The Effect of Power System Stabilizers (PSS) on Synchronous Generator Damping and Synchronizing Torques

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ABSTRACT

The synchronizing and damping torque coefficients in the range of the electromechanical oscillation frequencies provide a measure of the generators' contribution towards power system stability under small deviations, and may be taken as stability indices even for multi machine systems, although their interpretation is rather complex in this case. This paper presents the effect of Power System Stabilizer (PSS) on the synchronizing and damping torque coefficients for a synchronous generator connected to an infinite busbar through impedance; it explicitly includes the effects of its Automatic Voltage Regulator (AVR) and of the additional stabilizer signal derived from the rotor speed. .

Results obtained were compared with the conventional (AVR) using MATLAB 7 programming language.

Keywords: Power System Stabilizer, AVR, synchronizing torque, damping torque

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INTRODUCTION

A traditional function of the excitation system is to regulate generator voltage and thereby help control system voltage. The power system stabilizer (PSS) is a supplementary controller, which is often applied as part of the excitation control system. Grid codes and regulatory agencies are increasingly specifying PSS controls for new generation and retrofit on existing units. The basic function of the PSS is to apply a signal to the excitation system, creating electrical torques that damp out power oscillations.

Although the primary function of the PSS is to supply positive damping torque contributions, experience indicates that it can impact the generator-power system transient performance under certain conditions.

Dynamic instability is related to the high loading of modern electrical power systems, to the design of lower-cost synchronous generators and especially to the use of high-gain and quick-acting excitation systems. To improve the damping of electromechanical oscillations when necessary, such systems should be designed to allow proper processing of stabilization signals, usually derived from the machine rotor-speed or electrical power. [1]

J.H.Chow and J.J.Sanchez-Gasca [2] examine the four pole-placement for the design of the power system stabilizer with the emphasis on the frequency characteristics of these controllers.

M. A. Abido and Y. L. Abdel-Magid [3] proposed a robust design of multi-machine Power System Stabilizers (PSS) using Tabu Search (TS) optimization technique. The eigenvalues analysis and the nonlinear simulation results show the effectiveness of the proposed PSS to damp out the local as well as the interarea modes and enhance greatly the system stability over a wide range of loading conditions and system configurations.

K. Hongesombut, and Y. Mitani [4] focuses on the use of advanced techniques in genetic algorithm for solving power system stabilization control problems. These advanced techniques provide enhanced versatility for solving problems in power system stabilization control.

K.T.Law et.al[5] exploited the internal model (IMC) technique to analyze the inherent conflict between voltage regulation and damping improvement for synchronous generators.

Payman Shamsollahi [6] described an adaptive power system stabilizer using on-line trained neural networks which is tested on a single-machine infinite-bus power system model for a variety of disturbances.

C.X.Mao [7] described an adaptive optimal control algorithm for two real time control applications for synchronous generator and power system stabilizer.

2. PLANT MODEL

To investigate the effectiveness of using the power system stabilizer (PSS) with the automatic voltage regulator (AVR), the plant model which is the exciter-generator is shown in Figure 1 below. A mathematical model for the exciter-generator plant was derived depending on the Swing Equation viewpoint. The equation of central importance in power system stability analysis are the rotational inertia equation describing the effect of unbalance between the electromagnetic torque and the mechanical torque of the individual machines.

The normalized swing equation then can be expressed as two first order differential equations, then

$$\frac{d(\Delta\omega_r)}{dt} = \frac{1}{2H}(\overline{T}_m - \overline{T}_e - K_D\Delta\overline{\omega}_r)$$

(1)

$$\frac{d\delta}{dt} = \omega_o\Delta\overline{\omega}_r$$

(2)

The plant model will be introduced in the form of state space vector differential equation $\dot{x} = Ax + Bu$. [8, 9, 10, 11]

