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IMPROVED POWER SYSTEM STABILIZERS

R.J. Fleming SMIEEE   M.M. Gupta SMIEEE   Jun Sun Non-member

Power Systems Research Group
University of Saskatchewan

Abstract - This paper proposes three novel approaches to improve a conventional power system stabilizer (PSS) in a single machine to infinite bus system. These improved stabilizers use the conventional PSS in the usual manner plus modification of the terminal voltage feedback signal to the excitation system as a function of the accelerating power on the unit. This nonlinear action increases the power system stability greatly. Also, since these improved stabilizers are based on the conventional stabilizers they are simple to implement.

Keywords - Power system stabilizer (PSS), improved PSS, accelerating power, power system stability.

NOMENCLATURE

(p.u., except as indicated)

System Variables

δ	torque angle (degree)
ω	rotor speed (rad./sec.)
E_f	field voltage
ΔP_a	accelerating power
P_e	electrical power
P_m	mechanical power
V	infinite bus voltage
V_{ref}	reference input voltage
V_s	stabilizer output
V_t	terminal voltage

System Parameters

D	damping coefficient
H	inertia constant of the machine (secs.)
K_A	gain of excitation system
T_A	time constant of excitation system
$r_\ell + jX_\ell$	transmission line impedance
X_d	d-axis synchronous reactance of machine
X_q	q-axis synchronous reactance of machine
X'_d	d-axis transient reactance of machine
X'_q	q-axis transient reactance of machine
T'_{do}	d-axis transient open circuit time constant

General

s	Laplace operator
$\cdot$	over a letter indicates derivative

1 INTRODUCTION

A single machine to infinite bus system is shown in Figure 1.1.

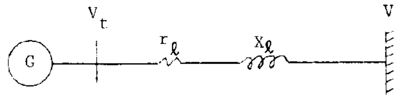

Fig. 1.1 A single machine to infinite bus system

The swing equations of this system in Figure 1.1 are:

$$\dot{\delta} = \omega \tag{1}$$

$$\frac{2H}{\omega_o}\dot{\omega} = P_m - P_e(\delta) - \frac{D}{\omega_o}\omega \tag{2}$$

When the mechanical power P_m is not in equilibrium with the electric power $P_e(\delta)$ and damping power $\frac{D}{\omega_o}\omega$ during and following disturbances, the rotor speed ω suffers electromechanical oscillations. The oscillations of concern to stability are in the 0.2 to 2.5 Hz frequency range [3]. Usually, the damping coefficient D is small and these oscillations are strong and lightly damped. This causes the rise of periodic variations in electrical quantities and, possibly, the initiation of torsional shaft oscillations in a multistage turbo-generator unit. The most extreme result is dynamic instability due to negative damping. Even in stable situations, insufficient damping of these oscillations limits the ability to transmit power out of the plant [2,4].

A proper stabilizing signal derived from the speed control loop and introduced into the excitation system can increase the damping torque of the machine at these oscillation frequencies; therefore, considerable attention and efforts have been directed toward using the excitation control systems to improve power system stability.

Three novel approaches to improve conventional stabilizers are proposed in this paper. Based on the conventional stabilizer, these improved stabilizers introduce an auxiliary stabilizing signal, (ΔP_a), which is a function of accelerating power into the terminal voltage feedback loop and make this feedback nonlinear. These improved stabilizers increase the power system stability greatly, while they are simple to implement.

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2 CONVENTIONAL STABILIZER

Figure 2.1 is a block diagram of a conventional power system stabilizer (PSS) application. It includes an output amplitude limited static exciter and an output limited stabilizer (PSS) with a transfer function G(s).

