Damping Subsynchronous Resonance Oscillations Using A Dynamic Switched Filter-Compensator Scheme

A.M. Sharaf, Senior Member, IEEE; and Bo Yin, Student Member, IEEE
Electrical and Computer Engineering Department
University of New Brunswick
Fredericton, NB, E3B 5A3 Canada
Phone: +1 506 4473134, Fax: +1 506 4533589 E-mail: sharaf@unb.ca; e8x73@unb.ca

Abstract

The paper presents a new effective method to damp subsynchronous resonance (SSR) – shaft torsional oscillations for large synchronous generators. This is achieved by using a dynamic power filter and static compensator (DFC) scheme. The proposed scheme with a switched series capacitor compensation and a modulated Tuned-Arm-Filter can be used to damp SSR oscillation modes using a novel Tri-loop Error-driven dynamic controller.

Keywords: *Torsional Oscillation, SSR Mitigation, Dynamic Tri-loop Controller*

I. INTRODUCTION

Shaft mechanical systems for large synchronous or induction motors and turbine generators can be subjected to severe torsional stresses due to triggered subsynchronous resonance (SSR) especially in electric grid networks with heavily series compensated transmission lines. These torsional oscillations exhibit a complex electro-mechanical resonance sustained phenomena which can seriously damage the mechanical shaft system.

Two IEEE benchmark models have been proposed by the IEEE-SSR Working Group. These benchmark models have obtained world-wide acceptance and are extensively used for the study of different proposed damping devices SSR coutermeasures [1-9].

In this paper, the synchronous generator stator current and voltage signals are used as damping signals. New proposed monitoring signals can also be utilized as alarm and damping signals to activate other FACTS based compensator isolation and damping devices.

The novel Dynamic Filter and Compensator (DFC) scheme developed by first Author [10] is capable of reducing the torsional oscillations causing mechanical shaft breakdown. The full unified AC system is digitally simulated by using the Power System Blockset (PSB) of Matlab/Simulink software.

II. SAMPLE STUDY SYSTEM

A novel on-line intelligent shaft monitor utilizing transformed signals under different levels of series capacitor compensation for three phase short circuit faults is also proposed in this paper. Figure 1 shows the Sample Turbine-Generator and Infinite Bus System. Figure 2 shows the novel Tri-loop Error-driven, Error-scaled PID Controller. Figure 3 shows the Proposed Damping Power Filter and Compensator System for generator case shown in Fig. 1.

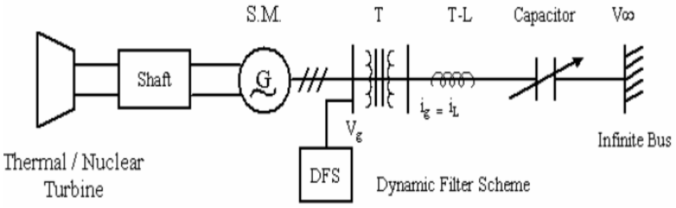


Fig.1 Sample Turbine-Generator and Infinite Bus System

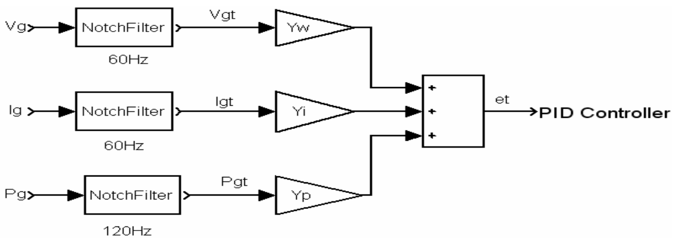


Fig.2 Tri-loop Error-driven, Error-scaled PID Controller

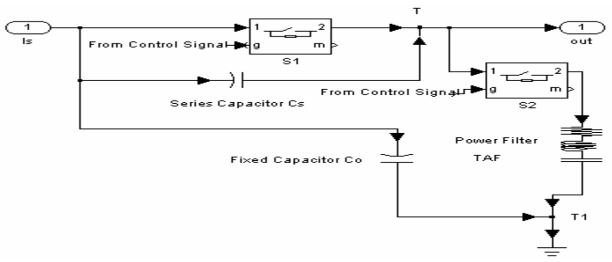


Fig.3 Proposed Damping Device with MPF/SCC Configuration Using two GTO Switching Devices S1, S2

