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TRANSIENT CASE FOR SUB-SYNCHRONOUS RESONANCE STUDY

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Sub-synchronous resonance, series compensation, Synchronous machine.

ABSTRACT: In recent years, much has been written and bibliographies have been published on the subject of Sub-synchronous Resonance (SSR). The model for the study of Sub-synchronous resonance is presented in this paper. Models were developed with the minimum sophistication needed to obtain useful results of transient case.

1. INTRODUCTION

In this paper, Series capacitor compensation in AC transmission systems is an economical means to increase load carrying capability, control load sharing among parallel lines and enhance transient stability. However, capacitors in series with transmission lines may cause sub-synchronous resonance that can lead to turbine-generator shaft failure and electrical instability at oscillation frequencies lower than the normal system frequency. Therefore, the effects of SSR must be fully understood and analyzed when planning series capacitor compensation in power systems. The main concern with SSR is the possibility of shaft damage from torsional stresses. Damage can result from the long term cumulative effects of low amplitude torsional oscillations or the short term effects of high amplitude torques. Typically, hydro units have mechanical parameters that are less prone to SSR problems than thermal units.

Sub-synchronous oscillations were first discussed in 1937 [1,2] and until 1971, shaft torsional oscillations were neglected. Two shaft failures at the Mohave Generating Station in Southern Nevada [3] led to the understanding and development of the theory of interaction between series capacitor compensated lines and the torsional modes of steam turbine-generators.

Presently, several computer programs and analytical tools are available for the study of SSR caused by the interaction of multi mass turbine - generators and series compensated transmission systems.

2. DATA FOR STUDY SSR

TABLE I shows the impedances for the rotor circuit expressed in per unit on the machine MVA base. Current, voltage, torque and rotor speed are also expressed in per unit. For transient representation, divide reactance in ohms by 377 to obtain the inductance in henries.

The generator standard impedances and time constants from which the circuit parameters of TABLE I were derived are shown in TABLE II. The term XL is armature leakage reactance. Circuit parameters are obtained from the standard impedances and time constants by an iterative process outlined in the appendix. Where the treatment of these standard machine impedances and time constants is not mathematically reducible to the rotor network defined in Fig. 1 and TABLE I, the result will differ.

TABLE 1: *Rotor circuit parameters for transient SSR studies*

Parameter	D-axis	Q-axis
$377R_f$	0.53	5.3
X_f	0.062	0.326
$377R_k$	1.54	3.1
X_k	0.0055	0.095
X_a	1.66	1.58
X_L	0.13	0.13

Table III shows the inertias and spring constants for the spring mass model. Inertia is expressed in terms of the inertia constant H based on rated kVA. The base torque is that required at synchronous speed to deliver mechanical power in kilowatts equal to the rated (base) kVA value. Base angle is 377 radians, the angle of shaft rotation in one second (the base time). The spring constant K is given in per unit where base spring constant is defined as base torque divided by base angle. The simple second order torque equation in this system of units is:

$$T(pu) = 2H\ddot{\theta} + D\dot{\theta} + K\theta$$

The spring constant is also given in per unit torque per radian. For transient studies, the mechanical damping is assumed to be zero.

$$X_d = X_L + X_{ad} \quad (1)$$

$$X_q = X_L + X_{aq} \quad (2)$$

$$\frac{1}{X_d''-X_L} = \frac{1}{X_{fd}} + \frac{1}{X_{kd}} + \frac{1}{X_{ad}} \quad (3)$$

$$\frac{1}{X_q''-X_L} = \frac{1}{X_{fq}} + \frac{1}{X_{kq}} + \frac{1}{X_{aq}} \quad (4)$$

$$0 = \frac{1}{X_{fd}-377T'_{do}R_{fd}} + \frac{1}{X_{kd}-377T'_{do}R_{kd}} + \frac{1}{X_{ad}} \quad (5)$$

$$0 = \frac{1}{X_{fq}-377T'_{qo}R_{fq}} + \frac{1}{X_{kq}-377T'_{qo}R_{kq}} + \frac{1}{X_{aq}} \quad (6)$$

$$0 = \frac{1}{X_{fd}-377T''_{do}R_{fd}} + \frac{1}{X_{kd}-377T''_{do}R_{kd}} + \frac{1}{X_{ad}} \quad (7)$$

