Effect of Exciter and PSS on SSR Damping

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Abstract-- **In this paper, the effects of different types of excitation systems and PSS on the SSR damping characteristics are studied. The complex torque coefficient approach realized by time domain simulation – the Test Signal Method is adopted. The studied system consists of a single-machine infinite bus system. Three types of excitation systems—IEEE AC1A, AC2A, ST1A excitation systems are selected as examples. Frequency scanning in the subsynchronous frequency range is performed to calculate the subsynchronous electrical damping characteristics of the unit. Effects of excitation systems with moderate or high response on the electrical damping are investigated. Two situations including excitation system without PSS and with PSS are considered. At the same time, different input signals of PSS are used respectively. In addition, the effects of the parameters of PSS on the electrical damping are also investigated. The results are analyzed in detail and some important conclusions are drawn.**

Index Terms-- **excitation system; PSS; subsynchronous resonance; Test signal method; time domain simulation; PSCAD/EMTDC**

I. INTRODUCTION

It is well known that a high response exciter is beneficial in increasing synchronizing torque. However, in so doing it introduces negative damping. With negative damping, power swing oscillations which have relatively low frequency, between 0.1~2 Hz, might occur [1]. There are several ways to damp the power swing oscillations. An effective way is to provide a power system stabilizer. The theories and researches on PSS have been much more mature [2]-[5].

Subsynchronous Oscillation has always been an important problem in power systems and great deal of attention has been focused on this subject. Various countermeasures to SSR problem have also been developed [6]. A lot of papers on the excitation control using the power system stabilizer (PSS) as a countermeasure of the SSR have been published [7]-[12]. Most of these researches are focused on designing the excitation control or a PSS by employing different methods to damp subsynchronous oscillations. But the SSR damping characteristics with different excitation systems and PSS are rarely discussed.

This paper establishes a study model of a single-machine infinite bus system with IEEE AC1A, AC2A, ST1A excitation systems and a single input signal power system stabilizer [13]. The effects of these exciters and PSS on the SSR damping characteristics are studied. The complex torque coefficient approach realized by time domain simulation—the Test Signal Method, is adopted. Through detailed simulations, the effects of exciter with PSS of different input signals on the SSR damping characteristics are obtained. These conclusions are greatly helpful and valuable for mitigating SSR problem with the excitation system and PSS.

Reference [14] shows the application scope of the complex torque coefficient approach. The conclusion that the Quasi-Steady-State model can not be adopted to study the SSO of the systems consist of HVDC or FACTS devices is presented in it. Furthermore, it shows that the complex torque coefficient approach realized by time domain simulation —the Test Signal Method provides a shortcut for studying the SSO of units connected to HVDC and FATCS. In [15] the SSO of a generating set connected to a static var compensator based on the Test Signal Method and the meaning of studying the SSO of a system consists of a single unit and a fixed frequency source are discussed. The conclusions in [14] and [15] are directly used in this paper to study the effect of different types of exciters and PSS on the SSR damping characteristics through the Test Signal Method. The program PSCAD/EMTDC is adopted. The electrical damping torque coefficient of the unit in the model is calculated. The related expression is:

$$D_e(f) = \mathrm{Re}(\frac{\Delta\dot{T}_e(f)}{\Delta\dot{\omega}(f)}) \qquad (1)$$

where D_e is the electrical damping torque coefficient of the unit in per unit, $\Delta\dot{T}_e(f)$ is the phasor of the increments of electromagnetic power of generator in per unit when a ripple torque of a frequency equal to f is forced on rotor, and $\Delta\dot{\omega}(f)$ is the phasor of the increments of angular velocity of the rotor in per unit when a ripple torque of a frequency equal to f is forced on rotor.

II. STUDIED MODELS

A. System Model

Fig. 1 shows the single diagram of the system under investigation. A single-machine infinite bus system (SMIBS) is adopted in this paper. The generator is represented as a single-mass model. The data of the first IEEE benchmark model [16] are used for the system components. The operation conditions are as follows. The output real power P_G is equal to 0.9 pu, the output reactive power Q_G is equal to 0.3 pu. The

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terminal voltage of the generator is equal to 1.0 pu.