III. SAMPLE MATLAB/SIMULINK RESULTS

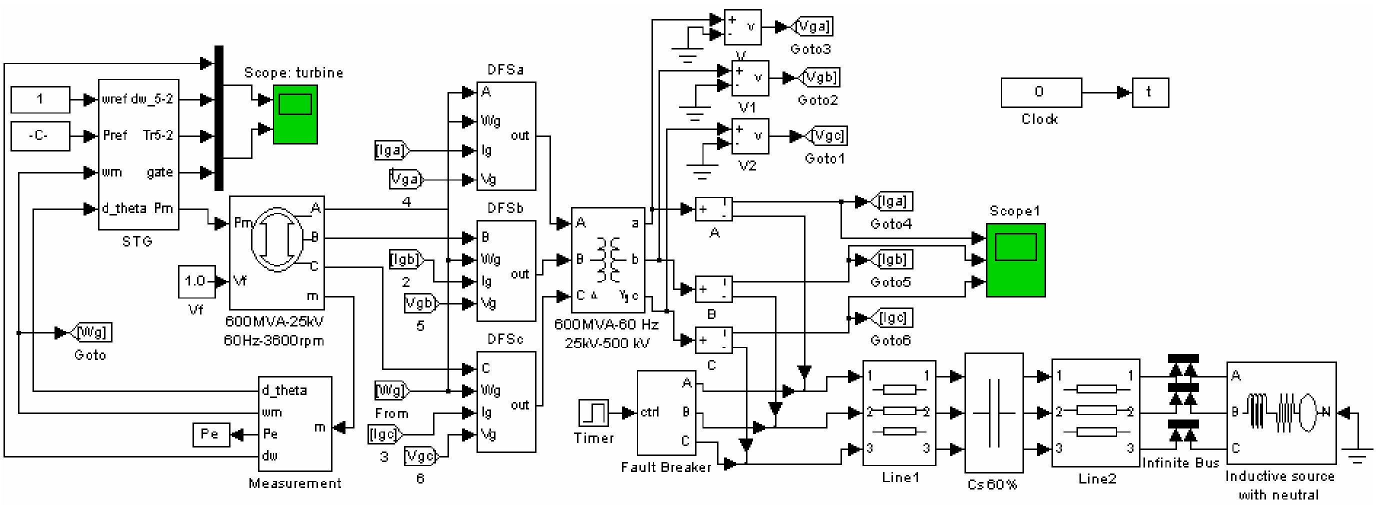


Fig.4 MATLAB/SIMULINK Unified Block Functional Model of the Sample Turbine-Generator and Infinite Bus System with IEEE SSR Benchmark Model-2

Fig. 4 shows the unified block functional model of the sample turbine-generator and infinite bus system. The system is developed IEEE benchmark [2] model used to study SSR-oscillations following a three phase bolted short circuit fault has been applied and cleared on a series-compensated power system.

