Thyristor Controlled Series Capacitor (TCSC) for Power System Stabilization

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Abstract: The dynamic stability (DS) of the power system is a big challenge that facing the power system engineers. This DS can be improved by providing suitably tuned power system stabilizers on selected generators to provide damping to critical oscillatory modes. Suitably tuned power system stabilizers, will introduce a component of electrical torque in phase with generator rotor speed deviations resulting in damping of low frequency power oscillations in which the generators are participating. The clear improvement in power electronic devices makes such problems adjustment easier and more controllable. This paper discusses the use of TCSC for damping the rotor oscillations of the synchronous machine by controlling its excitation. A system formed of a synchronous generator connected to infinity bus through a transmission line is discussed. The results of simulation are obtained using MATLAP SIMULINK which are discussed in some what details in this paper.

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1- Introduction:-

The use of Power System Stabilizers has become increasingly important to provide improved stabilization of the system. The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators. These oscillations, also called power swings, must be effectively damped to maintain the system stability. In some cases the stabilizers are used as an additional control feature so that excitation system with a high response may be used without compromising the small signal instability of the generators [1]. The output signal of the stabilizers is used as an additional input to the Excitation System block. Power system is a complicate nonlinear system which structure, parameter and running mode usually change. The study of the linearzed system is necessary for some purposes, such as control loop design. The most common disturbance is load variations, but parameter variations are also common, and the closed loop control system is used to compensate for such variations. Low or negative damping in a power system can lead to spontaneous appearance of large power oscillations. Several methods for increasing the damping in a power system are available such as static voltage condenser (SVC), high voltage direct current (HYDC) and power system stabilizer (PSS) [2]. Omer M. Awed-Badeeb discuss the use of PSS for damping power system oscillation [1]. Power system stabilization with synchronized measurement is presented in [3].

2- Thiristor Controlled Series Capacitor (TCSC) Construction:-

The general construction is shown bellow in figure (1), which contains capacitors in parallel with controlled reactor, and it is connected in series with the transmission line [5]. The equivalent impedance across the device is the capacitive reactance in parallel with inductive reactance. The practical circuit of TCSC consists of parallel capacitors connected with metal oxide varistor (MOV) to protect it against sudden high voltages, as well as some valves to limit the current during the connection and disconnection of the capacitors.

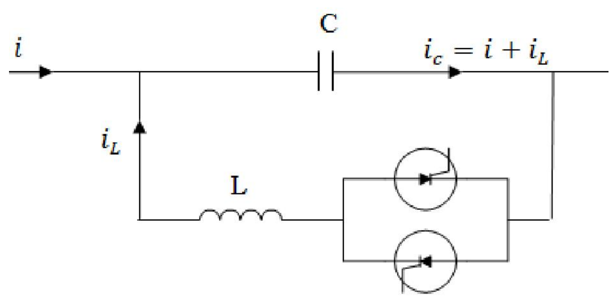

Figure (1) TCSC Construction

3- TCSC Model:-

A TCSC connected to a transmission line is shown below in figure (2).

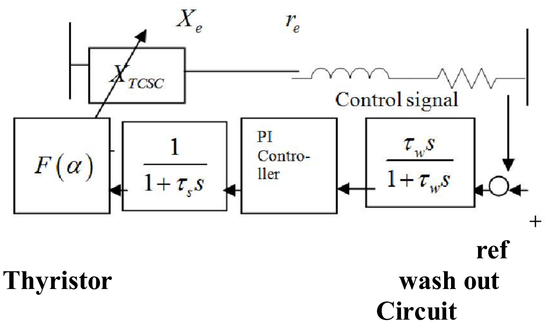

Figure (2) TCSC connected to a transmission line

Where:

X_{TCSC} : Is the TCSC reactance which is connected in series with the transmission line with reactance X_e, so the equivalent reactance is given by:

$$X_{eq} = X_e + X_{TCSC} \tag{3-1}$$

Wash out Circuit: Is a filter for high frequencies, and it has the time constant τ_w .

PI controller: It is used for partial shift of the motion equation roots to the most stable place in the complex level, so the system will be more stable and eliminate the negative effect of the excitation system.

