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Damping Subsynchronous Resonance in Dynamic Phasor and dq0 model using Thyristor Controlled Reactor

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Abstract— This paper presents the use of a Thyristor controlled reactor with local signal to mitigate subsynchronous resonance in a power system. The dynamic phasor base model and dq0 model of two area power system is considered in this paper. Modal speed deviation is used as local signal in both models. This local signal modulates the firing angle of TCR through PI controller in dynamic phasor base model and dq0 model of power system . This paper shows that the designing parameter of PI controller and mitigation behaviour of SSR using local signal in dynamic phasor based model and dq0 model closely match with each other.

Keywords— Dynamic Phasor Model, Thyristor controlled reactor , subsynchronous resonance

I. Introduction

Transmission utilities plan to increase power transfer capability between regions due to lack of local reserve. Under such circumstance, it is becoming more economical to implement series capacitor at the strategic links than undertaking other conventional network re-enforcement. The application of series capacitors is economical solution to increase power transfer capability of transmission line. However, series capacitor in transmission lines may closely coupled network mode and torsional mode of steam turbine – generator and ultimately lead to turbine-generator shaft failure. Hence SSR must be fully understood and analyzed while planning series capacitor compensation in power systems.

Terms, Definitions and symbols for SSR study is provided in [1]. Edris shows the two schemes of passive phase imbalance for mitigation of SSR [2]. The DFIG converter is used for SSR mitigation in [3]. The study system as per IEEE first benchmark model for SSR study is given in [4]. Generally, conventional dq0 modeling is applied to three phase variables to get time invariant models with balanced operation. However, this method fails to give time invariance under unbalanced operation. The dynamic phasor modeling gives time invariant model under balanced and unbalanced operating conditions. Dynamic phasors have been successfully used in modeling and analysis of electrical machines [5–7]; power system dynamics and faults analysis is done by dynamic phasor based model [8,9]; Dynamic phasor models are also suitable for the analysis and simulation of circuits with steady state harmonics. Mattaveli developed a TCSC model using dynamic phasors[10].

In this paper, dynamic phasor based model and dq0 model of two machine system with thyristor controlled reactor is developed. The modal speed deviation is used as local signal. The firing angle of TCR will modulate using damping controller in both models . The main aim of this paper is to conclude that the designing parameter of PI controller and mitigation behaviour of SSR in dynamic phasor based model and dq0 model closely match with each other .

The organization of the paper as follows, Section I contain the introduction, Section II contain dynamic phasor modeling, Section III contain Thyristor controlled reactor ,Section IV contain results and discussion and Section V conclude the research work.

II. DYNAMIC PHASOR MODELING

The power system voltage and current dynamics can be captured efficiently by a Fourier series computed over a sliding window of length equal to the nominal period, with slowly time-varying Fourier coefficients. Such coefficients will be referred to as dynamic phasor.
Any periodic waveform can be represented in terms of complex Fourier coefficient as given below

$$x(\tau) = \sum_{k=-\infty}^{k=\infty} < x >_k (t) e^{jkw_s \tau}$$

$$\tau \in (t - T, t)$$

$<x>_k$ is the k^{th} phasor of instantaneous signal x(t) and can be computed as follows

$$< x >_k (t) = \frac{1}{T}\int_{t-T}^{t} x(\tau)\, e^{-jkw_s \tau} d\tau$$

As the window of length 'T' slides over the waveforms of interest with time, the corresponding dynamic phasor vary accordingly. Note that if x(t) is periodic with a period T, corresponding dynamic phasor are constants.
The following properties of dynamic phasor used in this paper
(1) Derivative of the dynamic phasor is given by the following equation.

$$\frac{d < x >_k}{dt} = \langle\frac{dx}{dt}\rangle - -jkw_s < x >_k$$

(2) Dynamic phasor of the product of two signals u(τ) and v(τ) can be obtained by the discrete convolution of the corresponding dynamic phasor as given below.

$$\langle u\, v\rangle_k = \sum_{l=-\infty}^{\infty} \langle u\rangle_{k-l}\ \langle v\rangle_l$$

(3) Following are also the important results.

$$\langle x\rangle_k = \langle x\rangle_{-k}{}^{*} \qquad \text{if } x(\tau) \text{ is real,}$$

$$\langle x\rangle_k = \langle y\rangle_{-k}{}^{*}$$

if x(τ) and y(τ) are complex conjugates of each other where superscript '*' represents the complex conjugate of a variable. In periodic steady state the dynamic phasors corresponds to k^{th} harmonic of original waveform.

