SUBSYNCHRONOUS RESONANCE MITIGATION USING WIDE AREA MEASUREMENT SYSTEM

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ABSTRACT

This paper presents the wide area measurement based controller for subsynchronous resonance mitigation in two machine system. The dq0 model of the two machine system is considered in this paper. Generator 1 is multimass model as per given in IEEE first bench mark model and generator 2 is considered as lumped model. The computation of frequency from voltage phasor of each generator is used for SSR mitigation. The difference of frequency of two machine is used as control signal. This control signal modulate the firing angle of thyristor controlled reactor through controller. As the control signal is global signal, it will give damping to almost all torsional modes of oscillation and eliminates local controller for each torsional modes. This paper shows application of wide area controller in dq0 model mitigates subsynchronous oscillation in system..

Keywords: Wide area measurement system, Subsynchronous resonance

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1. INTRODUCTION

Day by day, load demand goes on increasing and hence it is very much necessary to increase the power transfer capability of transmission line. The series capacitor in transmission line is one of the economical solution to increase the power transfer capability of transmission line. This is the economical solution compare to increase the power generation and enhance the transmission structure. The huge amount of cost is involved in power generation as well in transmission structure. When line is series compensated and generator is steam turbine generator, it will lead to vary serious phenomena known as Subsynchronous resonance. This will ultimately lead to turbine-generator shaft failure. Such events are reported in 1970 and 1971 at Mohave generating station and hence it is necessary to understand and analyze the effect of subsynchronous resonance in power system.

A general definition of SSR[11] as per IEEE is “ Subsynchronous resonance is an electric power system condition where the electric network exchange energy with a turbine at one or more of the natural frequencies of the combined system below the synchronous frequency of

the system". Electrical torque and mechanical torque acts as input for system. If one of the torque gets changed ,it will excite the torsional mode of the multimass system . If this torsional mode coincide with network mode, electrical torque act in such a way that it will enhance the oscillation. This is particularly happened when line is series compensated and torsional modes are of subsynchronous in nature . IEEE Subsynchronous resonance task group [1] gives IEEE first bench mark model for computer simulation of subsynchronous resonance. Stankovic and Aydin [2] proposed synchronous machine model to analyze the asymmetrical faults in power system. In [3], author proposed static synchronous series compensator: A solid state approach to series compensation of transmission line. Mattavelli [4] developed a TCSC model using dynamic phasors. In [5] , Dynamic Phasors in Modeling and Analysis of Unbalanced Polyphase AC Machines is given. This paper include that the time domain simulation are not only a significant computational burden, but also offer little insight into problem sensitivities to design quantities. In[6], Paper presented Modeling of LCC-HVDC Systems Using Dynamic Phasors. L. Fan, Z. Miao [7] gives SSR mitigation using DFIG-Based Wind Generation. In [8] , author proposed passive phase imbalance for SSR mitigation with dynamic phasor model. Author conclude that passive phase imbalance is not general SSR mitigation. In [9] , author suggest estimation methods using dynamic phasors for numerical distance protection.

In this paper ,dq0 model of two machine system is developed. The difference of frequency computed from voltage phasor is used as control signal. This signal modulates the firing angle of thyristor controlled reactor through controller. In this paper, control signal is based on wide area measurement basis. This modulated firing angle through controller gives damping in Subsynchronous oscillation .This paper shows mitigation of subsynchronous oscillation in almost all torsional modes.

2. OBJECTIVES OF THE STUDY

The objective of this work are as follows

- To develop dq0 model of two machine system
- To compute frequency from voltage phasor
- Subsynchronous resonance mitigation in torsional modes using wide area measurement

3. COMPUTATION OF FREQUENCY

In this paper, dq0 model of two machine system is derived. Computation of frequency from voltage phasor in dq0 model is discussed below. This method is discussed in [10] .

It would be advantageous if the time –varying machine equation can be transformed to a time invariant set under balanced operation. This would result in the simplification of the calculations both for steady state and transient conditions. Park transformation [11] transform ‘abc’ variable to ‘dq0’ variable. Park transformation results in time invariant machine equation under balanced operation which are easier to handle.

The flow chart of computation of frequency from voltage phasor is shown below.

Figure. 1 Flow chart of computation of frequency

In the synchrophasor standard [12], frequency is defined as the derivative of the phase angle of the signal.

$$2\pi f = \frac{d\phi}{dt}$$

However, when the angular position of phasor changes abruptly under transient conditions, derivative of phasor leads to large undesirable spikes in the frequency measurement. Therefore, approach of computing frequency from PMU discussed in [10], is used here to obtain the frequency under transient condition.

The input analog signal is sampled at constant sampling frequency. The phasor estimator calculates the phasor representation of the input signal. Discrete fourier transform(DFT) is used as phasor estimator. The DFT of a discrete –time signal $x(n)$ is a finite duration discrete frequency sequence. The DFT allow to determine the frequency content of a signal. The DFT of finite duration sequence $x(n)$ is given below.

$$X_{(k)} = \frac{\sqrt{2}}{N} \sum_{n=0}^{N-1} x_{(k+n)} e^{-j \frac{2\pi n}{N}}$$

Where k is the first sample in the data window, and N is the number of samples in a cycle of the fundamental frequency component.