Tyristor: It is expressed by the time constant τ_s ,which implement the time delay of the thyristot operation.

$F(\alpha)$: Represents the transfer function.

To study the effect of TCSC in damping power system oscillation, it is connected to a system with synchronous generator connected with infinity busbar through a transmission line as shown in figure (3) below:

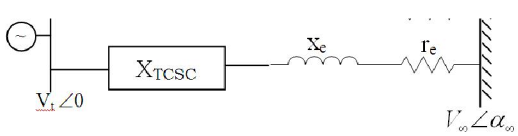

Figure (3) The system with TCSC

Where:

V_t : Is the synchronous generator terminal voltage.

V_∞ :Is the infinity bus voltage.

Neglecting the effect of the dampers for the classical model of the synchronous generator, the voltage equation for the phases (a,b,c) can be expressed as follows:-

$$V_{a,b,c} = V_{\infty a,b,c} + r_e i_{a,b,c} + L_{eq} i_{a,b,c'} \tag{3-2}$$

Where:

$$L_{eq} = L_e + L_{TCSC}$$

Applying Park" transformation to equation (3-2), the following equation can be obtained [6]:-

$$V_{0.d,q} = V_\infty \begin{bmatrix} 0 \\ -\sin(\delta-\alpha) \\ \cos(\delta-\alpha) \end{bmatrix} + r_e I_{0.d,q} - X_{eq} \begin{bmatrix} 0 \\ -I_q \\ I_d \end{bmatrix} \tag{3-3}$$

$$V_d = -V_\infty \sin(\delta-\alpha) + r_e I_d + X_{eq} I_q$$
$$V_d = -V_\infty \sin(\delta-\alpha) + r_e I_d + (X_e + X_{TCSC}) I_q$$
$$V_d = -V_\infty \sin(\delta-\alpha) + r_e I_d + X_e I_q + X_{TCSC} I_q \tag{3-4}$$

Equation (3-4) can be expressed in a linear form as follows:

$$\Delta V_d = -V_\infty \cos(\delta_0-\alpha_0)\Delta\delta + r_e \Delta I_d + X_e \Delta I_q + X_{TCSC}\Delta I_q + I_{q0}\Delta X_{TCSC} \tag{3-5}$$

Similarly ΔV_q can be expressed as follows:-

$$\Delta V_q = -V_\infty \sin(\delta_0-\alpha_0)\Delta\delta + r_e \Delta I_q + X_e \Delta I_d + X_{TCSC}\Delta I_d - I_{d0}\Delta X_{TCSC} \tag{3-6}$$

4- Variables State Equations of TCSC:-

Variables state that describe TCSC can be obtained by dividing figure (2) into two as in figure (4) and figure (5) as shown below:-

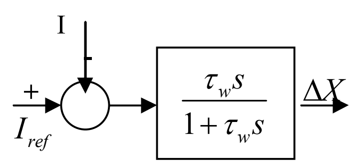

Figure (4) Wash out Circuit of TCSC

The transfer function of figure (4) can be obtained as follows:-

$$G_1(s) = \frac{\Delta X}{\Delta I_{ref} - \Delta I} = \frac{\tau_w s}{1+\tau_w s} \tag{4-1}$$

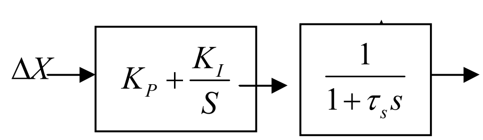

Figure (5) Thyristor and PI controller of TCSC

The transfer function $G_2(s)$ of the figure is as follows:-

$$G_2\left(S\right)=\frac{\Delta\alpha}{\Delta X}=\frac{SK_P+K_I}{\left(1+\tau_x S\right)S} \quad (4\text{-}2)$$

So the transfer function G(s) of the TCSC is :

$$G\left(s\right)=G_1\left(s\right)*G_2\left(s\right)$$

$$G\left(s\right)=\frac{\tau_w S}{1+\tau_w S}*\frac{SK_P+K_I}{\left(1+\tau_x S\right)S} \quad (4\text{-}3)$$

