MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

TRANSIENT AND DYNAMIC PERFORMANCE OF A HIGH-LOADED SYNCHRONOUS GENERATOR WITH PID POWER SYSTEM STABILIZER

M.A. MORSY SHANAB * F.A. KHALIFA ** W. SABRY ***

ABSTRACT

This paper presents a study of the control and stability of a synchronous generator connected to an infinite bus via two parallel transmission lines when the system operate at high loading conditions and subjected to different disturbances.

An effective mean of damping the oscillations resulting from the disturbances is to provide the synchronous generator with power system stabilizer (PSS). An adaptive proportional-plus-integral-plus-derivative (PID) PSS is suggested in this paper. In this technique, the controller parameters (proportional, integral, and derivative constants) are not fixed but they are computed and updated according to the system operating conditions.

Different stabilizing signals are used for the PID-PSS. Each signal is weighted by a factor used arbitrary to get the best performance of the generator under these conditions.

The computer results obtained from simulation study are compared with the results of the system without a controller.

* *Maj. Gen. Prof. Dr. Eng., Dpt. of Elect. Power and Energy, M.T.C., Cairo, Egypt.*

** *Col. Dr. Eng., Dpt. of Elect. Power and Energy, M.T.C., Cairo, Egypt.*

*** *Capt. Eng., Ass. Teacher, Dpt. of Elect. Power and Energy, M.T.C., Cairo, Egypt.*

1. INTRODUCTION

The problem of stability of synchronous generators has received and will receive a great deal of attention. The recent trends in power systems design is toward the application of a generating units of large size to feed high loads. Therefore, a control system is required to provide the compensation with which the reduction in stability margin is offset [1].

Stability analysis of a large electric power system depends almost entirely on digital computer simulation of system dynamic behaviour. Simulation implies the existance of mathematical models for a variety of apparatus, data files which contain model parameters for specific power systems and computer programs.

The application of adaptive PID-PSS to a synchronous generator connected to an infinite bus through two parallel transmission lines is considered. A nonlinear mathematical model for this system is prepared. The influence of the proposed PSS on the transient and dynamic performance of the synchronous generator is investigated, when the system is subjected to different disturbances and operating at high loading conditions.

2. THE POWER SYSTEM MODEL

The power system under consideration is shown in Fig.1. It consists of a synchronous generator connected to a large power system through a power transformer and two parallel transmission lines.

The mathematical model of the power system given in Fig.1, is based on the state-space formulation [2-5]. In this model, the state-space variables are chosen to be the currents. This can be expressed in the matrix form as :

$$[\dot{I}] = [A]\cdot[I] + [B]\cdot[U] \qquad \text{p.u.} \tag{1}$$

where :

$$[I]^t = \begin{bmatrix} i_{d1} & i_{d2} & i_f & i_D & i_{q1} & i_{q2} & i_Q \end{bmatrix}$$

The torque equation can be expressed in the form of :

$$\tau_j\cdot\dot{\omega} = T_m - T_e - T_d \qquad \text{p.u.} \tag{2}$$

where :

$$T_d = D.\omega \qquad \text{p.u.} \tag{3}$$

Also, the relation between δ, and ω can be defined as :

$$\dot{\delta} \triangleq \omega - 1 \qquad \text{p.u.} \tag{4}$$

The excitation system with which the synchronous generator is equipped is a static type 1-S exciter [1] and its block diagram is shown in Fig.2. The equations of the excitation system can be written in the state-space form as following :

$$\begin{bmatrix} \dot{E}_{fD} \\ \dot{V}_3 \end{bmatrix} = \begin{bmatrix} -1/T_A & -K_A/T_A \\ -K_f/(T_A \cdot T_f) & -\left(\frac{K_f\ K_A}{T_f\ T_A} + \frac{1}{T_f}\right) \end{bmatrix} \begin{bmatrix} E_{fD} \\ V_3 \end{bmatrix} + \begin{bmatrix} \frac{K_A}{T_A}\left(V_4 + \frac{E_{oA}}{K_A}\right) \\ \frac{K_f\ K_A}{T_f\ T_A}\left(V_4 + \frac{E_{oA}}{K_A}\right) \end{bmatrix} \quad \text{p.u.} \qquad (5)$$

By feeding-back the terminal voltage signal and comparing this signal with a reference value, the excitation system is related to be an automatic voltage regulator (AVR).