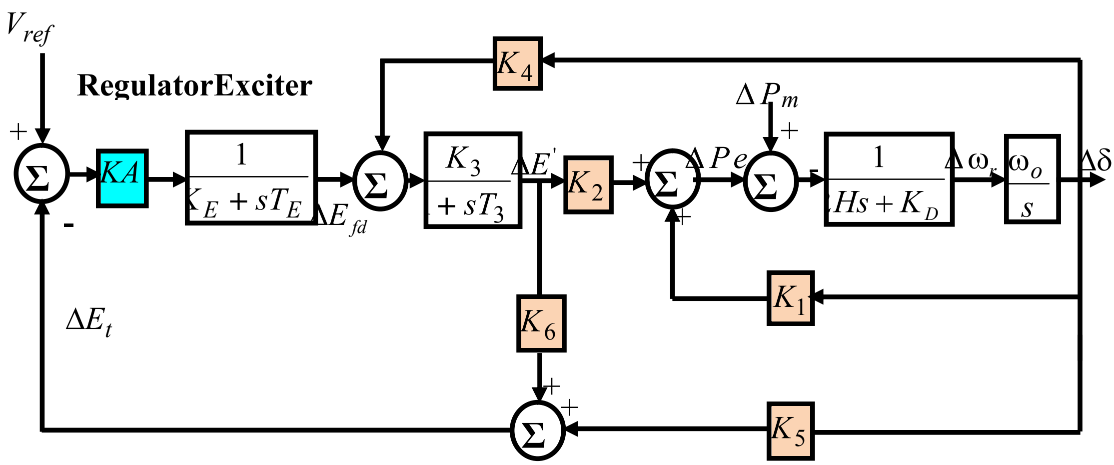


Figure 1 Exciter generator

The V_{ref} and ΔP_m will be taken as inputs to the plant then,

$$\frac{d}{dt}\begin{bmatrix}\Delta\omega_r \\ \Delta\delta \\ \Delta E' \\ \Delta E_{fd}\end{bmatrix} = \begin{bmatrix} \frac{-K_D}{2H} & \frac{-K_1}{2H} & \frac{-K_2}{2H} & 0 \\ \omega_o & 0 & 0 & 0 \\ 0 & \frac{-K_3K_4}{T_3} & \frac{-1}{T_3} & \frac{K_3}{T_3} \\ 0 & \frac{-KAK_5}{T_E} & \frac{-KAK_6}{T_E} & \frac{-K_E}{T_E} \end{bmatrix} \begin{bmatrix}\Delta\omega_r \\ \Delta\delta \\ \Delta E' \\ \Delta E_{fd}\end{bmatrix} + \begin{bmatrix} \frac{1}{2H} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & \frac{KA}{T_E} \end{bmatrix} \begin{bmatrix}\Delta P_m \\ V_{ref}\end{bmatrix}$$

(3)

Then from equation (3)

$$[A]=\begin{bmatrix} \frac{-K_D}{2H} & \frac{-K_1}{2H} & \frac{-K_2}{2H} & 0 \\ \omega_o & 0 & 0 & 0 \\ 0 & \frac{-K_3K_4}{T_3} & \frac{-1}{T_3} & \frac{K_3}{T_3} \\ 0 & \frac{-KAK_5}{T_E} & \frac{-KAK_6}{T_E} & \frac{-K_E}{T_E} \end{bmatrix}$$ and

$$[B]=\begin{bmatrix} \frac{1}{2H} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & \frac{KA}{T_E} \end{bmatrix}$$

3. PERFORMANCE EVALUATION of DESIGNED CONVENTIONAL AVR

For the conventional AVR the output in the state-space can be taken arbitrary, for the model of equation (3), the terminal voltage ΔE_t is taken to be an output and can be given as:

$$\Delta E_t = K_5 \quad \Delta\delta + K_6 \quad \Delta E' \tag{4}$$

or in a matrix form

$$\Delta E_t = [0 \quad K_5 \quad K_6 \quad 0] \begin{bmatrix} \Delta\omega_r \\ \Delta\delta \\ \Delta E' \\ \Delta E_{fd} \end{bmatrix} \tag{5}$$

The synchronizing torque and the damping torque coefficients can be calculated from the equations