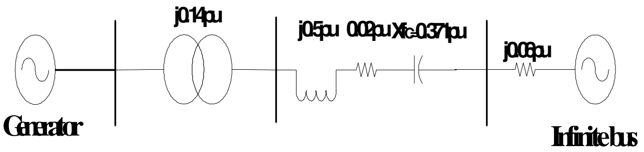

Fig. 1. The single diagram of the studied system

B. Excitation System Models [13]

IEEE AC1, AC2, and ST1 excitation systems are selected as examples. Type AC1A excitation system model shown in Fig. 2 represents a field-controlled alternator excitation system with non-controlled rectifiers and is applicable to brushless excitation systems. Type AC2A excitation system model shown in Fig. 3 represents a high initial response field controlled alternator-rectifier excitation system with non-controlled rectifiers. Type ST1A exciter model shown in Fig. 4 represents a potential-source controlled-rectifier system.

In this paper, the excitation system with moderate response is represented by type AC1A, while the excitation system with high response is represented by type AC2A and type ST1A [17].

The detailed parameters of each excitation system model are given in Appendix.

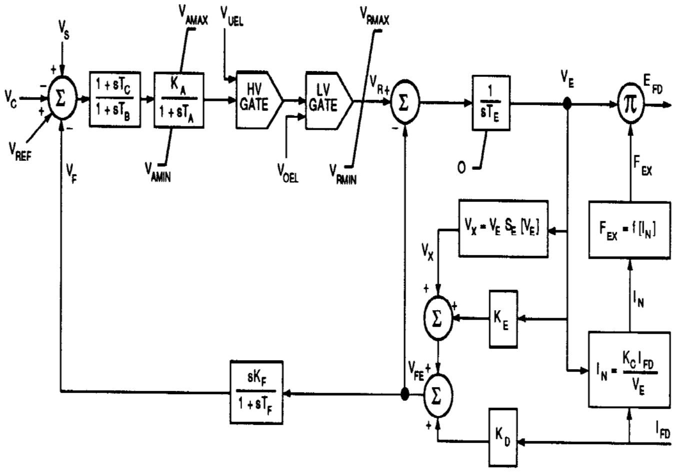

Fig. 2. IEEE type AC1A excitation system model

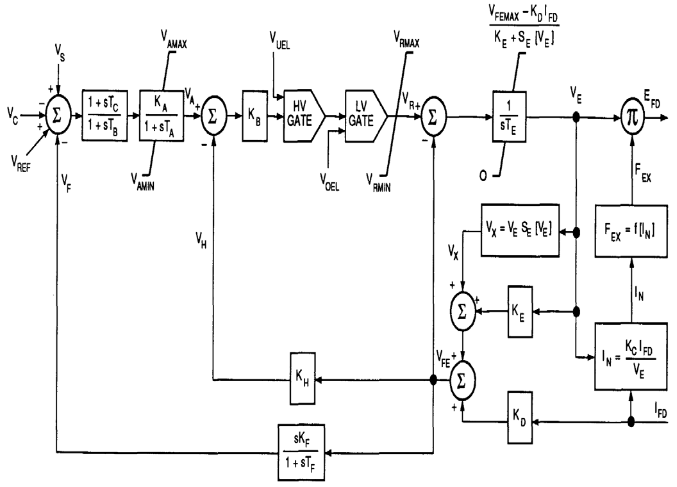

Fig. 3. IEEE type AC2A excitation system model

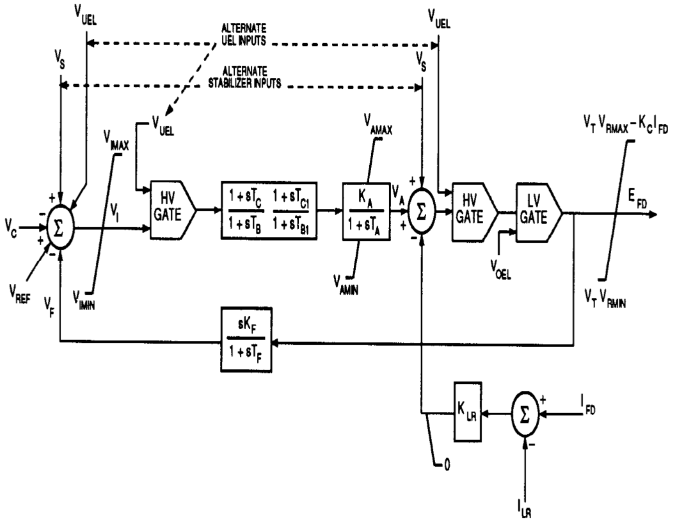

Fig. 4. IEEE type ST1A excitation system model

C. PSS Model [13]

Fig. 5 shows the generalized form of the power system stabilizer with a single input. Shaft speed deviation Δω and electrical power deviation $-\Delta P_e$ are selected as the input signal respectively in this paper. The PSS model consists of three blocks: a phase compensation block, a signal washout block, and a gain block. In addition, in order to restrict the level of generator terminal voltage fluctuation during transient conditions, limits are imposed on the PSS output.