TABLE 2: *Generator impedances and time constants*

Parameter	Value
X_d	1.79 pu
X_d'	0.169 pu
X_d''	0.135 pu
X_L	0.13 pu
X_q	1.71 pu
X_q'	0.228 pu
X_q''	0.200 pu
T_{do}'	4.3 s
T_{do}''	0.032 s
T_{qo}'	0.85 s
T_{qo}''	0.05 s
R_1	0.0

Figure 1: *Rotor model for transient study*

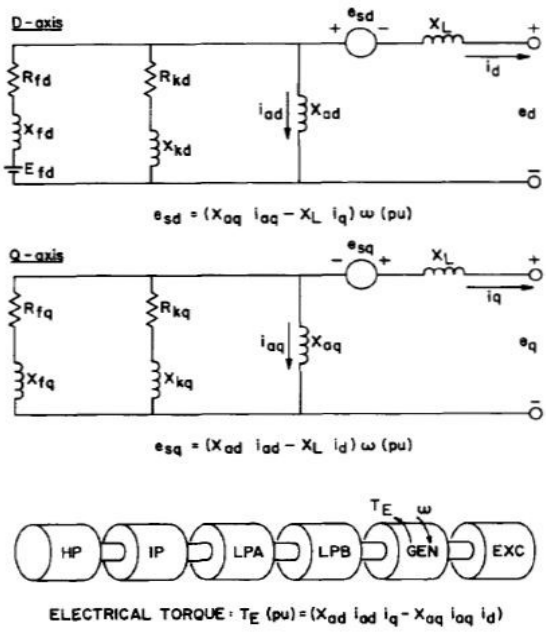

TABLE 3: *Rotor spring mass parameters*

Mass	Shaft	Inertia H(sec)	Spring Constant K (pu)	pu Torque/rad
HP		0.092897		
	HP-IP		7,277	19.303
IP		0.155589		
	IP-LPA		13,168	34.929
LPA		0.858670		
	LPA-LPB		19,618	52.038
LPB		0.884215		
	LPB-GEN		26,713	70.858
GEN		0.868495		
	GEN-EXC		1,064	2.822
EXC		0.0342165		