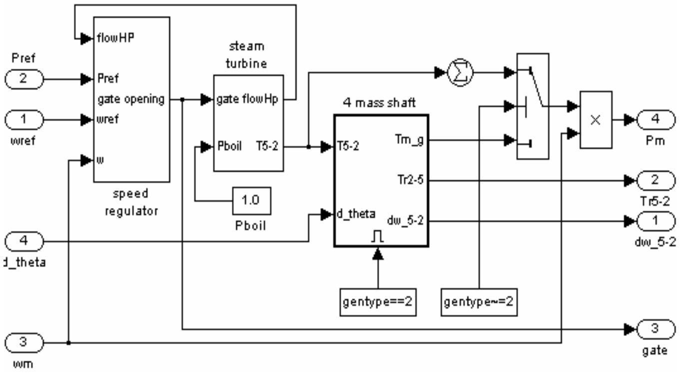


Fig.5 Steam Turbine and Shaft System IEEE Benchmark Functional Model

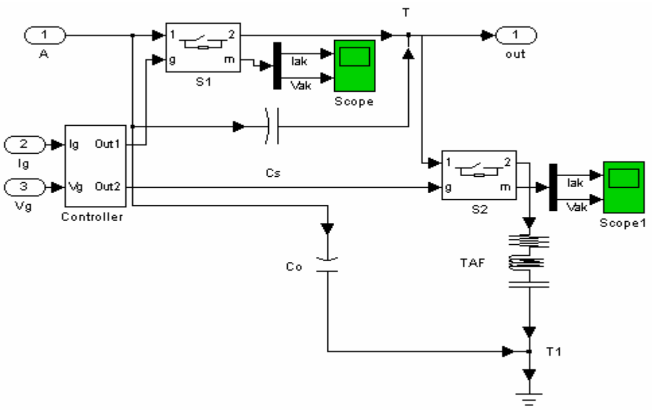


Fig. 6 The Damping-FACTS Based DFC with the Dynamic Series Capacitor, Fixed Capacitor, and Tuned-Arm-Filter

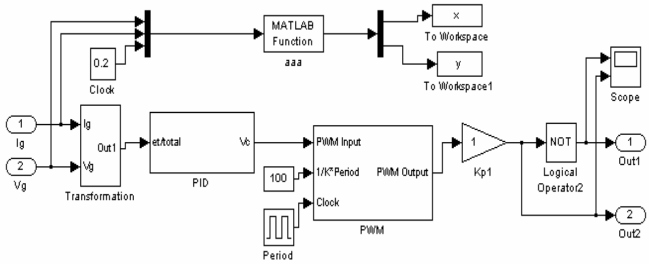
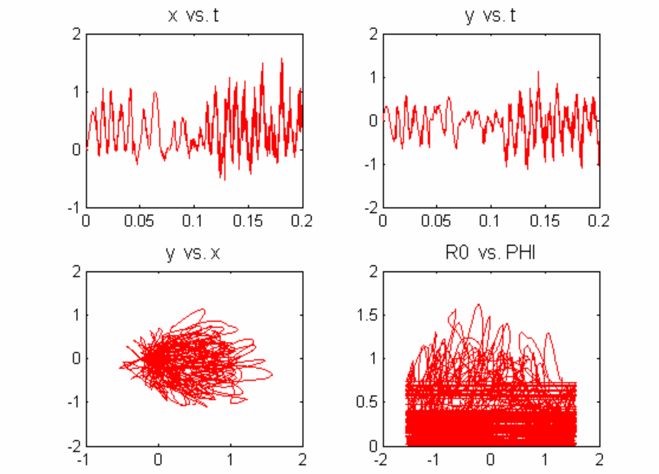


Fig.7 Dynamic Power Filter and Compensation Device Scheme to 0 S_1, S_2 PWM-Pulsing ($S_2 = \bar{S}_1$)

Fig.5 depicts the steam turbine and shaft system functional model. Fig.6 shows the proposed damping switched FACTS (DFC) device. Fig. 7 shows the dynamic tracking control scheme using the PWM switching signals s1, s2. Fig. 8, 9 show the system dynamic response without and with the DFC compensator scheme. The damping action of the DFC is mainly due to a detuning-modulated impedance effect of the near system topology change. The unified AC system, possible monitoring/damping signals (X, Y, R0, PHI) and compensator parameters are given in the Appendix.

IV. CONCLUSION

The paper presents a new method to damp subsynchronous resonance (SSR) oscillations for large synchronous generators. The damping signals using stator current and voltage is easy to implement and significantly reduce the cost. The DFC performance is validated as an effective SSR damping tool that dynamically detunes the SSR-resonance model by the PWM-switching of the combined blocking series and shunt tuned arm filter.