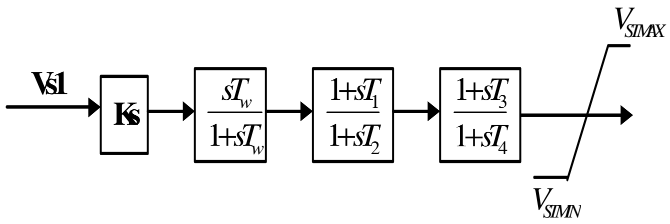

Fig. 5. Power system stabilizer model

The phase compensation block provides the appropriate phase-lead characteristic to compensate for the phase lag between the exciter input and the generator electrical torque. The Test Signal Method is adopted to determine the phase characteristics to be compensated with each type of exciter [1] so that the frequency response between the exciter input and generator electrical torque are calculated. The frequency range of the test signal applied on the reference voltage of the AVR is 0.1~2.0 Hz. In this paper, the oscillation frequency is equal to about 1.6 Hz. So the frequency range of interest here is set to 1~2 Hz and slight undercompensation is made. Based on these considerations, the parameters of PSS with different types of exciters are approximately calculated and are shown in Table I.

TABLE I
THE PARAMETERS OF PSS WITH DIFFERENT TYPES OF EXCITERS

Exciter	Input signal of PSS	K_S	T_ω (s)	T_1(s)	T_2(s)	T_3(s)	T_4(s)	V_{STMAX} (pu)	V_{STMIN} (pu)
AC1A	$\Delta\omega$	1	10	1.2128	0.0093	1.2128	0.0093	0.1	-0.066
	$-\Delta P_e$	0.1	10	0.15	0.01	0	0	0.1	-0.066
AC2A	$\Delta\omega$	1	10	0.3081	0.0365	0.3081	0.0365	0.1	-0.066
	$-\Delta P_e$	1	10	0.05	0.03	0	0	0.1	-0.066
ST1A	$\Delta\omega$	1	10	0.2915	0.0386	0.2915	0.0386	0.1	-0.066
	$-\Delta P_e$	2	10	0.1264	0.0890	0	0	0.1	-0.066

III. SIMULATION RESULTS AND ANALYSES

A. *SMIBS with constant exciter voltage*

The system shown in Fig. 1 is adopted. None of the exciter models are used. The exciter voltage is kept constant during the simulation. The simulation results are shown in Fig. 6. The curve of the damping torque coefficient vs frequency in the range of 5 to 55 Hz is given.

