MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

EIGENSTRUCTURE ASSIGNMENT FOR MULTIMACHINE POWER SYSTEM CONTROL

Imam R.M. El-Sedawi*   Iraky H. Khalifa**

ABSTRACT

The paper is concerned with the decentralized constant control of a multimachine power system through the eigenstructure assignment approach. Adopting decentralized control, would lower the cost and increase the reliability of the proposed scheme under any variation in the system structure.

Having an eigenstructure assignment approach, means determination of the proper feedback gains that realize an apriori set of eigenvalues and eigenvectors. The eigenvalues would determine directly the rate of change of any perturbation while eigenvectors would reshape that change in a way that can be accepted practically.

Since the interaction between machines has an effect on the overall damping of the system, the modification of the proposed closed-loop eigenvalues to enhance that damping is shown.

---

* Lecturer, **Associate Professor, Dept. of Electric Machines & Power Engineering, Faculty of Engineering & Technology, University of Helwan, Helwan, Cairo, Egypt.

INTRODUCTION

The rise in the demand for electrical power sources is the main reason of increasing size and complexity of power systems with very long transmission lines and fast excitation have made the stability and control problems more difficult than ever. But with engineering experience accumulation and accordingly control and computational techniques are getting more advanced and sophisticated, so new types of controllers are introduced.

The new types of controllers are required to increase the damping of interconnected machines during transient periods and not affecting the regular functions of voltage regulator and speed governor in the steady-state operation. The problem of improving the dynamic response of power systems has been considered by [1] using optimal theory to determine the state feedback. In [2], the same problem has been treated again using output feedback design. In reference [3], a different approach was applied using observers and a state estimator in the application of optimal controllers. A method is developed in [4] for multimachine power systems for the choice of state weighting matrix in conjugation with a left shift of dominant eigenvalues.

Since the system dynamics are governed by their eigenvalues and eigenvectors, none of the above methods has dealt directly with the system eigenstructure, which is the main issue in analyzing them.

This paper, considers the eigenstructure assignment problem using an algebraic approach [5] and utilizes it in getting the proper feedback matrix that results in a good dynamic performance with acceptable damping for the multimachine power system.

In section 2, control of a multimachine power system through the eigenstructure scheme is developed. The dynamic power system model is discussed and formulated in section 3. Section 4 describes the simulation and application of the eigenstructure assignment control algorithm to three electric power plants and the simulation results are presented and discussed.

Eigenstructure Assignment Using State Feedback

Consider the linear continuous time dynamical model described by;

$$\dot{x} = A x + B u \tag{1}$$

here $x \in R^n$ is a state vector, $u \in R^r$ is a control vector with A, B having the appropriate dimensions and the (A,B) is a controllable pair. Assuming that

$$u = K x \tag{2}$$

then from (1), the cosed-loop system is obtained as follows

$$\dot{x} = (A + BK) x \tag{3}$$

and the system characteristic equation is given by

$$\left| s\, I_n - (A + BK) \right| = 0 \tag{4}$$

and this can be written as follows

$$\left| (s\, I_n - A) (I_n - \Psi(s_i)\, BK) \right| = 0 \tag{5}$$

where

$$\Psi(s_i) = (s_i I_n - A)^{-1} \tag{6}$$

assuming that $s_i \notin \sigma(A)$ (spectrum of A). From (5) and (6), we get

$$\left| I_n - \Psi(s_i)\, BK \right| = 0 \tag{7}$$

using the determinant identities [5]

$$\left| I_r - K\, \Psi(s_i)\, B \right| = 0 \tag{8}$$

Equation (8) implies that the columns of the matrix $[I_r - K\, \Psi(s_i)\, B]$ are linearly dependent i.e. there exists a non zero vector f_i such that

$$[I_r - K\, \Psi(s_i)\, B]\, f_i = 0 \tag{9}$$

or

$$\begin{aligned} f_i &= K\, \Psi(s_i)\, B\, f_i \\ &= K\, v_i \\ &\in R^n \end{aligned} \tag{10}$$