Monitoring Signals

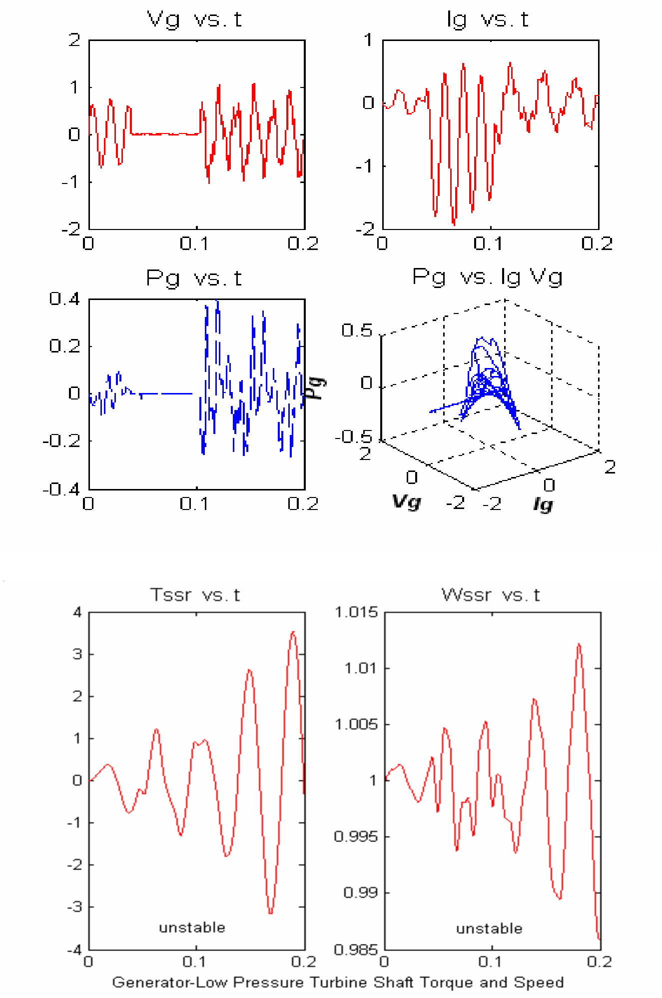
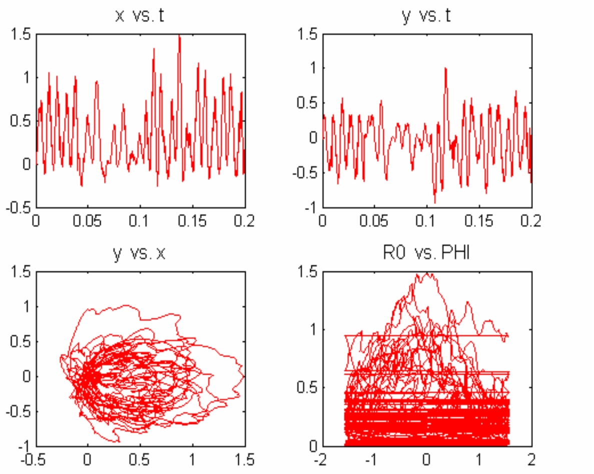


Fig. 8 The unified System Oscillatory Dynamic Response Without the DFC Compensator Scheme



Monitoring Signals

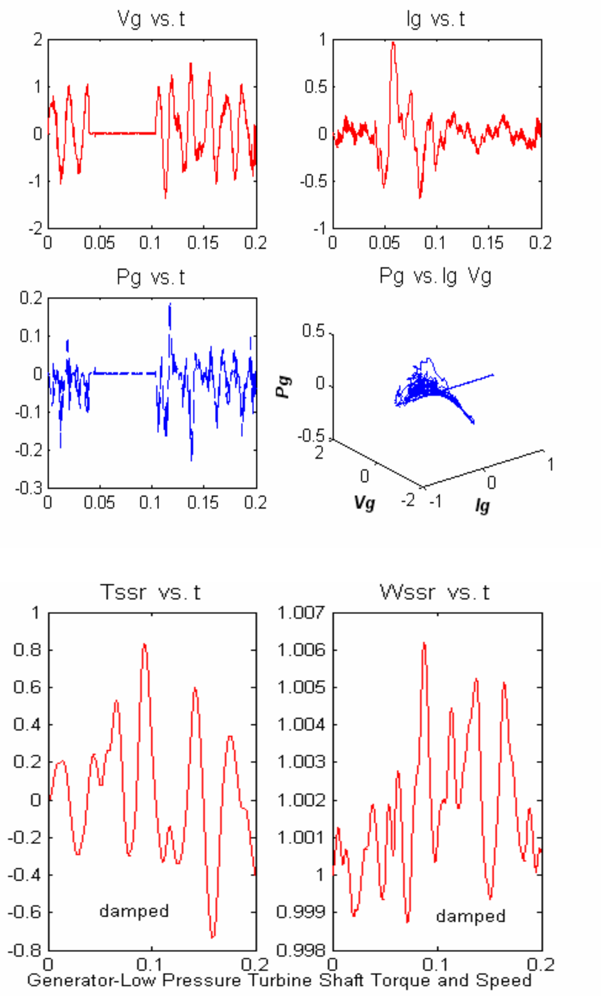


Fig. 9 The unified System Damped Dynamic Response With the DFC Compensator Scheme