$$\omega_n = \sqrt{K_S \frac{\omega_o}{2H}} \ \text{rad/s} \qquad (6)$$

And the damping ratio is

$$\zeta = \frac{1}{2}\frac{K_D}{2H\omega_n}$$

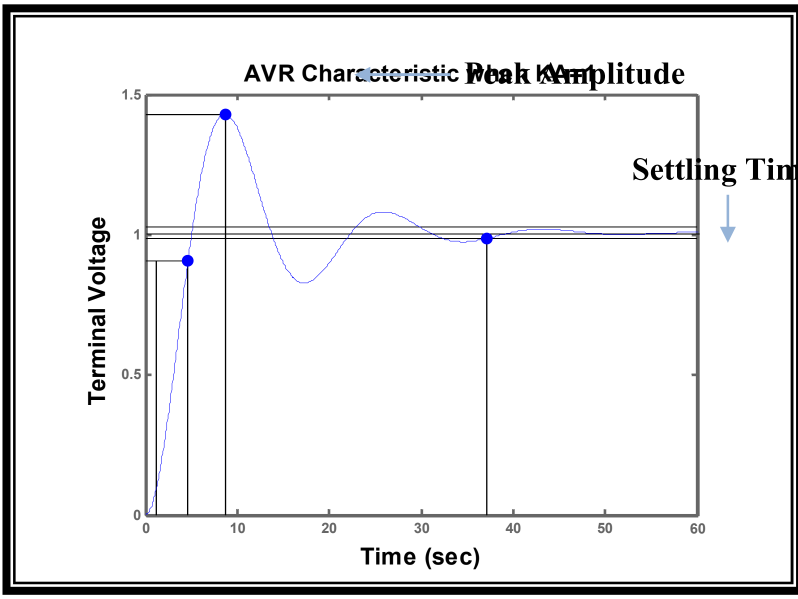
$$= \frac{1}{2}\frac{K_D}{\sqrt{K_S 2H\omega_o}} \qquad (7)$$

By changing the value of KA from 1 to 90 (the gain 90 is the maximum that after this value the instability will be reached). Then for these changes evaluating the values of the K_S, K_D (as given in equations 5 and 6), and the time domain specifications is evaluated are shown in Table 1. Figures 2 and 3 displays the plots of the output terminal voltage E_t versus t for number of KA values

Table 1 Conventional AVR

KA	ω_n	ω_d	ζ	K_S	K_D	Settling time	Peak Amplitude
1	0.37	0.36	0.265	0.7668	**1.395**	**37.2**	1.43
20	1.71	1.71	0.0542	0.8185	**1.2975**	**42.5**	1.86
40	2.46	2.46	0.0336	0.8766	**1.1572**	**47.5**	2.01
50	2.77	2.77	0.0273	0.9067	**1.0587**	**51.1**	2.11
60	3.08	3.07	0.0219	0.9404	**0.9443**	**57.3**	2.19
80	3.67	3.67	0.0107	1.0143	**0.5498**	**96.8**	2.26
90	3.99	3.99	0.0018	1.0598	**0.1033**	**504**	2.31

(**Note**: if V_{ref} is taken to be zero p.u, then the output will be the rate of change of the terminal voltage ΔE_t, else if V_{ref} is taken to be 1p.u then the output will be the terminal voltage E_t, which is the case in this paper).