where

$$v_i = \Psi(s_i)\, B\, f_i \tag{11}$$

is an eigenvector. Repeating (10) for i = 1,2,.....,n then

$$\begin{aligned} f_1 &= K\, v_1 \\ f_2 &= K\, v_2 \\ &\;\vdots \\ f_n &= K\, v_n \end{aligned} \tag{12}$$

and in compact form, we get

$$[f_1 , f_2 , \ldots\ldots , f_n] = K [v_1 , v_2 , \ldots\ldots , v_n] \tag{13}$$

then

$$F = K V \tag{14}$$

$$F = [\, f_1 , f_2 , \ldots\ldots , f_n \,], \quad V = [\, v_1 , v_2 , \ldots\ldots , v_n \,]$$

Ther from (12), we get

$$K = F\, V^{-1} \tag{15}$$

Tre vectors f_i $(i=1,2,\ldots,n)$ are called the parameter (design) free vectors.

Dynamic Modeling of Power System

In this section, the eigenstructure assignment technique presented in previous section will be applied to a power system shown in Fig. 1. The system considered [4] consists of three power plants, the first is a thermal unit while the second and the third are hydro units. As shown in the system diagram of Fig. 1, the three plants are connected radially to an infinite bus.

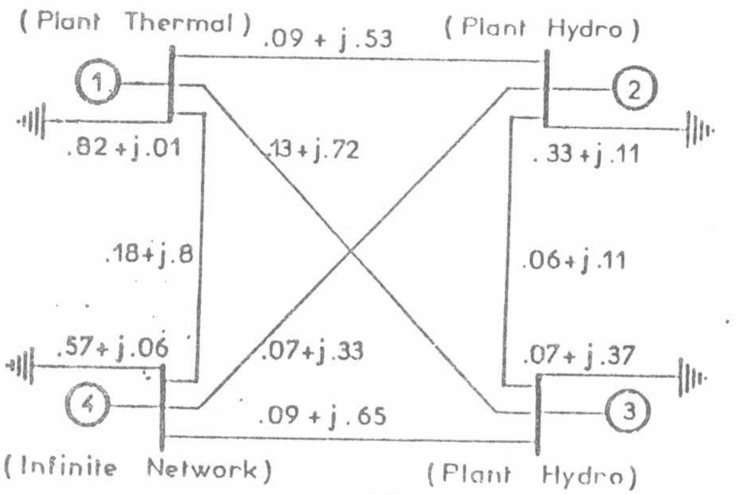

Fig. 1 Three plant power system

The individual plant is represented with four state variables: $\Delta\Psi_f$ (incremental flux linkage), $\Delta\delta$ (incremental torque angle), and $\Delta\omega$ (incremental angular velocity), plus a voltage regulator which is approximated as first order system (where T_E for the exciter in Fig. 2 is neglected). The voltage regulator is represented by the state variable Δv_f as shown in Fig. 2.

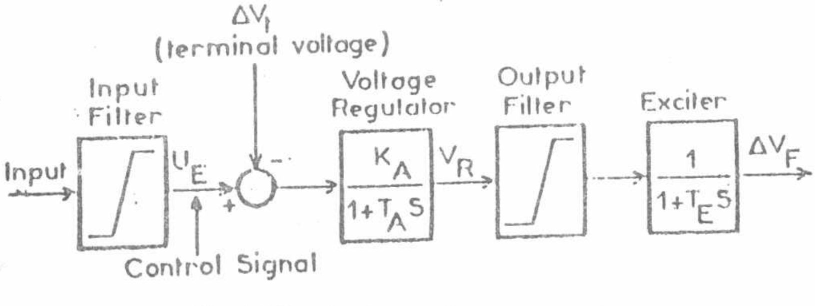

Fig.2 Typical exciter voltage

The linearized dynamical model of the system is given by :

$$\dot{x} = A\,x + B\,u$$

where x is a [12x1] state vector, and u is a [3x1] control vector. The values of the state distribution matrix A (12x12), and the input matrix B (12x3) are given as follows :

