camacho, “FACTS Modelling and Simulation in Power Networks” , page 12-20

[14] S. Meikandasivam, Rajesh Kumar Nema, Shailendra Kumar Jain, “Behavioral Study of TCSC Device – A MATLAB/Simulink Implementation” .

[15] PSAT v2.12