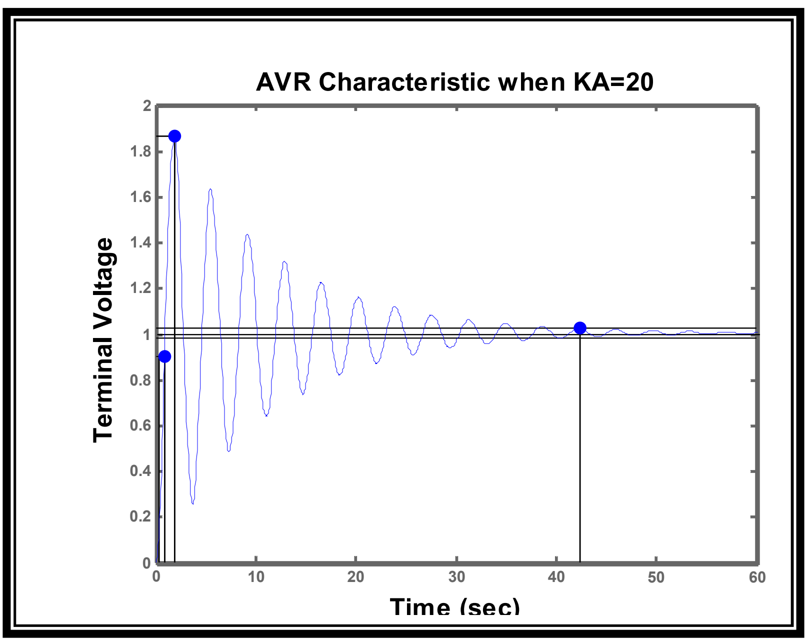
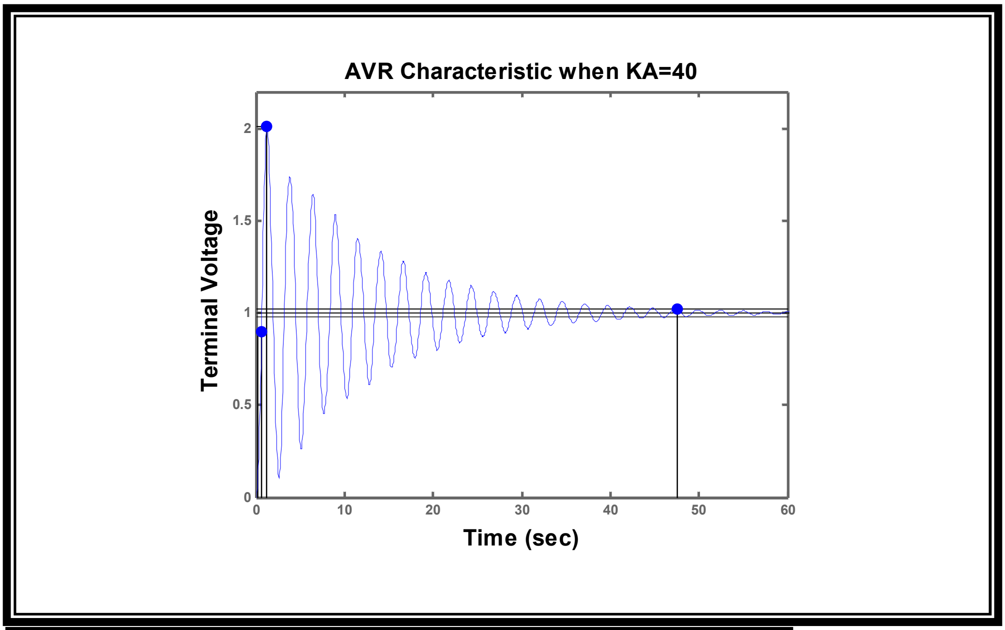


Figure 2 Terminal voltage of the generator with KA = 1 and KA = 20



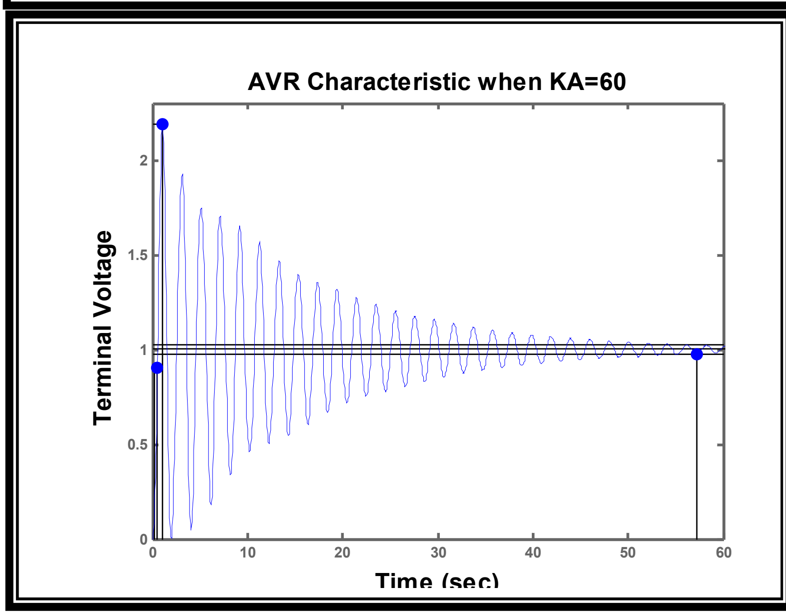


Figure 3 Terminal voltage of the generator with KA = 40 and KA =

4. PERFORMANCE EVALUATION of THE DESIGNED CONVENTIONAL AVR AND PSS

The basic function of the power system stabilizer (PSS) is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal(s). To provide damping, the stabilizer must produce a component of electrical torque in phase with the rotor speed deviations.

The basis for a PSS may be illustrated with the aid of the block diagram shown in Figure 4. This is an extension of the block diagram of Figure 1 and includes the effect of PSS.

Since the purpose of a PSS is to introduce a damping torque component, a logical signal to use for controlling generator excitation is the speed deviation.