Combining equations (1), (4) and (5), the complete system model will be constructed.

3. DESIGN OF THE PROPOSED PSS

In this paper, a proposed PID-PSS is designed. The parameters of this controller are not constant but they are computed according to the variation of the system operating conditions. Fig.3 shows block diagram of the controlled process, AVR, and the proposed PSS. Reference [6] shows the method on which the design is depended. For a wide range of system operating conditions, (active power (P), and reactive power (Q)), the obtained controller parameters are stored in look-up table against the system operating conditions. During on-line operation, the controller monitors the P and Q values of the system and picks up the corresponding controller parameters at each sampling instant. The system equation are :

$$\dot{X} = A \cdot X + B \cdot u \qquad (6)$$

$$Y = C \cdot X \qquad (7)$$

where

$$[I]^t = \begin{bmatrix} i_{d1} & i_{d2} & i_f & i_D & i_{q1} & i_{q2} & i_Q & E_{fD} & V_3 & \omega & \delta \end{bmatrix}$$

Taking the laplace transform for equations (6), and (7) :

$$S \cdot X(S) = A \cdot X(S) + B \cdot U(S) \qquad (8)$$

$$Y(S) = C \cdot X(S) \qquad (9)$$

Equation (8) can be rewritten as :

$$X(S) = (S \cdot I - A)^{-1} \cdot B \cdot U(S) \qquad (10)$$

The control signal is :

$$U(S) = H(S) \cdot Y(S) \tag{11}$$

$$\therefore U(S) = \frac{S \cdot T_w}{1 + S \cdot T_w} \cdot \left[K_p + \frac{K_I}{S} + K_D \cdot S\right] \cdot Y(S) \tag{12}$$

From equations (9), and (10) we have :

$$Y(S) = C \cdot (S \cdot I - A)^{-1} \cdot B \cdot U(S) \tag{13}$$

So,

$$H(S) = \frac{1}{C \cdot (S \cdot I - A)^{-1} \cdot B}$$

$$= \frac{S \cdot T_w}{1 + S \cdot T_w} \cdot \left[K_p + \frac{K_I}{S} + K_D \cdot S\right] \tag{14}$$

The gains K_p, K_I, and K_D may be computed by finding the eigen values of the open loop system, prespecifying the eigen values of the closed loop system, and substituting the three eigenvalues in equation (14), we get three equations when solved together we get K_p, K_I, and K_D. The input signal to the PSS may be expressed as :

$$V_{PSS} = w_1 \cdot \Delta\omega + w_2 \cdot \Delta\delta + w_3 \cdot \Delta\rho \tag{15}$$

4. SYSTEM PARAMETERS, RESULTS, AND DISCUSSION

To verify the proposed analysis given in this paper, the system data are given in references [2,6] as :

Rated MVA = 160 MVA
Excitation voltage = 375 V
Power factor = 0.86
Inertia constant = 1.765 Kw.sec./hp
Direct axis self inductance = 1.7 pu
Direct axis damper inductance = 1.605 pu
Direct axis mutual inductance = 1.55 pu
Direct axis damper resistance = 0.0131 pu
Field self inductance = 1.651 pu
Field resistance = 0.000742 pu
Quadrature axis self inductance = 1.64 pu
Quadrature axis damper inductance = 1.526 pu
Quadrature axis mutual inductance = 1.49 pu
Quadrature axis damper resistance = 0.054 pu
Transmission line impedance = 0.04 + j 0.8 pu
Transformer reactance = 0.1 pu

K_f = 0.004 pu

T_f = 0.04 sec.

Rated voltage = 15 KV
Field current = 926 A
Damping constant = 2
Frequency = 50 Hz

K_A = 25 pu

T_A = 0.05 sec.

V_{max} & V_{min} = ± 1.25 pu

The power delivered to the large bus system was considered to be :

$$P = 1.25 \quad p.u., \quad \text{and} \quad Q = 0.75 \quad p.u.$$

The controller constants was found to be :

$$K_P = 31.17 \ , \quad K_I = -187.65 \ \sec^{-1}, \quad \text{and} \quad K_D = 641.33 \ \sec.$$

The weighting factors of the input signals of the PSS are :

$$w_1 = 2.91 \ , \quad w_2 = 0.091 \ , \quad \text{and} \quad w_3 = 0.065$$

A disturbance is considered and simulated as a short circuit in one transmission line at its midpoint with a successful reclosure of the circuit breakers. We assume that the short circuit remain for 0.08 second and the breakers are reclosed after 0.16 second.