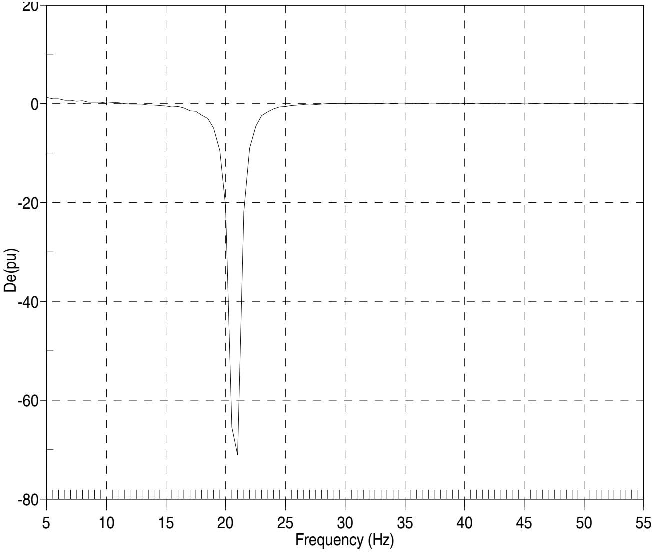

Fig. 6. Result of SMIBS with constant exciter voltage

From Fig. 6, it can be seen that the SSR occurs at the frequency near 21 Hz (converted into rotor side) for the system with constant exciter voltage and the biggest electrical negative damping is equal to about -71 in per unit.

B. *SMIBS with different types of excitation systems but without PSS*

In this case, three types of excitation systems described above are used respectively to study the effects of these excitation systems on the electrical damping. The curves of the damping torque coefficient vs frequency in the range of 5 to 55 Hz for the SMIBS with these types of excitation systems are compared in Fig. 7.

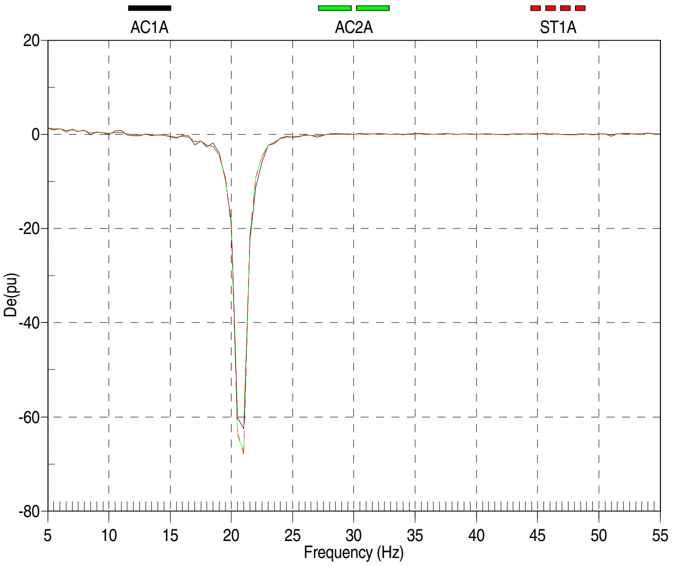

Fig. 7. Results of SMIBS with different types of excitation systems but without PSS

From Fig. 7, it can be seen that with different excitation systems the electrical negative damping around the resonant point all decrease a little.

C. *SMIBS with excitation systems and PSS*

Similarly, three types of excitation systems are used respectively, and each one is equipped with a PSS.

1) *IEEE Type ST1A Excitation System With a PSS*

As described above, shaft speed deviation Δω and electrical power deviation $-\Delta P_e$ are selected respectively as the input signal of the PSS in the following simulations. The parameters of PSS are given in Table I. The detailed simulations are as follows.

a) PSS with Δω as input signal

The results are shown in Fig. 8. The effect of PSS gain K_S on electrical damping in the subsynchronous frequency range is also investigated. The curve designated as K_s=0 corresponds to the condition that no PSS is applied in the system.