II A. SYNCHRONOUS MACHINE MODEL

The dynamic phasor model of synchronous machine [11] is as follows:

$$\frac{d}{dt}\langle \varphi_{pnz}\rangle_k = -[R_s]\langle i_{pnz}\rangle_k - \langle v_{pnz}\rangle_k - jkw_B\langle \varphi_{pnz}\rangle_k$$

$$\frac{d}{dt}\langle \varphi_r\rangle_k = -[R_r]\langle i_r\rangle_k - \langle v_r\rangle_k - jkw_B\langle \varphi_r\rangle_k$$

$$\frac{d}{dt}\langle \delta\rangle_k = \langle w - w_B\rangle_k - jkw_B\langle \delta\rangle_k$$

$$\frac{d}{dt}\langle \omega\rangle_k = -\frac{1}{J}[\langle T_m\rangle_k - \langle T_e\rangle_k] - jkw_B\langle \omega\rangle_k$$

The electromagnetic torque Te of the generator, can be expressed as follows

$$Te = \Psi_D\, i_Q - \Psi_Q\, i_D$$

$$\langle \Psi_D\rangle_k = \frac{1}{\sqrt{2}}[\langle \Psi_p\rangle_{k+1} - \langle \Psi_n\rangle_{k-1}]$$

$$\langle \Psi_Q\rangle_k = \frac{j}{\sqrt{2}}[\langle \Psi_p\rangle_{k+1} - \langle \Psi_n\rangle_{k-1}]$$

II B. DYNAMIC PHASOR MODEL OF NETWORK

The basic network equation variables are transformed to sequence variables and after that it is converted into dynamic phasor form. The general form of network equation is given below

$$< x_{pnz>_k} = A_N < x_{pnz>_k} + B_N < E_{pnz>_k} - jk\omega_s < x_{pnz>_k}$$

$$< i_{pnz>_k} = C_N < x_{pnz>_k} + D_N < E_{pnz>_k}$$

Where $< x_{pnz>_k}$ are the states of network. $< i_{pnz>_k}$ are the currents at the network ports and $< E_{pnz>_k}$ are the voltages at these ports.Network equations are time invariant under balanced and unbalanced operation. If network equations in 'abc' variable are linear time-invariant then there is no coupling between dynamic phasors corresponding to various k.

III. THYRISTOR CONTROLLED REACTOR

TCR consist with two anti parallel thyristor with reactor in series as shown below.

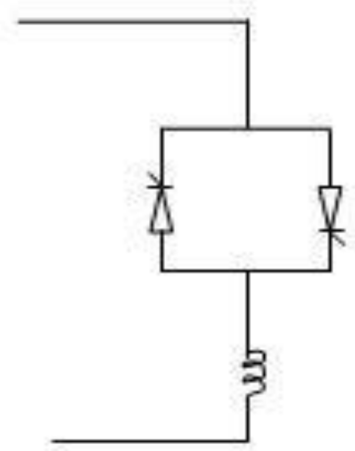

Fig.1 Thyristor controlled reactor

The anti parallel pair of thyristor will act as a bidirectional switch. The thyristor switch firing angle modulation gives modulated shunt reactance.
Firing angle α is related to conduction angle σ as follows

$$\propto + \frac{\sigma}{2} = \pi$$

$$I(\sigma) = VB_{max}\left(\frac{\sigma - \sin(\sigma)}{\pi}\right)$$

IV. RESULTS AND DISCUSSION

In this paper, two area system is taken as test system as shown below.