The generator response curves are shown in Fig.4-a, 5-a, and 6-a. They show that the proposed PSS has high capability in improving the performance of the generator in comparison with that of conventional AVR. The transient response of such a system is shown in Fig.4-b, 5-b and 6-b.

5. CONCLUSIONS

In this paper, the transient and dynamic performance of a synchronous generator when equipped with a continuous acting AVR and adaptive PID-PSS is described. The effect of feedback stabilizing signals on the generator response is also examined.

The proposed PID-PSS is proved to be an efficient mean for improving the synchronous generator transient and dynamic stability when the generator operate under high loads at a severe disturbance condition.

6. REFERENCES

1. Demello, F.P., Ewart, D.N., and Temoshok, M., "Stability of synchronous machines as affected by excitation systems, Machine and system parameters", Proc. American Power Conf., Vol. XXVII, PP. 1150-1159 (1965).
2. Anderson, P.M., and Fouad, A.A., "Power system control and stability", Vol.1, Book, The Iowa State University (1977).
3. Jha, R.S., "Power system analysis and stability", Book, Dhanpat rai and sons publishers, New Delhi (1980).
4. Uppal, S.L., "Electrical power", Book, Khana publishers, New Delhi (1985).
5. Bergen, A.R., "Power system analysis", Prentice-Hall, New Jersey (1986).
6. HSU, Y.Y., and Wu, C.J., "Adaptive control of a synchronous machine using the auto-searching method", IEEE Trans. of power systems, Vol.3, No.4, November (1988).

NOMENCLATURE

A_k	Weighting factor of feedback voltage signal.
D	Damping constant.
E_{fD}	Exciter output voltage.
E_{oA}	Initial value of E_{fD}.
i_{d1}	d-axis current component in T.L. No. (1).
i_{d2}	d-axis current component in T.L. No. (2).
i_D	d-axis current of damper winding.
i_f	Field current.
i_{q1}	q-axis current component in T.L. No. (1).
i_{q2}	q-axis current component in T.L. No. (2).
i_Q	q-axis current of damper winding.
K_A	Regulator amplifier gain.
K_D	Derivative gain.
K_f	Gain of exciter stabilizing circuit.
K_I	Integral gain.
K_P	Proportional gain.
T_A	Regulator amplifier time constant.
T_d	Damping torque.
T_e	Electrical torque.
T_f	Time constant of exciter stabilizing circuit.
T_m	Mechanical torque.
T_w	Washout time.
V_{max} & V_{min}	The maximum and minimum voltage values.
V_{ref}	reference voltage.
V_{PSS}	PSS output signal.
w_1, w_2, w_3	The weighting factors of the feedback signals of PSS.
δ	Power angle.
$\Delta\delta$	Error in power angle.
$\Delta\omega$	Error in rotor speed.
$\Delta\rho$	Error in active power.
τ_j	Inertia time constant.
ω	Rotor speed.