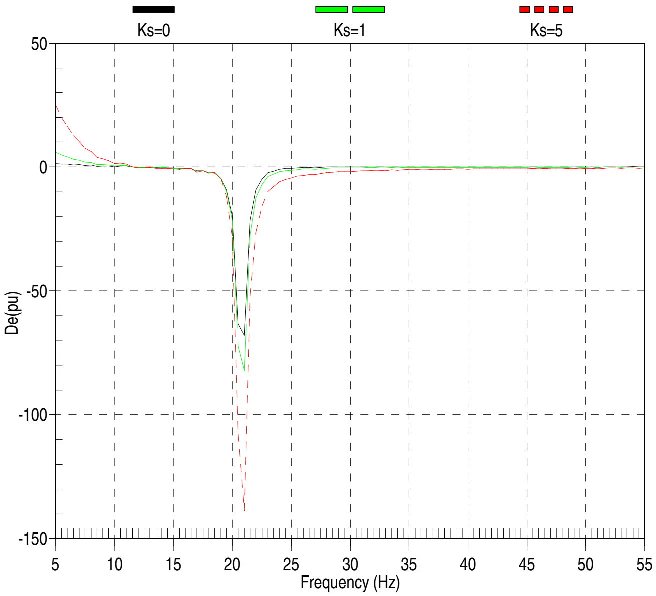

Fig. 8. Results of PSS with $\Delta\omega$ as input signal

Fig. 8 shows the curves of the damping torque coefficient vs frequency in the range of 5 to 55 Hz for a Delta-Omega stabilizer. The figure shows that with the Delta-Omega stabilizer the electrical negative damping around the resonant point increase. That is to say that with the Delta-Omega stabilizer it is adverse to SSR. In addition, the electrical negative damping around the resonant point increase as the value of K_S increases. It means that with the increasing gain of the Delta-Omega stabilizer the SSR damping deteriorated.

b) PSS with $-\Delta P_e$ *as input signal*

The results are shown in Fig. 9. The effect of PSS gain K_S on electrical damping in the range of subsynchronous frequencies is also investigated.

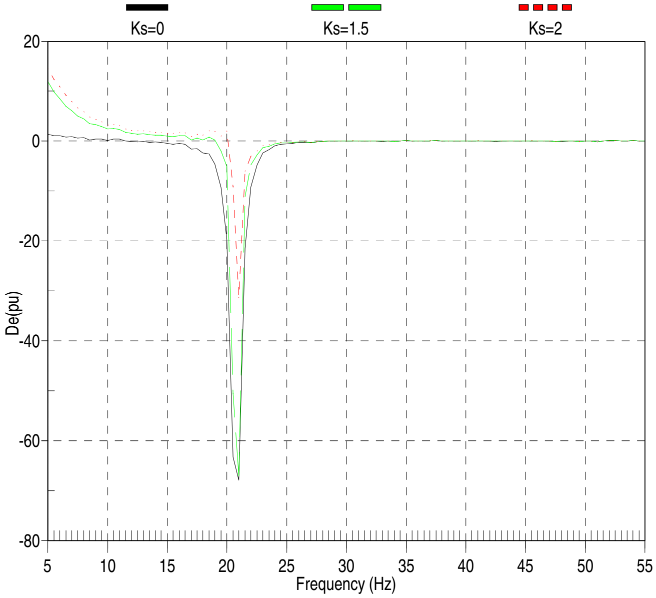

Fig. 9. Results of PSS with $-\Delta P_e$ as input signal

Fig. 9 shows the curves of the damping torque coefficient vs frequency in the range of 5 to 55 Hz for a Delta-P stabilizer. From the figure it can be seen that the electrical negative damping around the resonant point decrease when the Delta-P stabilizer is applied. That is to say that it is helpful to damp SSR with the Delta-Omega stabilizer. In addition, the electrical negative damping around the resonant point decrease as the value of K_S increases. It means that the SSR damping will be further improved with the bigger K_s.

2) IEEE Type AC2A Excitation System With PSS

The studied situations are the same with those of Type ST1A. The parameters of PSS are also shown in Table I. The detailed simulations are given as follows.

a) PSS with $\Delta\omega$ *as input signal*

The results are shown in Fig. 10.