If the reference current is constant, $\Delta I_{ref}=0$

$$\therefore G_1\left(s\right)=\frac{\Delta X}{-\Delta I}=\frac{\tau_w s}{1+\tau_w s}$$

$$\Delta X+\tau_w\dot{\Delta X}=-\tau_w\Delta I$$

$$\therefore \dot{\Delta X}=\frac{-1}{\tau_w}\Delta X-\Delta I \quad (4\text{-}4)$$

$$\therefore G_2\left(s\right)=\frac{SK_P+K_I}{1+\tau_x S}=\frac{\Delta\alpha}{\Delta X}$$

$$K_P\dot{\Delta X}+K_I\Delta X=\Delta\alpha+\tau_x\dot{\Delta\alpha}$$

Substituting $\dot{\Delta X}$ from (4-4) it is found that:

$$\dot{\Delta\alpha}=\frac{-1}{\tau_x}\Delta\alpha+\frac{K_P}{\tau_x}\left(\frac{-1}{\tau_w}\Delta X-\Delta I\right)+\frac{K_I}{\tau_x}\Delta X$$

$$\dot{\Delta\alpha}=\frac{-1}{\tau_x}\Delta\alpha+\frac{-K_P+\tau_w K_I}{\tau_x\tau_w}\Delta X-\frac{K_I}{\tau_x}\Delta I \quad (4\text{-}5)$$

Equations (4-4) and (4-5) are the variables state equations and can be expressed in matrix form as follows:

$$\begin{bmatrix}\dot{\Delta\alpha}\\ \dot{\Delta X}\end{bmatrix}=\begin{bmatrix}\frac{-1}{\tau_x}, & \frac{-K_P+\tau_w K_I}{\tau_x\tau_w}\\ 0, \frac{-1}{\tau_w} & \end{bmatrix}\begin{bmatrix}\Delta\alpha\\ \Delta X\end{bmatrix}+\begin{bmatrix}\frac{-K_P}{\tau_x}\\ -1\end{bmatrix}\Delta I \quad (4\text{-}6)$$

5- Simulation Results:-

Simulation is done using MATLAB SIMULINK for a system formed of a synchronous generator connected to infinity bus through a transmission line. The system data are presented in Table (1) below.

The study is done for the mentioned system in the availableness of excitation system firstly without TCSC, and the results are presented. Then the study is done after addition of the TCSC device. The relations between ($\Delta\omega$, $\Delta\delta$, ΔP_e) and the time when the system is subjected to a sudden and continues disturbance for the input mechanical power by 0.1 pu, are ploted during the two different cases.

Table (1) System data

The synchronous and transmission line data:	
$X_d=1.7\,pu$	$X_q=1.67\,pu$
$X'_d=0.245\,pu$	$R_a=0.001096\,pu$
$X_e=0.4\,pu$	$R_e=0.02\,pu$
$P_e=1\,pu$	$P_f=0.85$ lag
$\omega_0=377$ r.p.m	$\tau_{d0}=5.9$ sec
$H=2.37$ sec	
The excitation system data:	
$K_A=200$	$\tau_A=0.05$ sec
$K_f=0.025$	$\tau_f=1$ sec

5-1 System Response without TCSC:-

Figures [(6) (7), (8)] hows that the oscillations for ΔP_e, $\Delta\delta$ and $\Delta\omega$ is increasing with the time, in other words it can be said that the system is not stable. This is due to the negative effect of the excitation system in the stability.