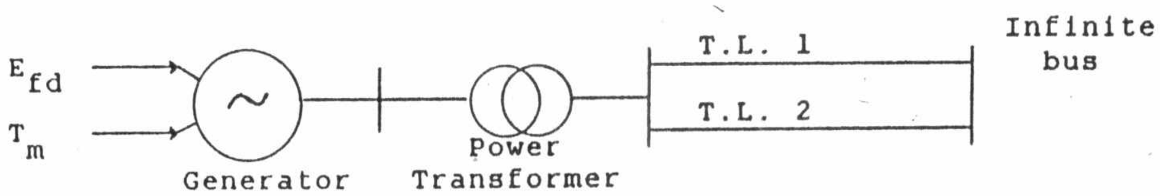

Fig.1. *The power system*

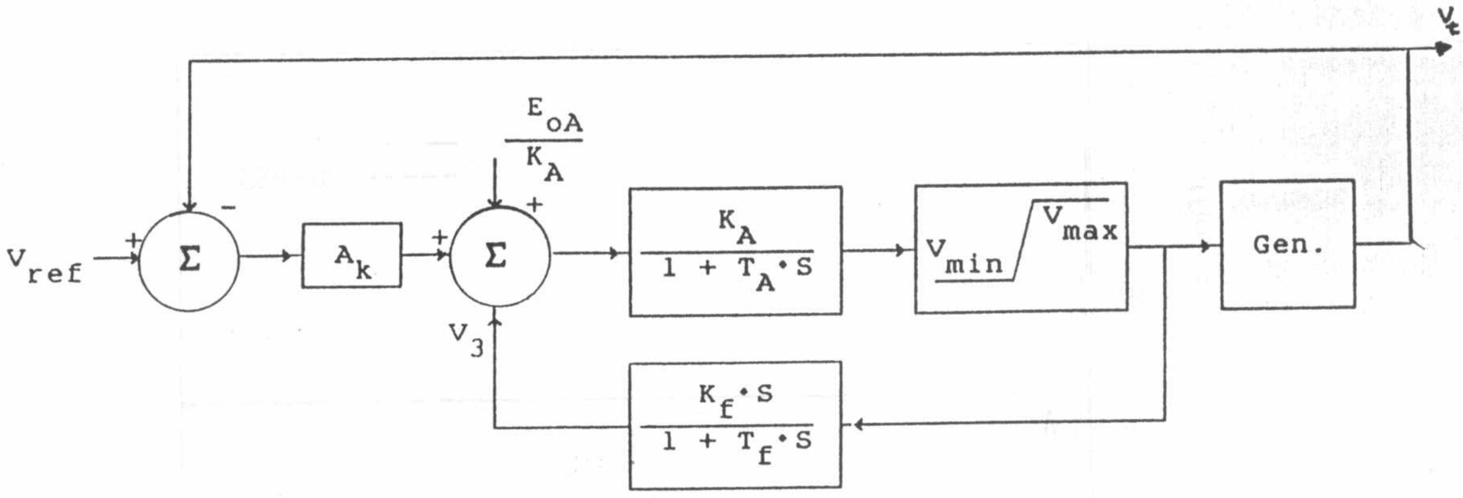