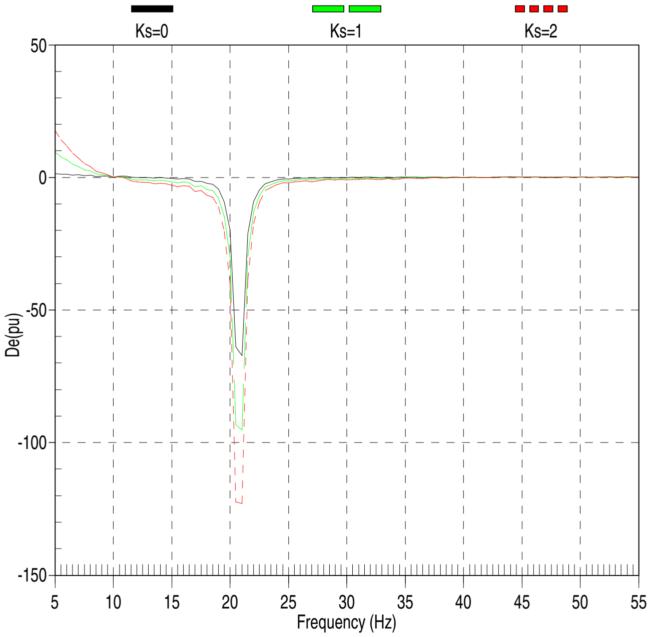

Fig. 10. Results of PSS with $\Delta\omega$ as input signal

b) PSS with $-\Delta P_e$ *as input signal*

The results are shown in Fig. 11.

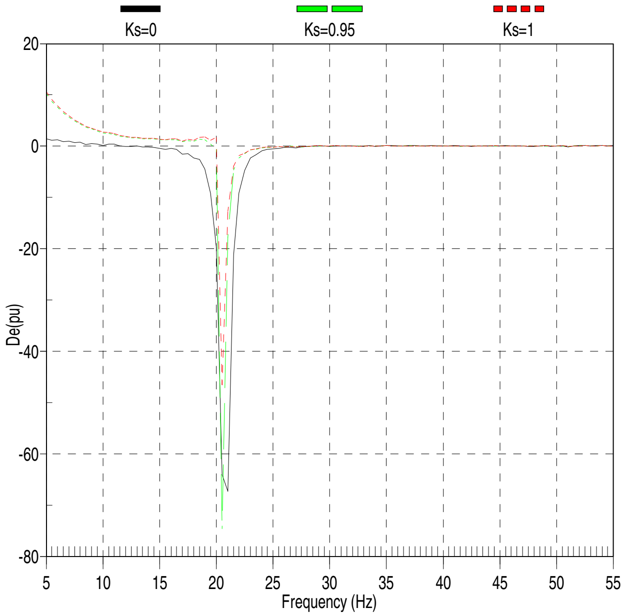

Fig. 11. Results of PSS with $-\Delta P_e$ as input signal

Type AC2A and Type ST1A excitation systems both represent a high initial response excitation system. From Fig. 8 ~Fig. 11, it can be seen that the effects of these two type excitation systems on the SSR damping characteristics are similar. With a Delta-Omega stabilizer the electrical negative damping around the resonant point increase. This is not helpful to damp SSR. At the same time, as the value of K_S increases the electrical negative damping around the resonant point increase. On the contrary, with a Delta-P stabilizer the electrical negative damping around the resonant point decrease. This is helpful to damp SSR. At the same time, the electrical negative damping around the resonant point decrease as the value of K_S increases.

3) *IEEE Type AC1A Excitation System With PSS*

The studied situations are also the same. The detailed simulations are given as follows.

a) PSS with $\Delta\omega$ as input signal

The results are shown in Fig. 12. The effect of PSS gain K_S on electrical damping in the range of subsynchronous frequencies is investigated.