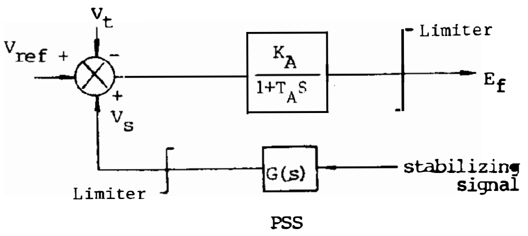

Fig. 2.1 Block diagram of a PSS

The data for the example system to which the controllers shown in Figure 2.1. are applied as follows.

Base MVA = 100 MVA, H = 4.30 (secs.)

D = 8.0 (p.u.), $X_d = X_q = 1.164$ (p.u.)

$X'_d = X'_q = 0.146$ (p.u.), $T'_{do} = 3.84$ (secs.)

$X_\ell = 0.136$ (p.u.), $r_\ell = 0.009$ (p.u.)

The operating point of the machine is shown in Table I.

Table I. The operating point of the machine

P_o (MW)	Q_o (MVAR)	V_{to} (p.u.)	δ_o (deg.)
90.00	37.62	1.05	40.73

The key point of designing a PSS is to determine the best transfer function G(s) to provide the damping needed. By using rotor speed ω as a stabilizing signal and using the phase compensation method [5] of design, G(s) for the machine was obtained as shown in (3).

$$G(s) = \frac{4\ s}{(1 + 4\ s)} \times \frac{0.15\ (s^2 + 9.88\ S + 97.56)}{(1 + 0.05\ s)^2} \qquad (3)$$

The first term in (3) is a reset term that is used to "wash out" the compensation effect with a time constant of 4 secs. The second term is a lead compensation pair that can be used to compensate the system phase lag [1,3].

3 IMPROVED STABILIZER

The only difference between the improved stabilizer and the basic stabilizer is that the stabilizing signal ΔP_a is introduced into the terminal voltage feedback loop, where ΔP_a is the difference between electrical power and mechanical power and can be measured approximately [6]. Figure 3 is the block diagram of the improved stabilizer where the feedback from terminal voltage V_t is a function of ΔP_a.

Because $K(\Delta P_a)$ is a function of ΔP_a, the terminal voltage feedback becomes nonlinear feedback.

The principle of designing $K(\Delta P_a)$ is as follows: When $\Delta P_a > 0$, this means $P_e > P_m$, positive $K(\Delta P_a)$ should be chosen to force the terminal voltage feedback so that the field voltage E_f will go down to make electrical power go down to balance mechanical power as soon as possible. When $\Delta P_a < 0$, $K(\Delta P_a)$ should be negative to reduce the terminal voltage feedback in order to increase electrical power as soon as possible.

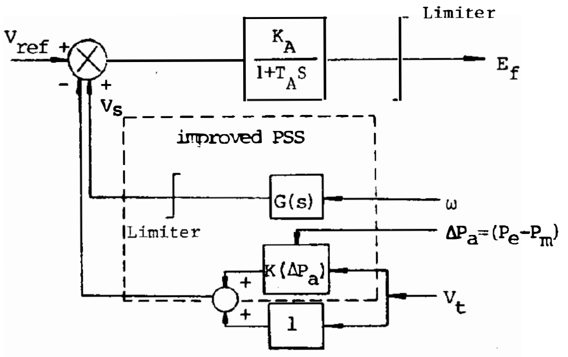

Fig. 3. Block diagram of improved stabilizer

According to the above principle, $K(\Delta P_a)$ has been chosen in three ways to improve performance: PSS(A), PSS(B), and PSS(C) respectively.

3.1 Stabilizer PSS(A)

Figure 3.1.1 shows K as a function of ΔP_a in graphical form. In this case, K switches between positive and negative values according to the sign of ΔP_a. The effect is somewhat similar to bang-bang control. A small dead zone bound can be considered around $\Delta P_a = 0$, as indicated by the dashed lines in Figure 3.1.1.