Fig.2. *Block diagram of AVR*

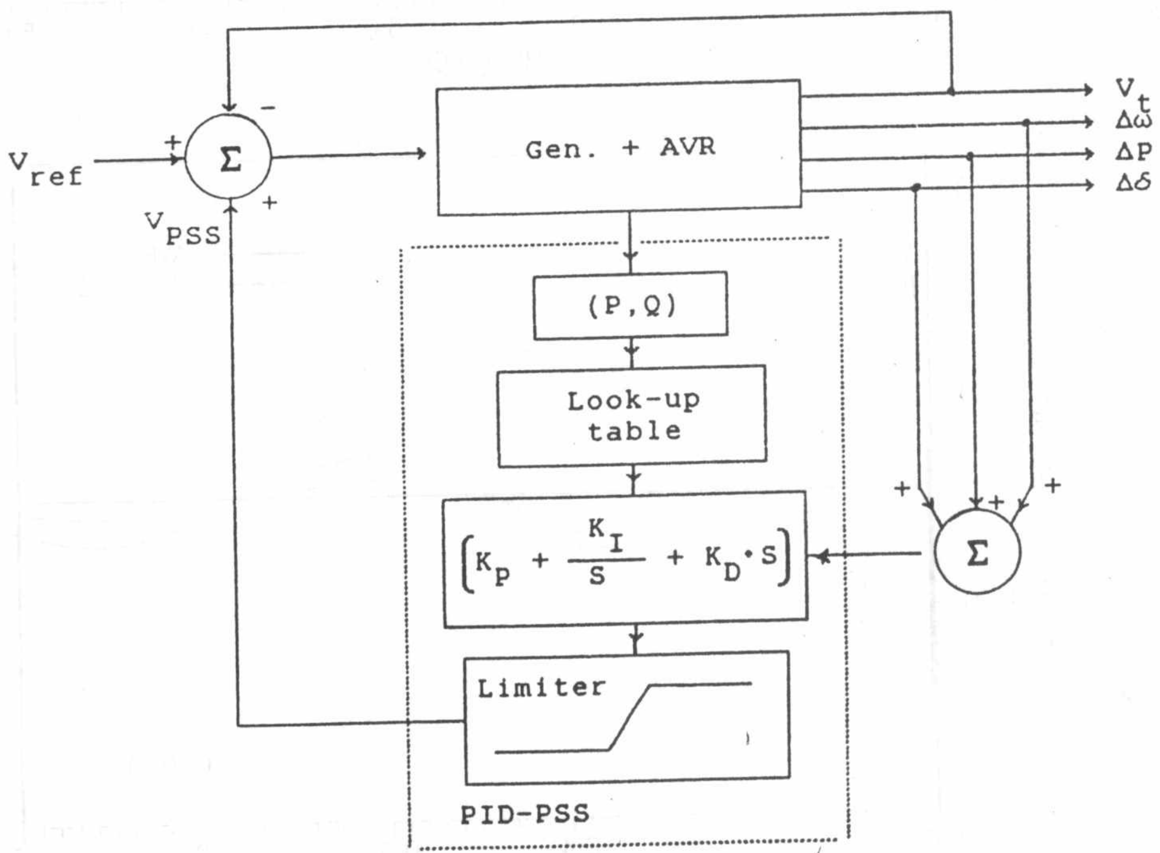

Fig.3. *Block diagram of the PID-PSS*