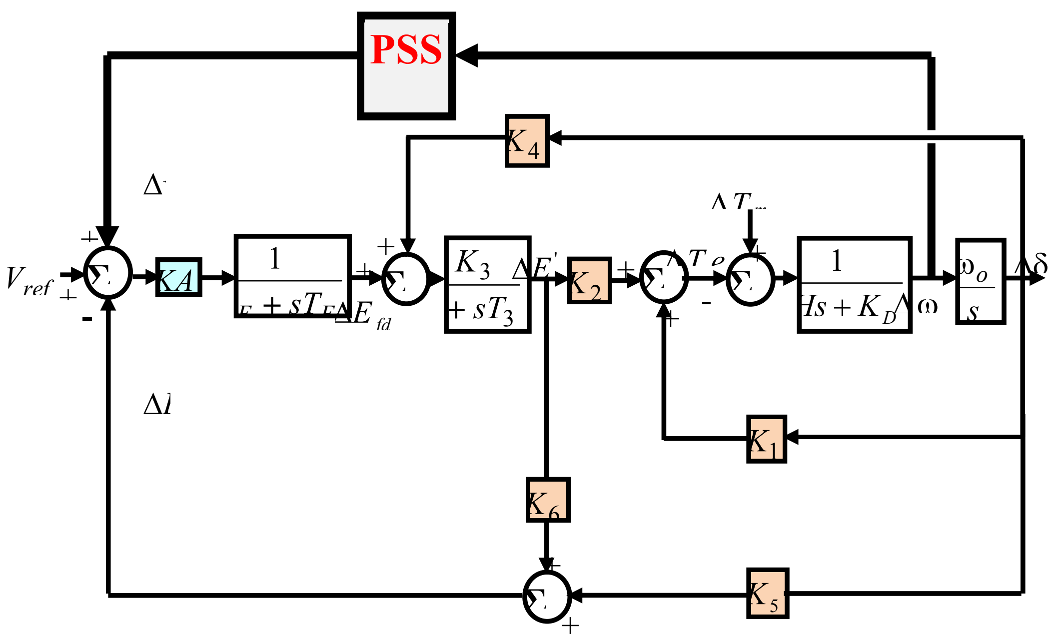
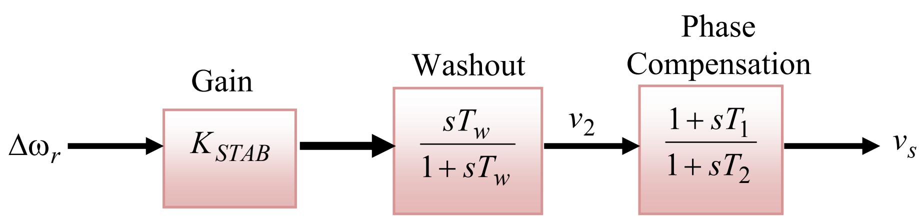


Figure 4 Block diagram representation with

The PSS transfer function, should have appropriate phase lead compensation circuits to compensate for the phase lag between the exciter input and the electrical torque.

If the phase-lead network provides more compensation than the phase lag between ΔT_e and Δv_s, the PSS introduces, in addition to a damping component of a torque a negative synchronizing torque component. Conversely, under compensation a positive synchronizing torque is introduced.

The PSS representation in Figure 5 consists of three blocks: a phase compensation block, a signal washout block, and a gain block.



System state matrix including PSS is shown below

Figure 5 Block diagram showing the PSS

$$\frac{d}{dt}\begin{bmatrix}\Delta\omega_r\\ \Delta\delta\\ \Delta E'\\ \Delta E_{fd}\\ \Delta v_2\\ \Delta v_s\end{bmatrix}=\begin{bmatrix}\frac{-K_D}{2H} & \frac{-K_1}{2H} & \frac{-K_2}{2H} & 0 & 0 & 0\\ \omega_o & 0 & 0 & 0 & 0 & 0\\ 0 & \frac{-K_3K_4}{T_3} & \frac{-1}{T_3} & \frac{K_3}{T_3} & 0 & 0\\ 0 & \frac{-KAK_5}{T_E} & \frac{-KAK_6}{T_E} & \frac{-K_E}{T_E} & 0 & 0\\ \frac{-K_DK_{STAB}}{2H} & \frac{-K_1K_{STAB}}{2H} & \frac{-K_2K_{STAB}}{2H} & 0 & \frac{-1}{T_w} & 0\\ \frac{-T_1K_DK_{STAB}}{2HT_2} & \frac{-T_1K_1K_{STAB}}{2HT_2} & \frac{-T_1K_2K_{STAB}}{2HT_2} & 0 & \frac{1}{T_2}-\frac{T_1}{T_2Tw} & \frac{-1}{T_2}\end{bmatrix}\begin{bmatrix}\Delta\omega_r\\ \Delta\delta\\ \Delta E'\\ \Delta E_{fd}\\ \Delta v_2\\ \Delta v_s\end{bmatrix}$$

$$+\begin{bmatrix}0\\0\\0\\ \frac{KA}{T_E}\\0\\0\end{bmatrix}\left[V_{ref}\right]$$