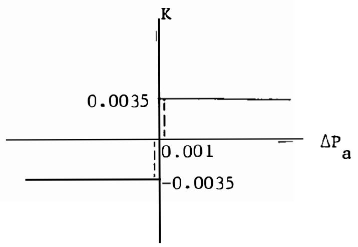

Fig. 3.1.1 $K(\Delta P_a)$ for improved PSS(A)

Nonlinear computer simulations were carried out for both small and large disturbances to study the performance of this system. A 10 MW mechanical power step change and a 0.02 p.u. voltage reference step change are considered as small disturbances and a three-phase short circuit of 0.1 secs. duration on the infinite bus as a large disturbance.

In the nonlinear simulation program, the resistances of the system components were included, saturation was represented in both axes as a function of the total air gap flux for a round rotor machine, one damping winding in the q-axis was included, and the round rotor machine representation included transient saliency.

Figures 3.1.2, 3.1.3 and 3.1.4 are the responses comparing the improved PSS(A) with the conventional PSS and no PSS (only terminal voltage feedback) for the cases of small and large disturbances respectively.

The maximum overshoot Mp and settling time Ts (for 1% bound) of rotor speed in the case of a 10 MW mechanical power step change are listed in Table II.

Table II. Rotor Speed Overshoot and Settling Time

	ROTOR SPEED ω	
EXCITATION CONTROL	Overshoot Mp (p.u.)	Settling time Ts (secs.)
No PSS	0.3280	2.525
PSS	0.2239	1.350
Improved PSS(A)	0.2064	0.525

The following conclusions can be obtained by comparing the improved PSS(A) with the basic PSS.

1. The oscillation frequency without the PSS is about 2.1 Hz. The improved PSS(A) damps the oscillation much more than the PSS.
2. The improved PSS(A) decreases the overshoot somewhat further than the PSS. This means that the improved PSS(A) is not so sensitive to large power disturbances. This can also be shown in the responses of large disturbances.
3. However, the settling time decreases from 1.350 (secs.) to 0.525 (secs.). This indicates that the improved PSS(A) is quite effective for small power disturbances.

3.2 Improved PSS(B)

Figure 3.2.1 shows K as a linear function of ΔP_a.

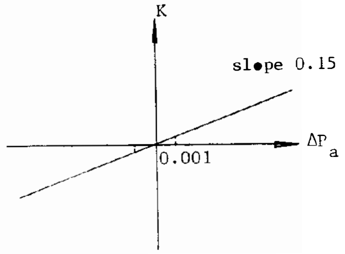

Fig. 3.2.1 $K(\Delta P_a)$ for improved PSS(B)

The dashed line in Fig. 3.2.1 represents the small error bound around $\Delta P_a = 0$. By using this function of K, it is clear that the larger absolute values of ΔP_a will have more effect on terminal voltage feedback, therefore, improved PSS(B) must have more effect on large disturbances.

Figures 3.2.2, 3.2.3 and 3.2.4 are the responses comparing the improved PSS(B) with the PSS in the cases of small and large disturbances respectively.

Table III is given to compare maximum overshoot and settling time (for 1% bound) of rotor speed ω in the case of 10 MW mechanical power step change.

Table III. Rotor Speed Overshoot and Settling Time

	ROTOR SPEED ω	
EXCITATION CONTROL	Overshoot Mp (p.u.)	Settling time Ts (secs.)
PSS	0.2239	1.350
Improved PSS(B)	0.1665	1.225

From these results, it is found that the improved PSS(B) decreases overshoot significantly, however, the settling time is almost the same as for the PSS. This means the improved PSS(B) is effective for large power disturbances but not sensitive to small power disturbances. Therefore, a combination of the advantages of PSS(A) and PSS(B), giving PSS(C) is developed below.

3.3 Improved PSS(C)

Figure 3.3.1 is the function $K(\Delta P_a)$ for an improved PSS(C) which is the combination of improved PSS(A) when ΔP_a is small and improved PSS(B) when ΔP_a is large.