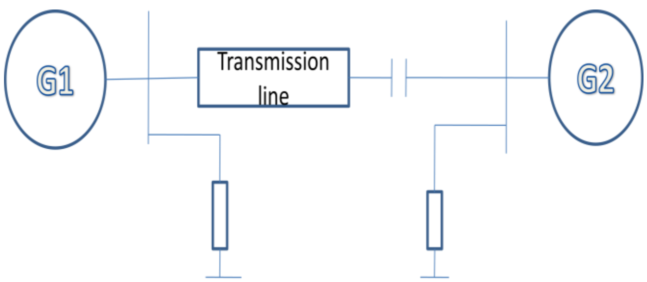

Fig. 2 Two machine system

In this two area system , G1 is modelled as per IEEE first bench mark multimass system [4] and G2 as lumped model.

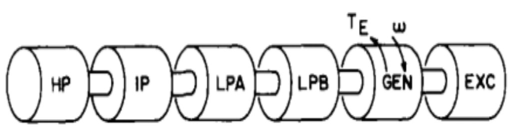

Fig.3 IEEE first bench mark Turbine- Generator modal

Active power and reactive power of generator 1 is 0.6 pu and 0.2 pu . Active power and reactive power of generator 2 is 0.5 pu and 0.2 pu. Power flow from generator 1 to generator 2 through transmission line is 0.1 pu . The transmission line reactance is 0.7 pu . The capacitors supplies 0.1 pu at generator 1 and generator 2. Load connected at generator 1 has active power 0.5 pu and reactive power 0.3 pu .The load connected at generator 2 has active power 0.6 pu and reactive power 0.3 pu. The amount of series compensation is 0.1 pu.
The mechanical torque disturbance of 0.05 pu is applied at generator G1 during 3 to 3.01 sec .This disturbance is pulse type of disturbance.

In this paper , dq0 model and dynamic phasor based model are derived for two machine system. In both models, the generator initially run without controller .The disturbance as mention above is applied to generator G1 and plot the modal speed deviations of G1 multimass system.Again, same disturbance is applied to the generator G1 with controller and plot the modal speed deviations. Modal speed deviation TM4 signal is control signal. This signal is used to modulate firing angle alpha of TCR through PI controller. The PI controller are tuned for SSR damping.
The schematic of controller is shown below.

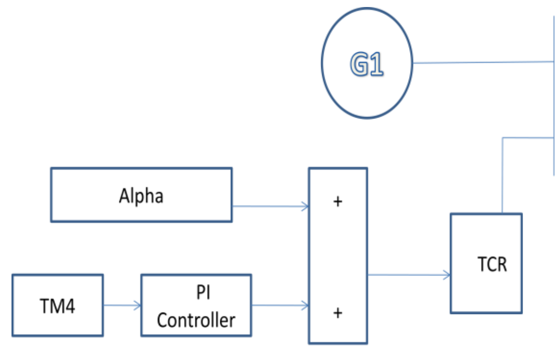

Fig.4 Schematic of controller

The modal speed deviation with dq0 model without controller is shown below

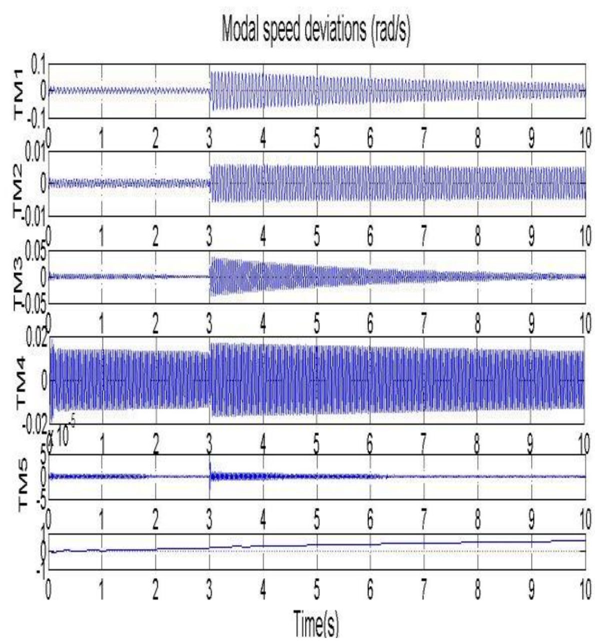

Fig.5 The modal speed deviation without controller in dq0 model.