(8)

The terminal voltage ΔE_t is taken to be an output and can be given as in equation (4)
or in state-space representation

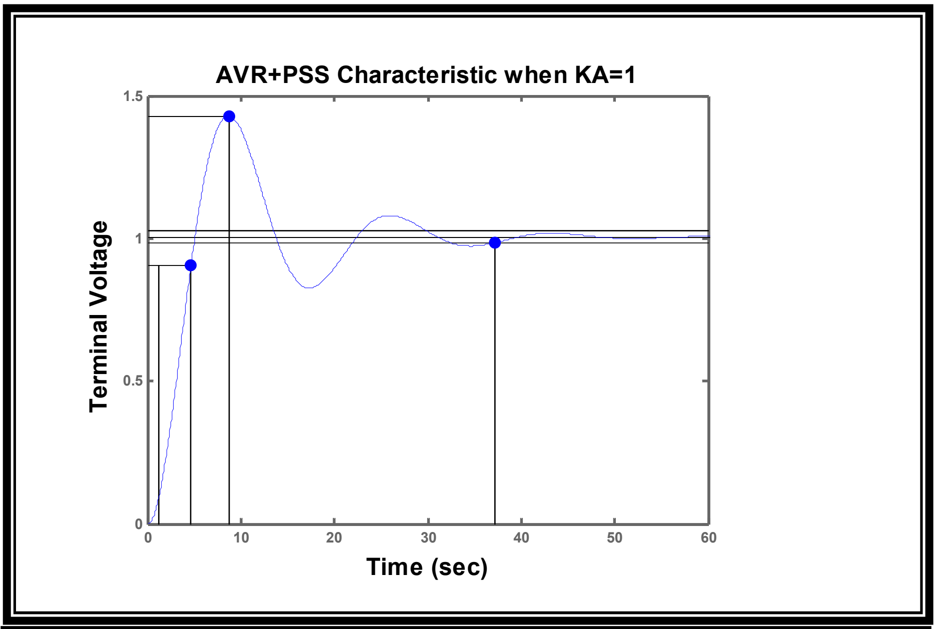
$$\Delta E_t=\begin{bmatrix}0 & K_5 & K_6 & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}\Delta\omega_r\\ \Delta\delta\\ \Delta E'\\ \Delta E_{fd}\\ \Delta v_2\\ \Delta v_s\end{bmatrix}$$

(9)

By changing the value of *KA* from 1 to 90. Then for these changes evaluating the values of the K_S, K_D and the time domain specifications, as given in Table 2. Figures 6 and 7 displays the plots of the output terminal voltage E_t versus t for number of KA values in the presence of PSS. From these figures, it can be shown how the damping torque coefficient (K_D) increases and with respect to the damping torque coefficient evaluated in Table 1.

Table 2 Conventional AVR and PSS

KA	ω_n	ω_d	ζ	K_S	K_D	Settling time	Peak Amplitude
1	0.37	0.36	0.2650	0.7668	1.395	37.2	1.43
20	1.71	1.71	0.0563	0.8185	1.3478	40.7	1.86
40	2.46	2.45	0.0371	0.8766	1.2777	43.6	2
50	2.77	2.77	0.0316	0.9067	1.2254	44.3	2.1
60	3.08	3.07	0.0271	0.9404	1.1686	46.1	2.18
80	3.67	3.67	0.0186	1.0143	0.9557	55.7	2.29
90	4.00	4.00	0.0127	1.0613	0.7112	73.8	2.3