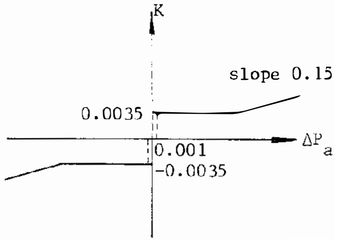

Fig. 3.3.1 $K(\Delta P_a)$ for improved PSS(C)

It can be predicted that the improved PSS(C) must be effective for large as well as small power disturbances and it must decrease both the overshoot as well as the settling time. These advantages are clearly shown in Figures 3.3.2, 3.3.3 and 3.3.4 and Table IV. Table IV is given to compare maximum overshoot and settling time (for 1% bound) of rotor speed ω in the case of a 10 MW mechanical power step change. Also, it is found that the improved PSS(C) does not have a significant effect on the static deviation of terminal voltage in the case of step change.

Table IV. Rotor Speed Overshoot and Settling Time

	ROTOR SPEED ω	
EXCITATION CONTROL	Overshoot Mp (p.u.)	Settling time Ts (secs.)
PSS	0.2239	1.350
Improved PSS(C)	0.1664	0.600

4 CONCLUSIONS

From the simulation results, it is concluded that these three kinds of improved stabilizers can improve power system stability much more than the conventional PSS which has been used widely in power systems since the 1970's. While the improved PSS is based on conventional PSS and only a ΔP_a stabilizing signal is introduced into the terminal voltage feedback loop, it is simple to implement the improved PSS. Comparing the three kinds of improved stabilizers, the improved PSS(C) is the best one since it is effective for both small and large disturbances, and is also effective to improve both overshoot and settling time of rotor speed deviations.

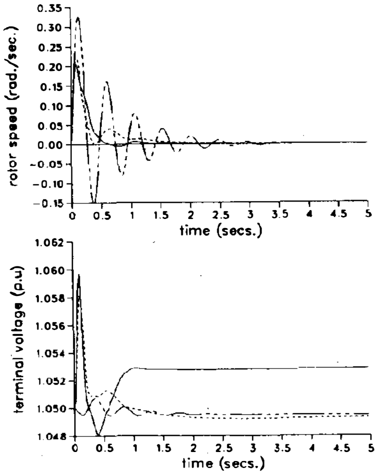

Fig. 3.1.2 Responses for the case of 10 MW mechanical power step change

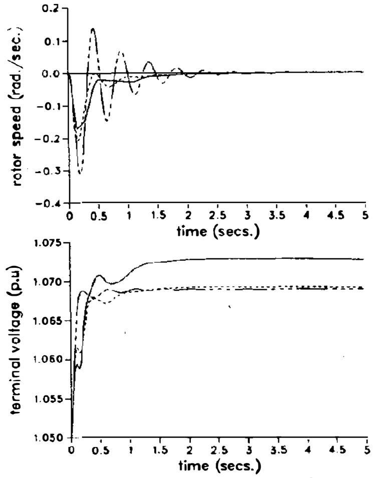

Fig. 3.1.3 Responses for the case of 0.02 p.u voltage reference step change

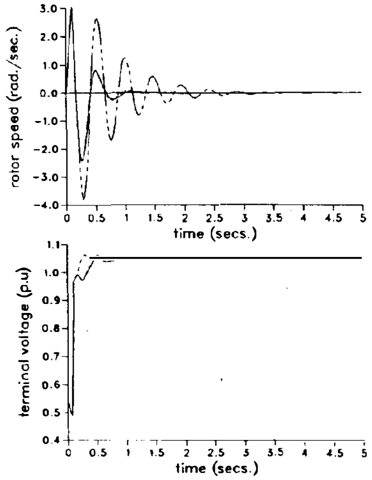

Fig. 3.1.4 Responses for the case of a three phase short circuit of 0.1 (sec.) duration on infinite bus