$$A = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

where

$$A_{11} = \begin{bmatrix} -.922 & 1.0 & -.266 & -.009 \\ -2.75 & -2.78 & -1.36 & -.037 \\ 0 & 0 & 0 & 1.0 \\ -4.95 & 0 & -55.5 & -.039 \end{bmatrix} \qquad A_{12} = \begin{bmatrix} .024 & 0 & -.087 & .002 \\ -.158 & 0 & 1.11 & .011 \\ 0 & 0 & 0 & 0 \\ .222 & 0 & 8.17 & .004 \end{bmatrix}$$

$$A_{13} = \begin{bmatrix} .072 & 0 & -.25 & .003 \\ -.46 & 0 & 2.8 & -.02 \\ 0 & 0 & 0 & 0 \\ .924 & 0 & 17.5 & .02 \end{bmatrix} \qquad A_{21} = \begin{bmatrix} .021 & 0 & .121 & .003 \\ -1.1 & 0 & -1.62 & .015 \\ 0 & 0 & 0 & 0 \\ -2.43 & 0 & 1.37 & -.034 \end{bmatrix}$$

$$A_{22} = \begin{bmatrix} -.21 & 1.0 & -1.6 & .005 \\ -1.9 & -1.8 & 9.3 & -.12 \\ 0 & 0 & 0 & 1.0 \\ -3.1 & 0 & -56. & .032 \end{bmatrix} \qquad A_{23} = \begin{bmatrix} .06 & 0 & .46 & .002 \\ -1.0 & 0 & 1.49 & .04 \\ 0 & 0 & 0 & 0 \\ .12 & 0 & 29.8 & -.029 \end{bmatrix}$$

$$A_{31} = \begin{bmatrix} -.002 & 0 & .083 & 0 \\ -6.78 & 0 & -10.1 & .09 \\ 0 & 0 & 0 & 0 \\ -1.24 & 0 & .498 & -.017 \end{bmatrix} \qquad A_{32} = \begin{bmatrix} .011 & 0 & .22 & 0 \\ -2.1 & 0 & 1.7 & -.123 \\ 0 & 0 & 0 & 0 \\ .07 & 0 & 6.37 & .011 \end{bmatrix}$$

$$A_{33} = \begin{bmatrix} -.197 & 1.0 & -1.2 & -.003 \\ -54.4 & -20. & 70.1 & -2.37 \\ 0 & 0 & 0 & 1.0 \\ -3.4 & 0 & -21. & -.017 \end{bmatrix}$$

$$B^T = \begin{bmatrix} 0 & 36.1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 78.9 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1000 & 0 & 0 \end{bmatrix}$$

Simulation Results and Discussion

Using the eigenstructure assignment technique given in previous section, the control strategy for the multimachine power system has been solved.
Let the closed-loop eigenvalues be assigned at the following locations : -12, -14, -18, -16, -15, -17, -19, -10, -11, -12, -13, and -14. The corresponding eigenvectors are

$$v_1 = \begin{bmatrix} 0.3441 & 0.2415 & 0.1374 & 0.1786 \\ -3.8136 & -3.1586 & -2.3471 & -2.6937 \\ -0.0086 & -0.0048 & -0.0018 & -0.0028 \\ 0.1027 & 0.0667 & 0.0323 & 0.0455 \end{bmatrix}$$

$$v_2 = \begin{bmatrix} 0.3994 & 0.3064 & 0.2425 & 0.9522 \\ -5.9153 & -5.1501 & -4.5590 & -9.3656 \\ -0.0054 & -0.0032 & -0.0020 & -0.0279 \\ 0.0804 & 0.0547 & 0.0389 & 0.2787 \end{bmatrix}$$

$$v_3 = \begin{bmatrix} -24.5191 & -26.1823 & -29.7896 & -37.1520 \\ 265.5664 & 309.6585 & 382.0160 & 513.4842 \\ 0.5879 & 0.5402 & 0.5337 & 0.5927 \\ -6.4664 & -6.4822 & -6.9381 & -8.1584 \end{bmatrix}$$