The modal speed deviation with same dq0 model with controller is shown below.

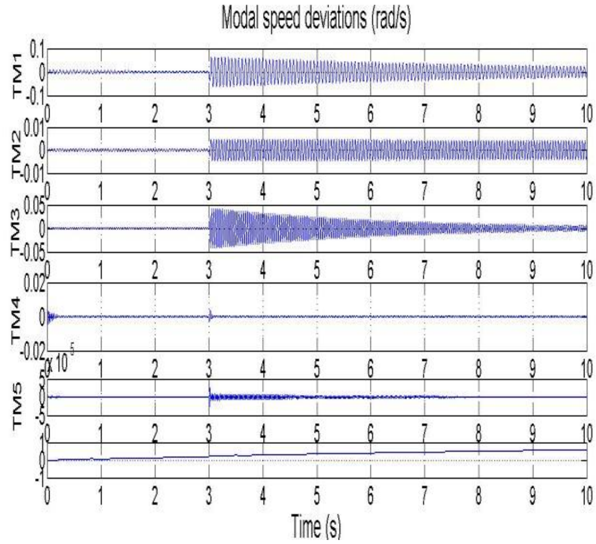

Fig.6 The modal speed deviation with controller in dq0 model

The modal speed deviation TM4 shows considerable damping in sub synchronous oscillation with controller. With same parameter, the modal speed deviation with dynamic phasor based model without controller is shown below.

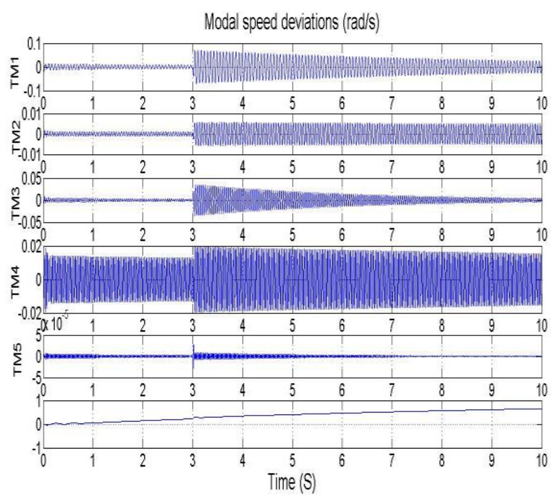

Fig.7 The modal speed deviation without controller in dynamic phasor model

With same parameter, the modal speed deviation with dynamic phasor based model with controller is shown below.

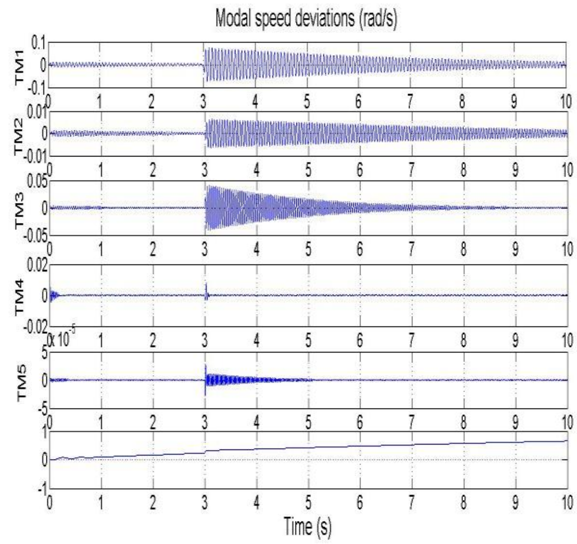

Fig.8 The modal speed deviation with controller in dynamic phasor modal

V. CONCLUSION

The modal speed deviation plots in both models clearly shows the effect of controller on subsynchronous oscillation. The dq0 model and dynamic phasor based model shows nearly same subsynchronous oscillation mitigation behavior. The dynamic phasor based model used nearly same tuning parameter of PI controller as used in dq0 model. This can be more helpful for designing the parameters of subsynchronous damping controllers. It may also be helpful for the applications which involve unbalanced operation of the system.

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