——————— PSS(A)
··················· PSS
———‑‑‑——— no PSS

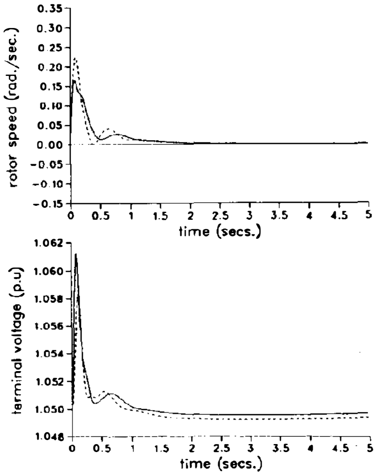

Fig. 3.2.2 Responses for the case of 10 MW mechanical power step change

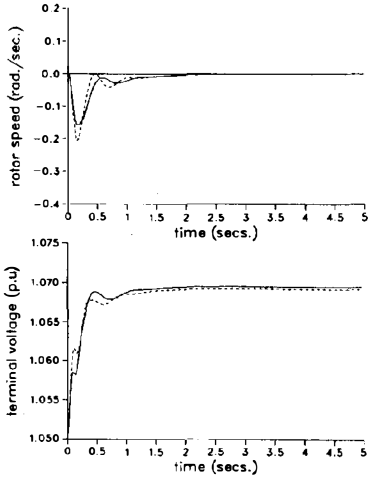

Fig. 3.2.3 Responses for the case of 0.02 p.u voltage reference step change

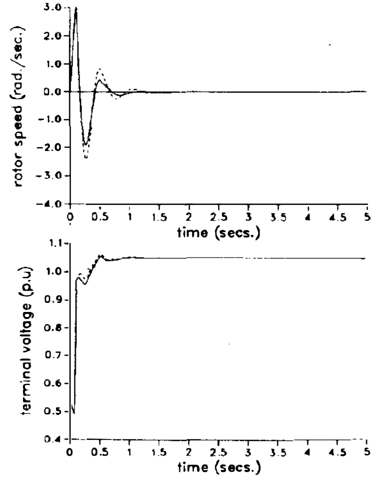

Fig. 3.2.4 Responses for the case of a three phase short circuit of 0.1 (sec.) duration on infinite bus

——————— PSS(B)
··················· PSS

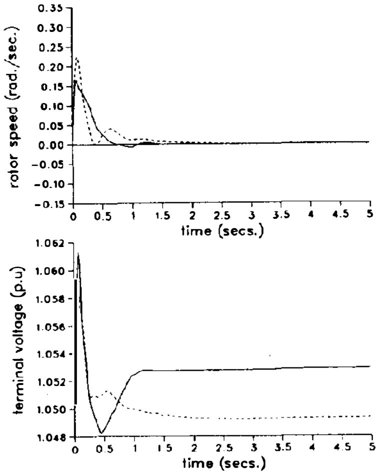

Fig. 3.3.2 Responses for the case of 10 MW mechanical power step change

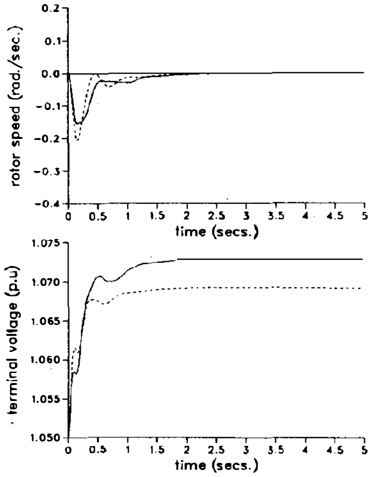

Fig. 3.3.3 Responses for the case of 0.02 p. voltage reference step change

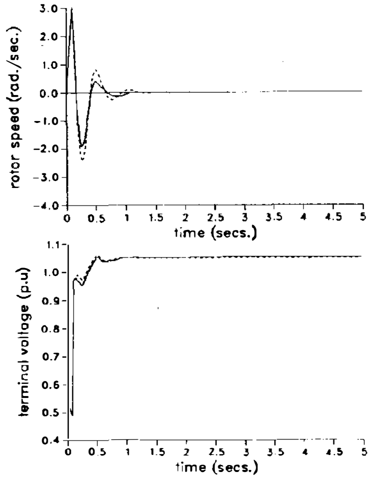

Fig. 3.3.4 Responses for the case of a three phase short circuit of 0.1 (sec.) duration on infinite bus