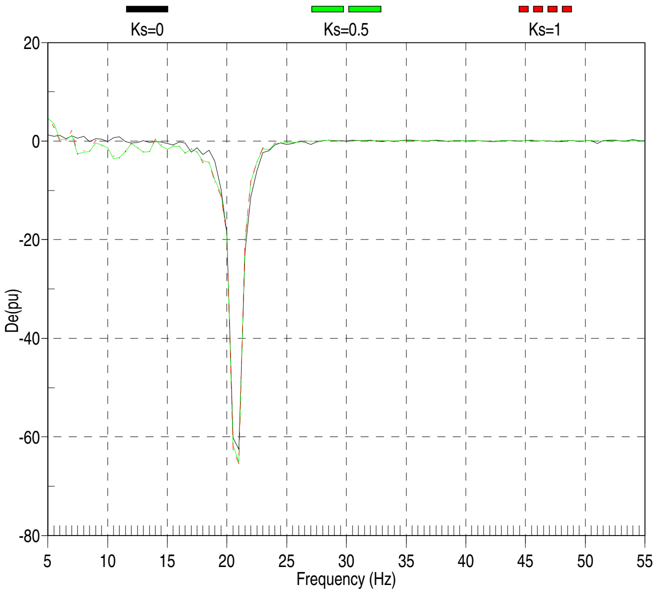

Fig. 12. Results of PSS with $\Delta\omega$ as input signal

From the result shown in Fig. 12, it can be seen that the electrical negative damping around the resonant point increase, but the variation is little. In addition, the damping torque coefficient is not sensitive to K_S.

b) PSS with $-\Delta P_e$ as input signal

The results are shown in Fig. 13.

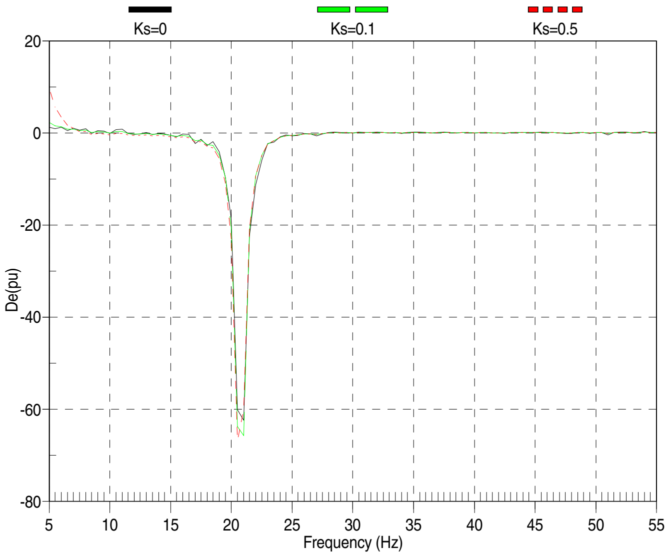

Fig. 13. Results of PSS with $-\Delta P_e$ as input signal

From the result shown in Fig. 13, it can be seen that the electrical negative damping around the resonant point also increase, but the variation is little. In addition, the damping torque coefficient is not sensitive to K_S.

The results of different types of excitation systems with a Delta-Omega stabilizer are compared in Fig. 14 and the results of these excitation systems with a Delta-P stabilizer are compared in Fig. 15.