The feedback gain matrices for each machine are found to be

$$K_1 = [\ -33.9341 \quad -1.5584 \quad -126.9983 \quad 54.9892\ ]$$

$$K_2 = [\ -17.1698 \quad -0.7481 \quad 167.8498 \quad 53.8996\ ]$$

$$K_3 = [\ -0.8490 \quad -0.0298 \quad 1.4154 \quad 1.96980\ ]$$

Now, we study the dynamic behaviour of the system for coupled and decoupled modes respectively. The respective closed-loop responses obtained from a digital simulation of the system, are presented in Figs. 3 and 4 for decoupled system and Figs. 5 and 6 for coupled system.

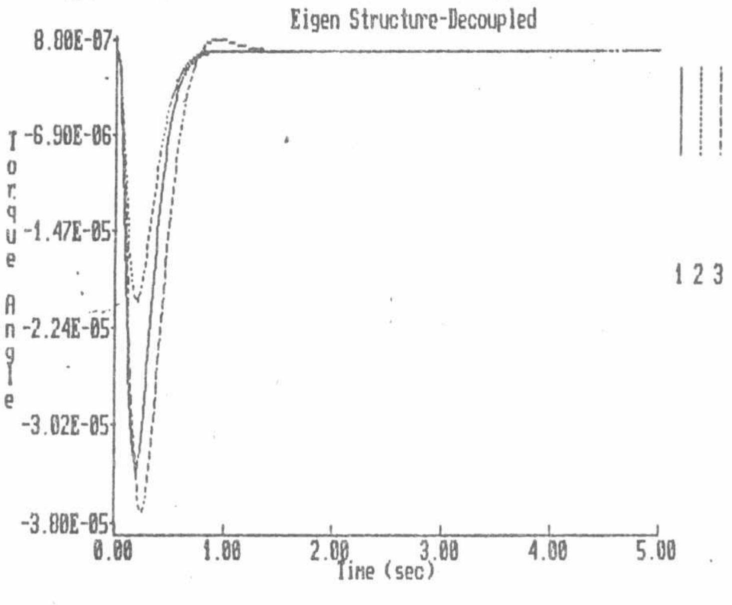

Fig. 3

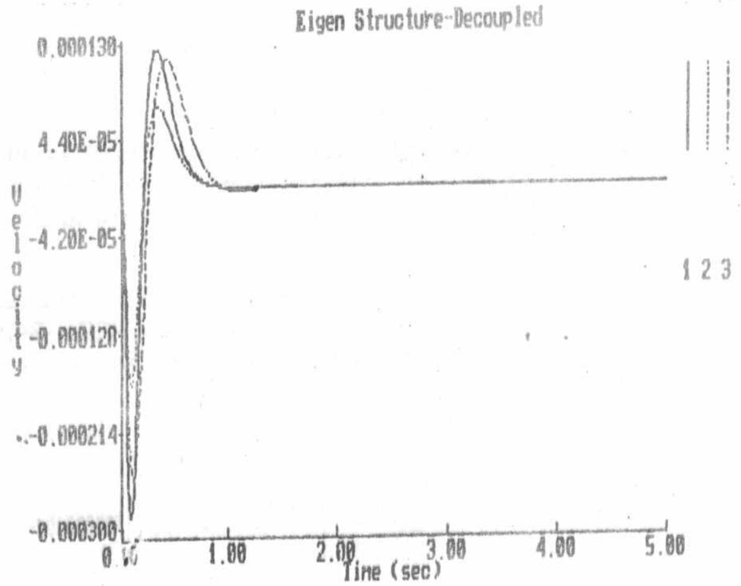

Fig. 4

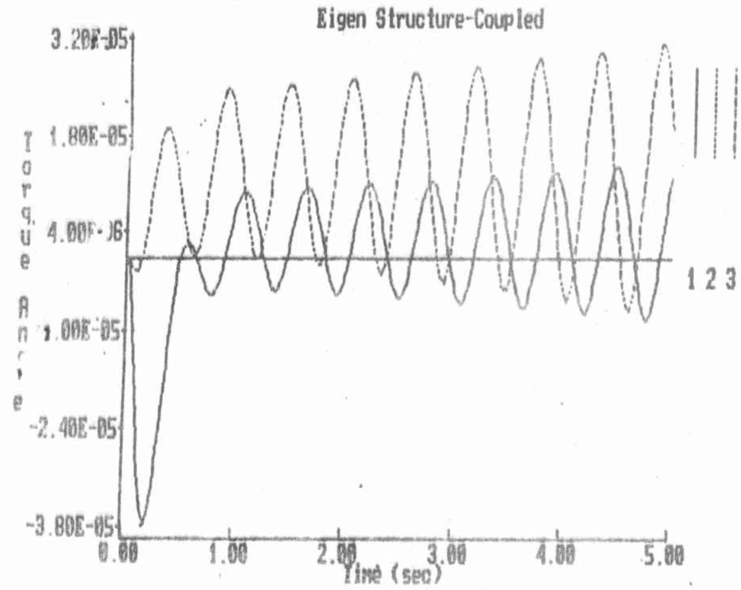

Fig. 5

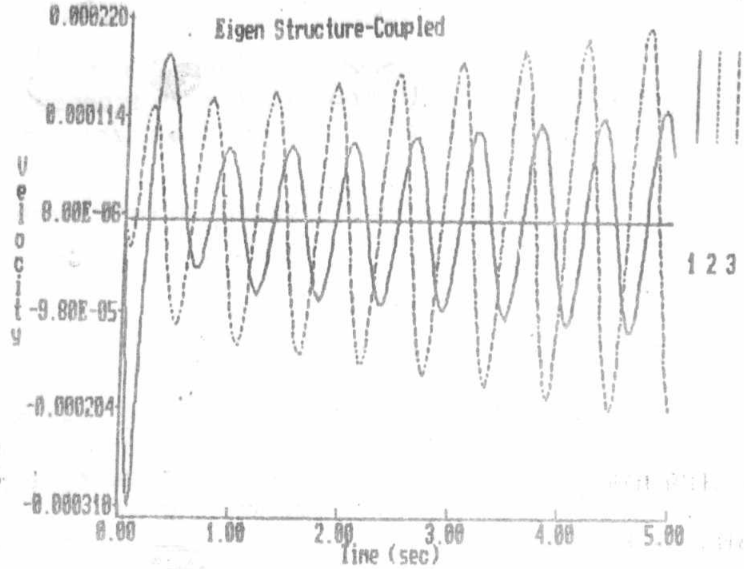

Fig. 6