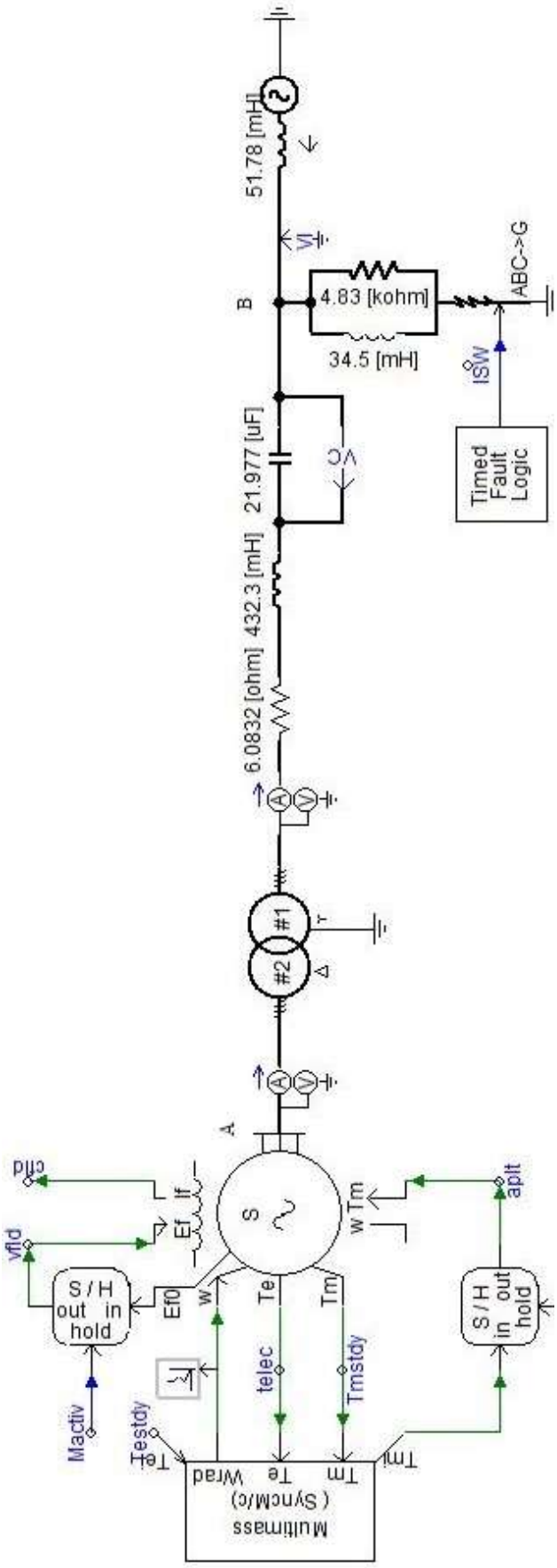

FIGURE 2: *Simulated system in PSCAD/EMTDC*

3. SIMULATION MODEL AND RESULTS

Field Voltage of Synchronous machine held at the same value

Mech. Torque of Synchronous machine held at the initial value

Multimass enabled at time = 1.4 sec. The input allows the multimass to be enabled only when the machine is active. The multimass is initialized with smoothed value of electrical torque from the machine model.

FIGURE 1: *Shows the Simulation Model for the Study of SSR in PSCAD/EMTDC.*

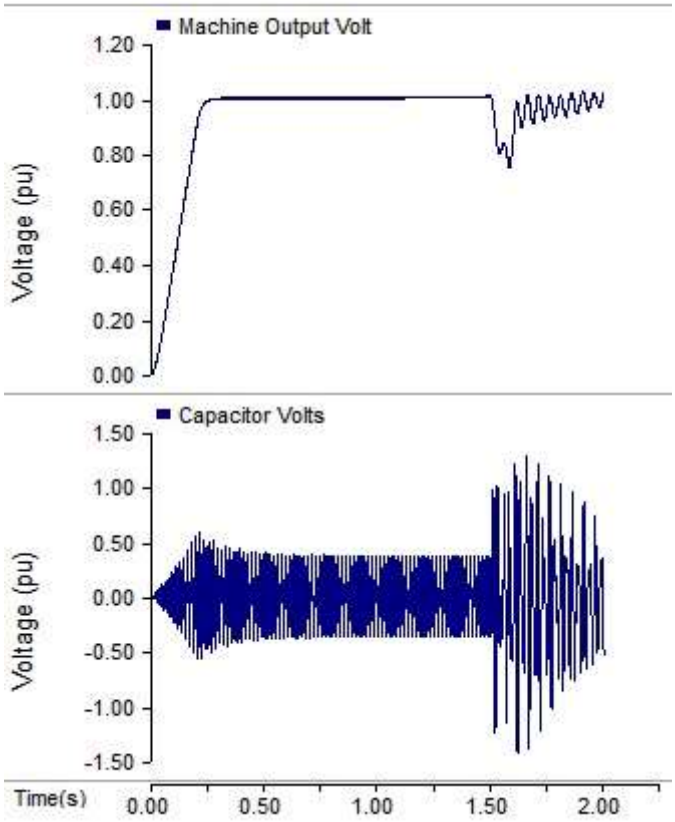

FIGURE 3: *Machine and capacitor o/p voltage*

TABLE VI shows the minimum additional information required to specify a transient case. Study results should show at least the following as a function of time:

a. Generator phase currents
b. Phase voltages on bus A (see Fig.1)
c. Capacitor voltages

d. Generator rotor speed deviation
e. Electrical torque
f. Shaft torque for each shaft section