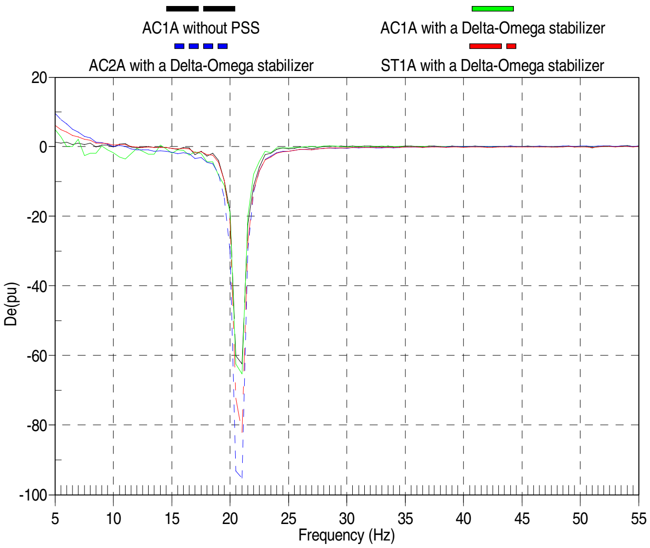

Fig. 14 Three types of excitation systems with a Delta-Omega stabilizer

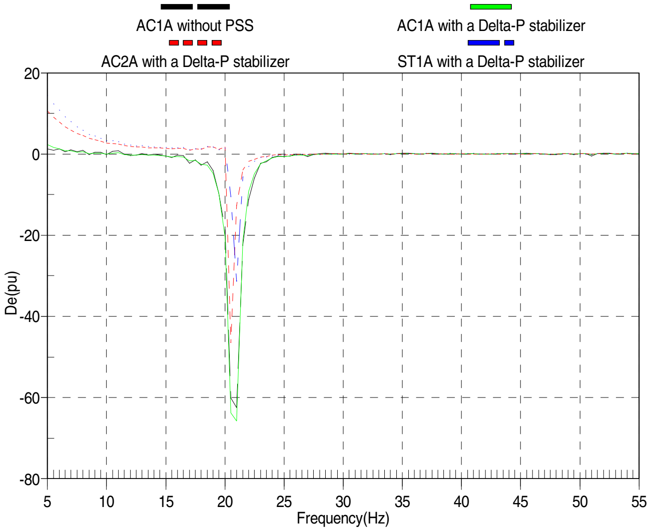

Fig. 15 Three types of excitation systems with a Delta-P stabilizer

IV. CONCLUSIONS

In this paper, the effects of different types of excitation systems with and without PSS on the SSR damping characteristics are studied in detail. The investigations show that:

(1) When the system is without PSS, the electrical negative damping around the resonant point all decreased with different excitation systems. This is helpful to mitigate the SSR.

(2) When a Delta-Omega stabilizer is applied in the system, for the high response excitation systems (such as Type AC2A and Type ST1A) the electrical negative damping around the resonant point increase. This is not helpful to damp SSR. At the same time, the electrical negative damping around the resonant point increase further as the value of K_S increases. For the moderate response excitation systems (such as Type AC1A) the electrical negative damping around the resonant point also increase, but the variation is little, and the damping torque coefficient is not sensitive to K_S.

(3) When a Delta-P stabilizer is applied in the system, for the high response excitation systems the electrical negative damping around the resonant point decrease. This is helpful to damp SSR. At the same time, the electrical negative damping around the resonant point decrease further as the value of K_S increases. For the moderate response excitation systems the electrical negative damping around the resonant point increase, but the variation is little, and the damping torque coefficient is not sensitive to K_S.

(4) When each type of exciter cooperates with the Delta-Omega stabilizer, the electrical negative damping around the resonant point increase. This will be adverse to damp SSR. Contrarily, when each type of exciter, especially the high response excitation systems, cooperates with the Delta-P stabilizer, the electrical negative damping around the resonant point greatly decrease. That is to say that when the Delta-P stabilizer is used to damp the power swing oscillations, it will be also helpful to damp the SSR.

V. APPENDIX

Parameters of Each Excitation Systems

A. *Data for a Type AC1A Excitation System*

T_R= 0	K_F= 0.03	V_{AMIN}= -14.5
R_C= 0	T_F= 1.0	V_{RMAX}= 6.03
X_C= 0	K_E= 1.0	V_{RMIN}= -5.43
K_A= 400	T_E= 0.80	$S_E[V_{E1}]$ = 0.10
T_A= 0.02	K_D= 0.38	V_{E1}= 4.18
T_B= 0	K_C= 0.20	$S_E[V_{E2}]$ = 0.03
T_C= 0	V_{AMAX}= 14.5	V_{E2}= 3.14

B. *Data for a Type AC2A Excitation System*

T_R= 0	K_H= 1.0	V_{AMIN}= -8.0
R_C= 0	K_F= 0.03	V_{RMAX}= 105
X_C= 0	T_F= 1.0	V_{RMIN}= -95
K_A= 400	K_E= 1.0	V_{FEMAX}= 4.4
T_A= 0.01	T_E= 0.60	$S_E[V_{E1}]$ = 0.037
T_B= 0	K_D= 0.35	V_{E1}= 4.4
T_C= 0	K_C= 0.28	$S_E[V_{E2}]$ = 0.012
K_B= 25	V_{AMAX}= 8.0	V_{E2}= 3.3

C. *Data for a Type ST1A Excitation System*

K_A= 21.0	T_{B1}= 0	K_F= 0
T_A= 0	V_{RMAX}= 6.43	T_F= 0
T_C= 1.0	V_{RMIN}= -6.0	K_{LR}= 4.54
T_B= 1.0	K_C= 0.038	I_{LR}= 4.4
T_{C1}= 0		

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