——————— PSS(C)
··················· PSS

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Ronald J. Fleming (SMIEEE, P.Eng.) was born in Saskatchewan, Canada, in 1930. He received his education in Saskatchewan, completing his Ph.D. in 1968 in electrical engineering. He served as process instrument engineer with Atomic Energy of Canada Ltd. for two years and has been active as a consultant and research contractor in the area of electric power system control for several years. He has been on the faculty of the Department of Electrical Engineering at the University of Saskatchewan since 1958, teaching and doing research in the area of power system modeling and control. He has been participating in the research activities of the Power Systems Research Group and was Head of the Electrical Engineering Department from 1984 to 1988. He is currently a professor in the Electrical Engineering Department.

Madan M. Gupta received the B.Eng. (Honors) in 1961, and the M.Sc. in 1962, both in electronics-communications engineering, from BITS Pilani, India. He received the Ph.D. degree for his studies in adaptive control systems in 1967 from the University of Warwick, U.K.

From 1962 to 1964, he served as a lecturer in electrical-communications engineering at the University of Roorkee, India. He joined the faculty of the College of Engineering at the University of Saskatchewan in 1967 as a sessional lecturer, becoming a full professor in July 1978. His present research interests are in the areas on non-invasive methods in medical diagnosis, medical imaging, intelligent robotic systems, cognitive information, neural networks, and computer vision.

He is co-author with A. Kaufmann, of the books **Introduction to Fuzzy Arithmetic: Theory and Applications** (Van Nostrand Reinhold, 1985) and **Fuzzy Mathematical Models in Engineering and Management Science** (North-Holland, in press) and is the editor of the books **Fuzzy Automata and Decision Processes** (1977), **Advances in Fuzzy Set Theory and Applications** (1979), **Approximate Reasoning in Decision Analysis** (1982), **Fuzzy Information, Knowledge Representation, and Decision Analysis** (1983), **Approximate Reasoning in Expert Systems** (1985), **Fuzzy Computing** (1988), **Fuzzy Logic in Knowledge-based Systems Decision and Control** (1988), all with North-Holland, and **Adaptive Methods for Control Systems Design** (IEEE Press, 1986). He is the subject editor for the **Encyclopedia of Systems and Control** (Pergamon Press, Oxford, 1987) and has authored or co-authored over 200 research papers. He is an advisory editor for the **International Journal of Fuzzy Sets and Systems**(IFSA) and other journals in the field.

His recent research interest lies in the theory and design of new sensors, new devices and intelligent systems using biological and cognitive processes as a basic (for possible applications in health sciences, space exploration, manufacturing processes and robotics).

Jun Sun was born in Shanghai, China, on May 2, 1946. She graduated in electrical engineering from Tsinghua University, Beijing, China, and received the M.Sc. degree in electrical engineering from Chongqing University, Chongqing, China, and the M.Sc. degree in electrical engineering from the University of Saskatchewan, Saskatoon, Canada, in 1968, 1982 and 1987 respectively.

From 1968 to 1979 she was with the North-East Power Company, China, working in the Power Plant Electrical Adjustment and Test Department. In 1982 she joined the faculty of Chongqing University, Chongqing, China, and was a lecturer of electrical engineering. In 1985 she joined the Electrical Engineering Department of the University of Saskatchewan, Saskatoon, Canada, and now is working towards a Ph.D. degree in the area of excitation control of power systems.