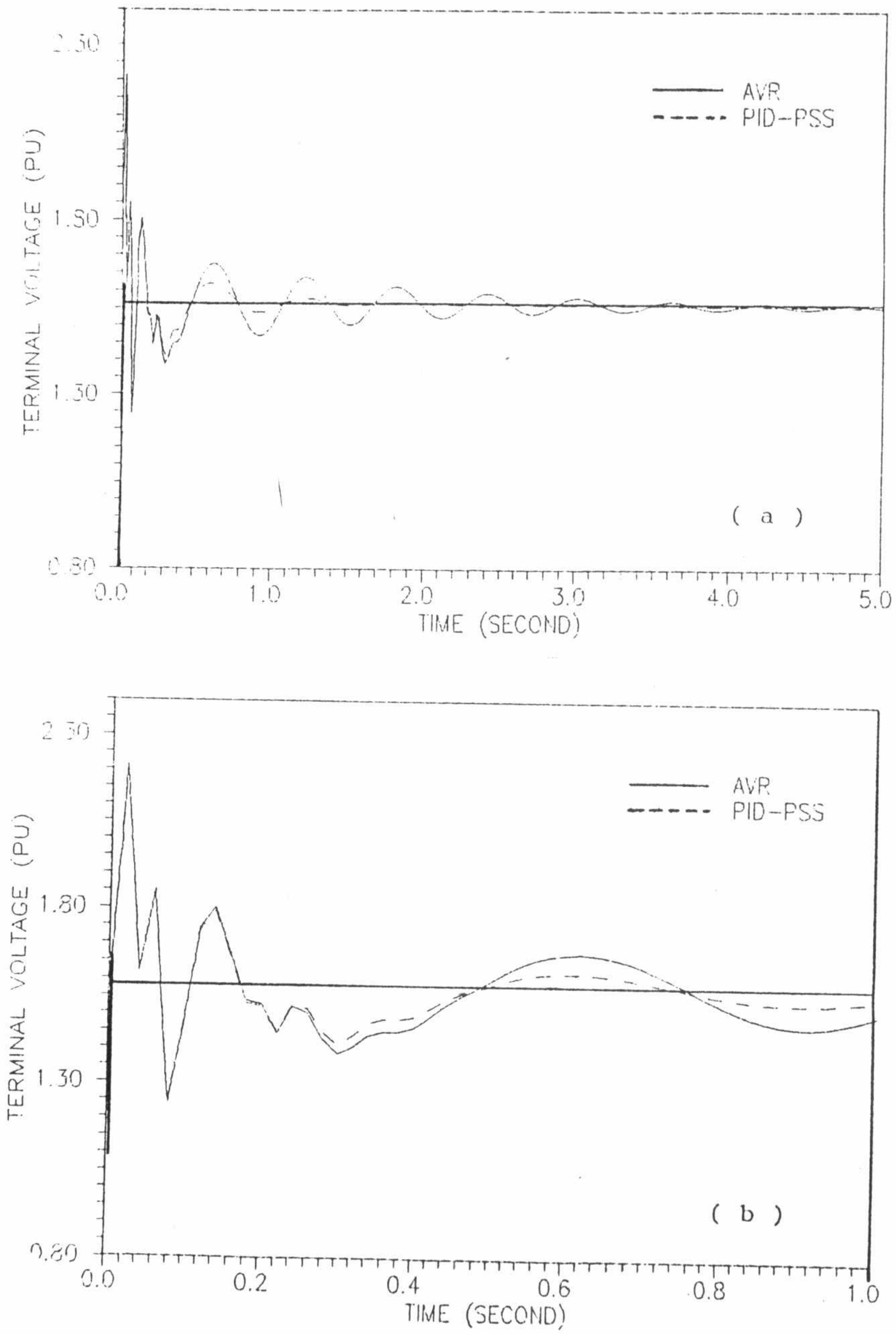

Fig.4. *Terminal voltage/time curve*

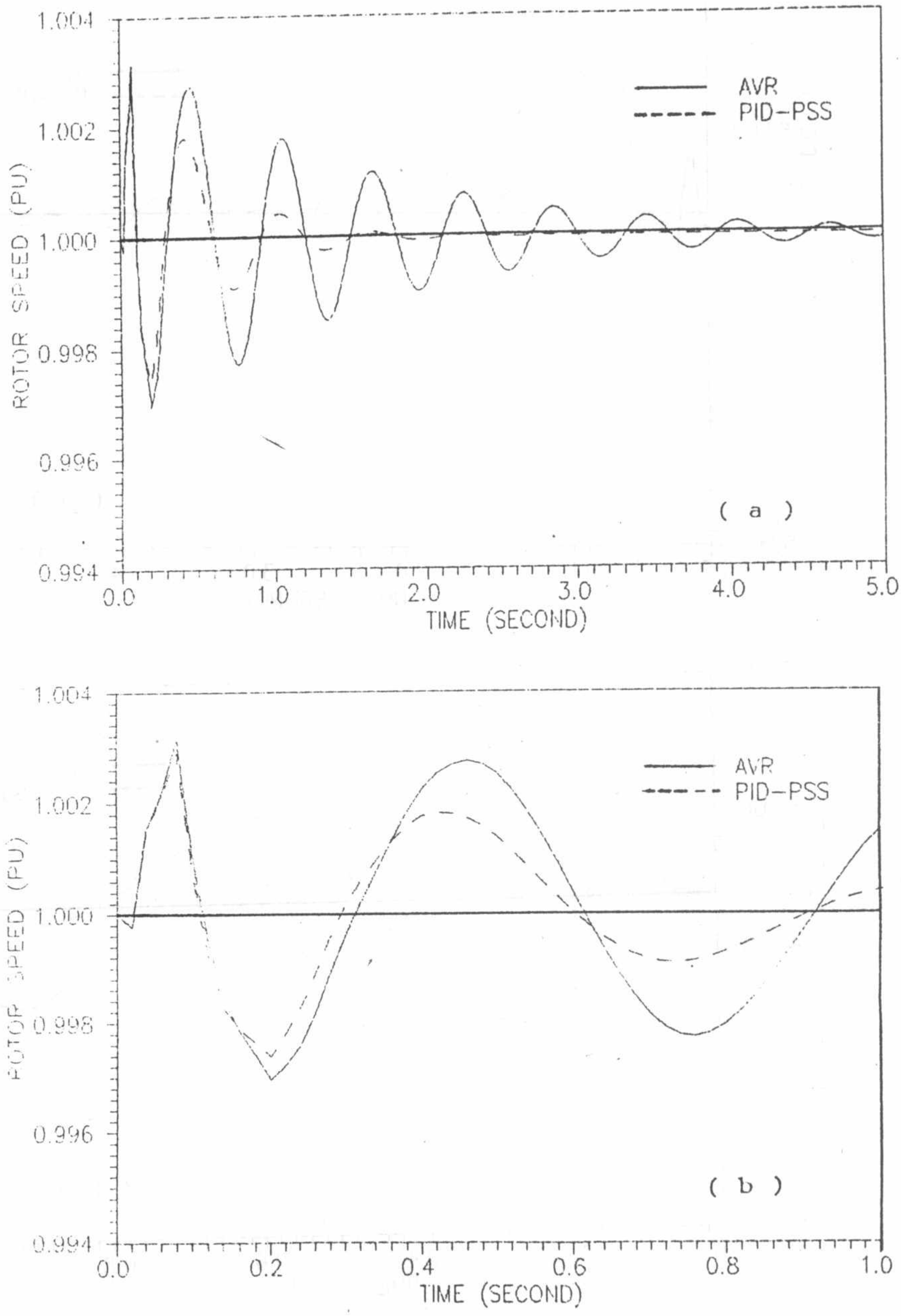