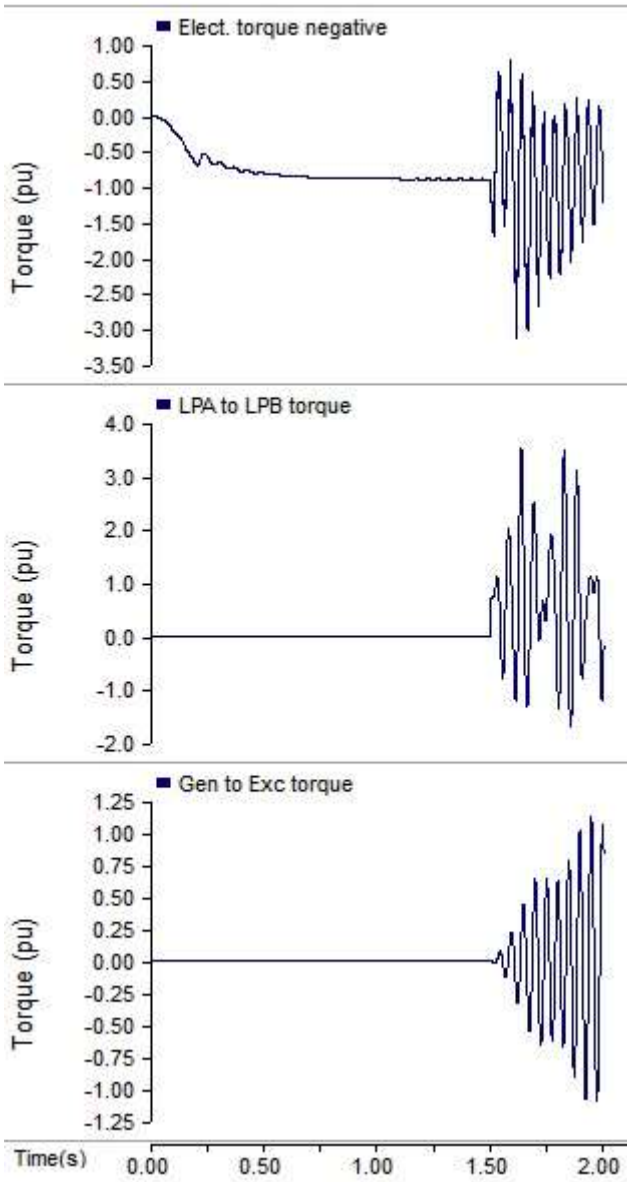

FIGURE 4: *Response curve for transient case 1-T (Diff. torque)*

For case 1-T, X_c is tuned to approximately 40 hertz both during and after the fault to excite the second torsional mode. The fault impedance X_F has been adjusted to produce a capacitor transient voltage approaching the lower gap setting during the fault. A fault duration of .075seconds (four and one-half cycles at 60 hertz) was chosen to produce a notching the generator power envelope lasting three half cycles of the rotor second torsional frequency. This notch is intended to increase the shaft torsional response.

TABLE 6: *Transient case description*

Parameter	Value
Generator power output Po	0.9 pu
Generator power factor PF	0.9 (lagging)
Fault reactance X_F (L-G)	0.04 pu
Fault location	B
Type of fault	LLL-G
Prefault phase voltage	$V_a = 0$
Clear 1st phase i=0	0.075 s after fault
Clear 2nd phase	next current zero
Clear 3rd phase	next current zero
Capacitor reactance X_c	0.371 pu

4. CONCLUSION

Simple models and transient test cases have been presented for the study of sub-synchronous resonance. The generator model is successfully simulated using PSCAD/EMTDC. Authors are presently working on different cases of SSR.

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