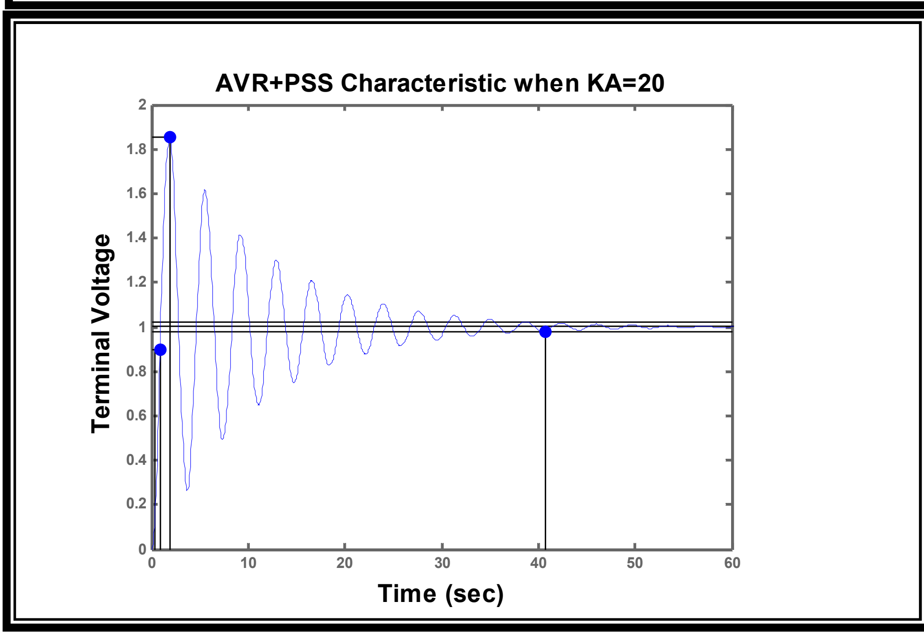
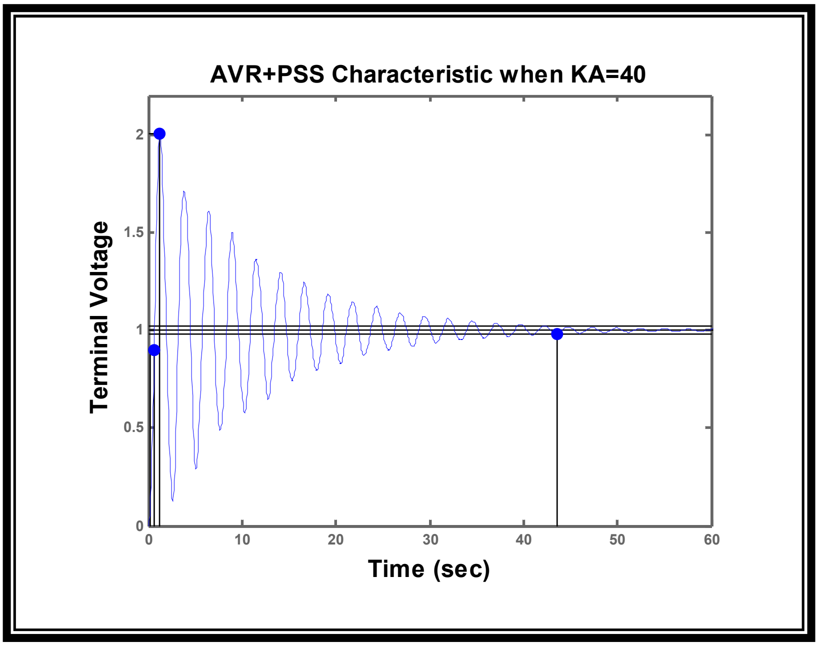