Fig.5. *Rotor speed/time curve*

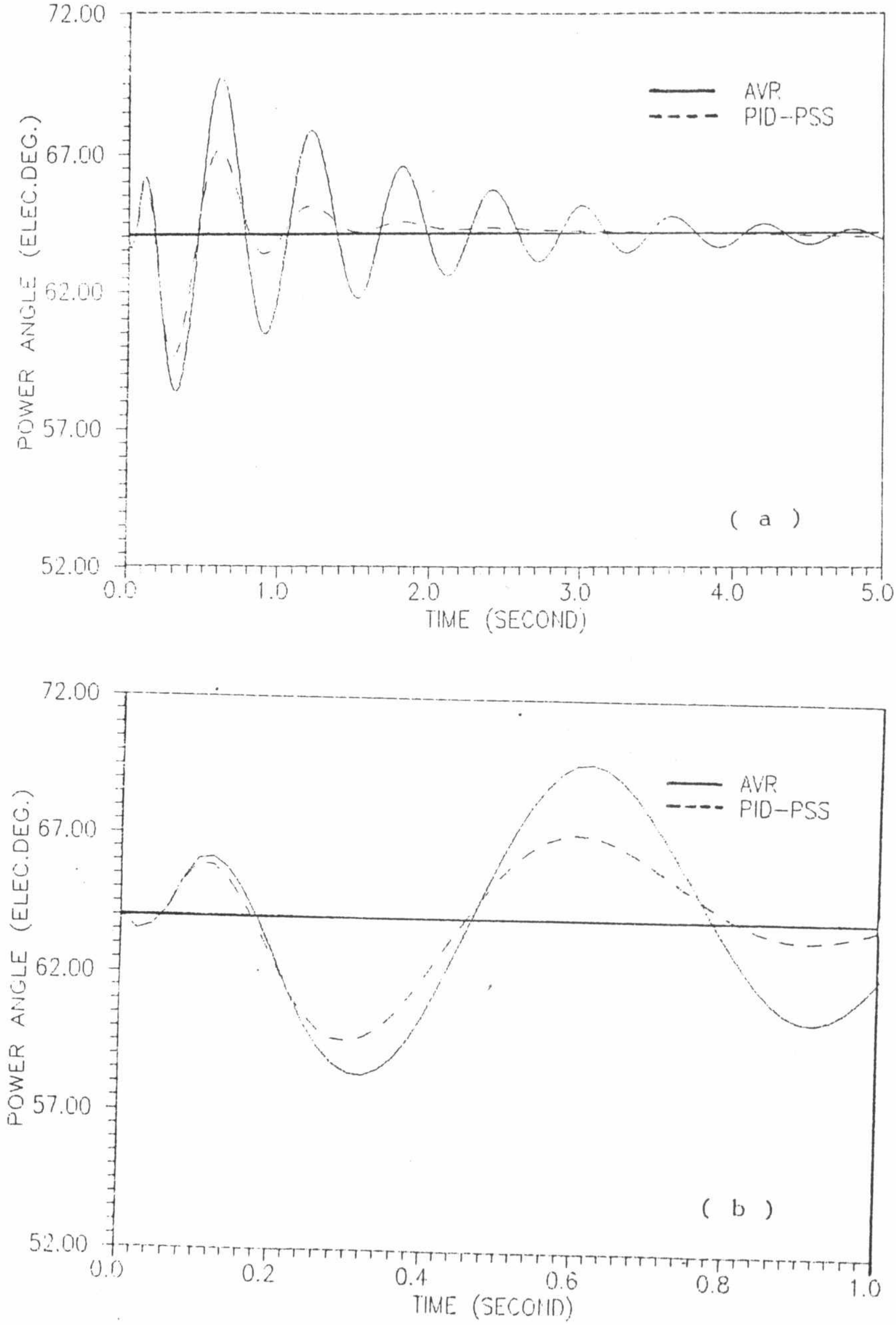

Fig.6. *Power angle/time curve*