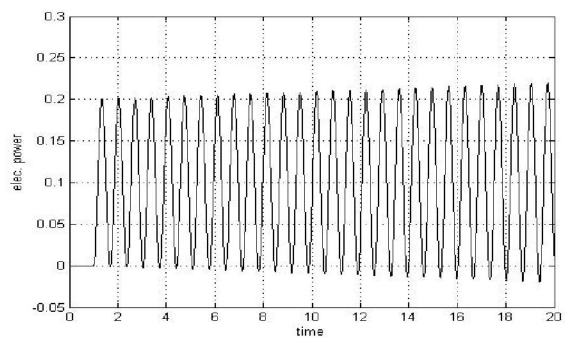

Figure (6) Relation between ΔP_e and the time without TCSC

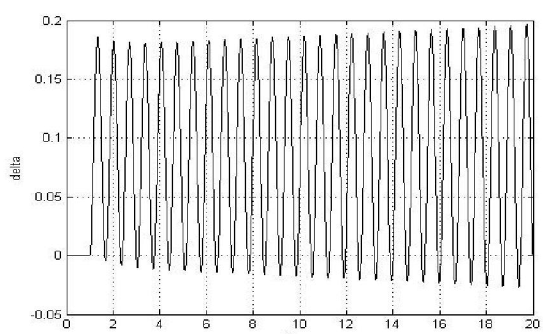

Figure (7) Relation between $\Delta\delta$ and the time without TCSC device

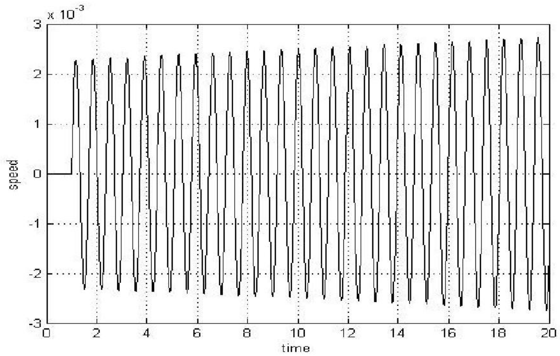

Figure (8) Relation between $\Delta\omega$ and the time without TCSC

5-2 System Response after Addition of TCSC Device:-

After addition of TCSC the system has become stable, and this is clearly shown in figures [(9), (10), (11)] which show the relations between ΔP_e , $\Delta\delta$ and $\Delta\omega$ with time

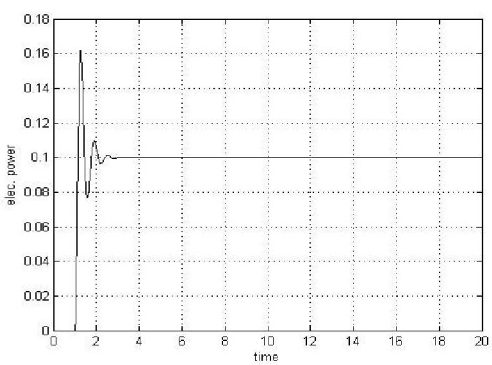

Figure (9) Relation between ΔP_e and the time with TCSC

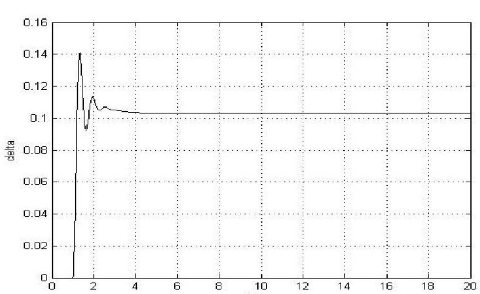

Figure (10) Relation between $\Delta\delta$ and the time with TCSC

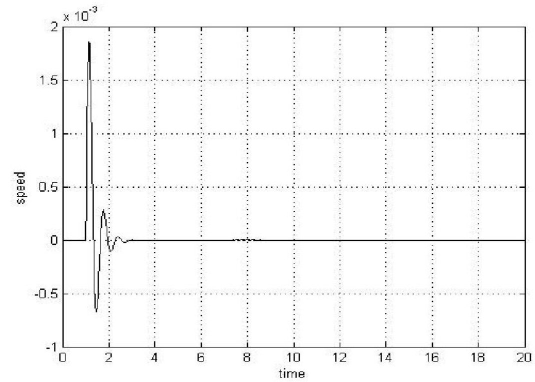

Figure (11) Relation between $\Delta\omega$ and the time with TCSC

6- Conclusion:-

Power system stability implements a big side of power system engineers care, due to its clear effect in the life time and safety of the synchronous generator.

The results show that the excitation system causes a large oscillation for the power system, since it is adding a negative damping torque due to its high response. This makes a shift for the roots of motion equation from the negative part to the positive one. According to the results addition of TCSC solves this problem completely and the system became stable. Moreover power flow control through the transmission line is improved by controlling the line impedance by the triggering angle α according to the required loading conditions.

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