Figure 6 Terminal voltage of the generator with KA = 1 and KA = 20



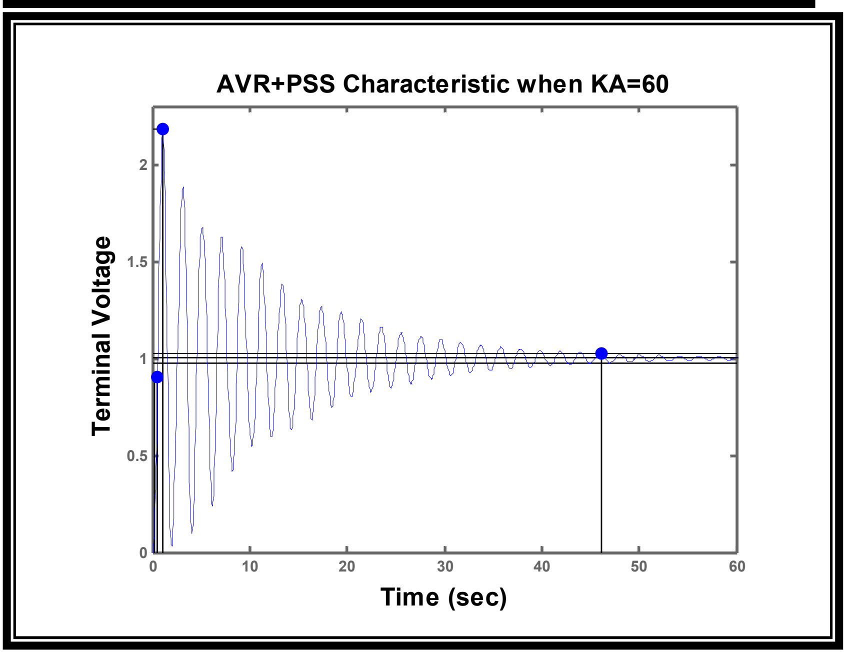


Figure 7 Terminal voltage of the generator with KA = 40 and KA = 60

5. CONCLUSIONS

In this paper at first the conventional AVR was adopted to the synchronous generator whose data are given in Appendix A. The synchronizing torque coefficient and the damping torque coefficient are given in Table 1 and the time domain responses are displayed in Figures 2 and 3. Then the conventional AVR with the power system stabilizer (PSS) was adopted to the same synchronous generator. The synchronizing torque coefficient and the damping torque coefficient are given in Table 2 and the time domain responses are displayed in Figures 6 and 7.

From the evaluated Tables and the time domain plots it is shown that the damping is low, and if the gain of the regulator is increased then the damping will be less. In order to solve this problem and to *increase damping*, the Power System Stabilizer (PSS) was used. Then K_D was increased after using the PSS from 0.1033 to 0.7112 for a gain KA = 90, also the settling time was enhanced and decreased from 504 sec to 73.8 sec and the same thing is true for the other gains. It is clear that the synchronizing torque does not so effected by the PSS as shown in Tables 1 and 2.

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List of symbols

ω_o =	Rated speed in elect.rad/s
ω =	rotor Speed
$\Delta\omega_r$ =	Speed deviation in pu
$\Delta\delta$ =	Rotor angle deviation in elect.rad
KA =	Regulator gain
T_E =	Time constant of the exciter
δ =	Rotor angle with respect to infinite bus
H =	Inertia constant in MW.s/MVA
T_m =	Mechanical torque in N.M
T_e =	Air-gap torque or electromagnetic torque
K_D =	Damping torque coefficient
K1 to K6 =	Constants

APPENDIX (A)

The power system data are as follows:
K_A = (1 to 90), K_D = 0, K_1 = 0.7643, K_2 = 0.8649, K_3 = 0.323, K_4 = 1.4187, K_5 = -0.1463, K_6 = 0.4168, K_E = -0.02, H= 3.5 MW.s/MVA, T_E = 0.56, T_3 = 2.465 s.

تأثير مثبت منظومة القدرة على عزم التخميد وعزم التزامن للمولد المتزامن

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الخلاصة

أن معاملاتِ عزوم المزامنة والتخميد في مدى تردداتِ تذبذبِ خاصية الكهروميكانيك يُعطيانِ مقياس لمساهمةِ المولّداتَ المتزامنة في إستقرارية المنظومةِ الكهربائية في حالة الإنحرافاتِ الصغيرةِ، وقدْ يُؤْخَذانِ كفهارس إستقرارِ حتى لأنظمةِ الماكناتِ المتعددةِ، بالرغم من تعقيد الموضوع في هذه الحالةِ. يُقدّمُ هذا البحث تأثيرَ مثبّتِ النظامِ الكهربائي (PSS) على معاملاتِ عزوم المزامنة والتخميد لمولّد متزامن أوصلَ إلى قضيب لانهائي خلال معاوقة كهربائيةِ. ومن ضمّنُ التأثيراتَ تأثير منظّمِ الفولطية الآلي (AVR)وتأثير إشارةِ المثبّتِ الإضافيةِ المأخوذة مِنْ سرعةِ الدوّار .

أن النَتائِج المكتسبة قُورنتْ بإستعمال منظّمِ الفولطيةِ الآلي التقليدي (AVR) وبأستخدام اُللغة البرمجية MATLAB 7.

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