When constant frequency sampling clock synchronized with nominal frequency are used, the true value of positive sequence phasor $X(k)_1$ and measured positive sequence phasor $X'(k)_1$ is different and they are related as given below.

$$X'(k)_1 = PX(K)_1 e^{jk(\omega - \omega_0)t}$$

Where co-efficient P is given by

$$P = \left[\frac{\sin N \frac{(\omega - \omega_0)\Delta t}{2}}{N \sin \frac{(\omega - \omega_0)\Delta t}{2}} \right] e^{j(N-1)\frac{(\omega - \omega_0)\Delta t}{2}}$$

The magnitude and phase angle of 'P' (DFT leakage) depends upon the sampling rate N and the difference between the nominal and actual frequencies.

A PMU using a constant frequency sampling clock must apply correction factors 'P' to the estimated phasor before the result is used in the output.

Frequency at time t is $\omega(t) = (\omega_0 + t \omega')$

where ω_0 is nominal frequency and ω' is the rate of change of frequency

$$\phi(t) = \int \omega dt = \phi_0 + t\omega_0 + \frac{1}{2}t^2\omega'$$

If $\phi(t)$ is assumed to be

$$\phi(t) = a_0 + a_1t + a_2t^2$$

At time $t=0$,

$$\omega_0 = a_1 \quad f_0 = a_1/2\pi$$

$$\omega' = 2a_2 \quad f' = a_2/\pi$$

for 'n' angle measurements,

$$\begin{bmatrix} \phi_0 \\ \vdots \\ \phi_{n-1} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ \vdots & \vdots & \vdots \\ 1 & (n-1)\Delta t & (n-1)^2\Delta t^2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix}$$

Where Δt is the time interval between the samples

In matrix form ,

$$[\Phi] = [B][A]$$

The unknown vector [A] is calculated by Weighted least square method

$$[A] = [B^T B]^{-1} B^T [\Phi]$$

$$[A] = [G][\Phi]$$

The matrix [G] is pre-calculated and stored. From [A], frequency can be calculated as below.

$$\frac{d\phi}{dt} = a_1 + 2a_2t$$

As discussed earlier

$$2\pi f = \frac{d\phi}{dt}$$

$$f = \frac{1}{2\pi} (a_1 + 2a_2t)$$

4. THYRISTOR CONTROLLED REACTOR

TCR consist with two anti-parallel thyristor with reactor in series. The anti-parallel pair of thyristor will act as a bidirectional switch. The TCR gives thyristor based modulated shunt reactance. Thyristor switch firing angle modulation gives mitigation of subsynchronous oscillation.

Firing angle α is related to conduction angle σ as follows

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

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

5. RESULTS AND DISCUSSION

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

Figure 2 Two machine system

IEEE first bench mark is widely used for computer simulation of subsynchronous resonance. It has six masses system and hence it has five torsional mode of oscillation and one common mode of oscillation .In this paper , two machine system is used. Out of this ,one machine (generator-1) is consider as per IEEE first bench mark model and second machine(generator-2) is consider as lumped model. The amount of active power and reactive power of G1 is 0.6 pu and 0.2 pu respectively. The amount of active power and reactive power of G2 is 0.5 pu and 0.2 pu respectively. The capacitor supplies 0.1 pu at both generators. The load connected at G1 has active power demand 0.5 pu and reactive power 0.2 pu . The load connected at G2 has active power demand 0.6 pu and reactive power 0.2 pu . The active power flow through transmission line is 0.1 pu. The transmission line reactance is 0.7 pu and amount of series compensation is 0.1 pu. The disturbance in mechanical torque amount 0.05 pu applied at generator G1 during 3 to 3.01 sec.

Frequency of generator G1 voltage phasor (f_1) and frequency of generator G2 voltage phasor (f_2) is computed as discussed above . The ($f_1 - f_2$) signal is control signal. This signal is used to modulate firing angle of TCR through PI controller. The PI controller are tuned for Subsynchronous oscillation damping. The schematic of controller is shown below.

Figure 3 Schematic of Controller

For computation of frequency in dq0 model , vector of ‘n ‘ angle measurements taken is 40 and no of sample in one cycle is 8

The dq0 model of two machine system without wide area measurement controller gives modal speed deviation in all modes as shown below.

Figure 4 Subsynchronous oscillation in dq0 model without WAMS controller

With WAMS controller in same dq0 model, observable damping in subsynchronous oscillation is obtained as shown below.

Figure 5 Subsynchronous oscillation in dq0 model with WAMS controller

6. CONCLUSION

The application of wide area controller in dq0 model gives considerable damping in almost all torsional modes of two machine system. The modulated firing angle of Thyristor

controlled reactor through WAMS controller eliminates local dedicated controller for each torsional mode.

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