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VI. PPENDIX

1. AC System Parameters:

(a) Synchronous Generator (3 phase, round rotor)

S_g = 600MVA V_g = 25KV (Unit: pu)

X_L = 0.14 R_a = 0.0045 X_d =1.65 X_q = 1.59

$X_{d'}$ = 0.25 $X_{d''}$ = 0.2 $X_{q'}$ = 0.46 $X_{q''}$ = 0.2

$T_{d0'}$ = 4.5 s $T_{d0''}$ =0.04 s $T_{q0'}$ =0.55s $T_{q0''}$ =0.09s

(b) Transmission line (3 phase)

$V_{LL} = 500\ KV$ Length= 250 km

Positive and zero sequence parameters:

R_1 = 0.01273 Ω / km ; R_0 = 0.3864 Ω / km ;

L_1 = 0.9337 mH/km; L_0 = 4.1264 mH/km;

C_1 = 12.74e-3 uF/km; C_0 = 7.751e-3 uF/km

(c) Power Transformer (Δ / Y)

Rated Voltage: 25/500 KV (Line-Line)

Rated Power: 600 MVA (3 phase)

2. Proposed Dynamic Monitoring Signals (X, Y, R0, PHI)

$$R0 = \sqrt{x^2 + y^2} \ , \ PHI = \tan^{-1}(y/x)$$

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} Tw \end{bmatrix} \begin{bmatrix} Vg \\ Ig \end{bmatrix}$$

Where the temporal rotational matrix T_w is defined as:

$$\begin{bmatrix} Tw \end{bmatrix} = \begin{bmatrix} \sin\varpi t & \cos\varpi t \\ -\cos\varpi t & \sin\varpi t \end{bmatrix}, w_r = 377 r/s$$

3. DFC Dynamic Filter and Compensator

Fixed Capacitor: $C_0 = 50\,\mu F$

Series Switched Capacitor (SCC): $C_s = 15\ \mu F$

Modulated Tuned Arm Power Filter (MPF):

$R_f = 0.5\ \Omega,\ L_f = 15\ mH, C_s = 50\ \mu F$

4. Three Phase Short Circuit Fault at Substation Bus

T_{on} = 0.04 s T_{off} = 0.1s

5. PID Controller and PWM Switching

PI Type (Proportional plus integral): Kp=10, Ki=0.5, τ = 0.05

Tri-loop control scheme damping signal weights for $v_g, i_{g,} p_g$

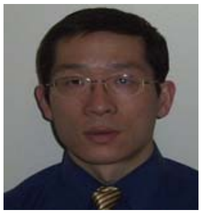
$\gamma_v = 1, \gamma_I = 0.5, \gamma_r = 0.5$

$\alpha_D = t_{on}/T_{s/w}$ =0.6 0< α <1. 0 $T_{s/w} = 1/f_{s/w}$; $f_{s/w}$ =100Hz.

VII. BIOGRAPHIES

Adel M. Sharaf obtained his B.Sc degree in Electrical Engineering from Cairo University in 1971. He completed the M.Sc degree in 1976 and the Ph.D degree in 1979 from University of Manitoba, Canada. He was employed by Manitoba Hydro as Special Studies Engineer, responsible for engineering and economic feasibility studies in Electrical Distribution System Planning and Expansion. He authored and co-authored over 385 scholarly technical journals, conference papers, and engineering reports.

Dr. Sharaf holds a number of US and International Patents (Pending) in electric energy and environmental devices. He is the President & Technical Director of both Sharaf Energy System Inc. & Intelligent Environmental Energy Systems Inc., Fredericton, Canada.



Bo Yin received his B.Sc degree in Electrical Engineering from Zhengzhou University China in 1993. He was employed by Henan No.1 Power Company as an Electrical Engineer, responsible for the Power Electronics, Protection and Control System feasibility. Mr. Yin is currently an M. Eng Candidate in Electrical & Computer Engineering of University of New Brunswick, Fredericton, NB, Canada.