From the above results, we can see that the decoupled system reaches steady state faster than ever, and in the case of coupled system, the oscillation is increased and the rate of convergence is very small as observed in Figs. 5 and 6.

To improve the system behaviour in the coupled mode, the closed-loop eigenvalues be reassigned at the following locations : -19, -21, -17, -23, -20, -22, -24, -15, -18, -17, -19, and -16. The coresponding eigenvectors are given below

$$v_1 = \begin{bmatrix} 0.1560 & 0.1220 & 0.0979 & 0.0804 \\ -2.5086 & -2.2050 & -1.9666 & -1.7744 \\ -0.0022 & -0.0015 & -0.0010 & -0.0007 \\ 0.0382 & 0.0276 & 0.0205 & 0.0157 \end{bmatrix}$$

$$v_2 = \begin{bmatrix} 0.2177 & 0.1784 & 0.1488 & 0.3994 \\ -4.3114 & -3.8885 & -3.5409 & -5.9153 \\ -0.0017 & -0.0011 & 0.0008 & -0.0054 \\ 0.0332 & 0.0248 & 0.0190 & 0.0804 \end{bmatrix}$$

$$v_3 = \begin{bmatrix} 193.9 & -132.5 & 27.3 & 50.3 \\ -3260.7 & 2095. & -513.9 & -896.3 \\ -2.1 & 1.6 & -0.2 & -0.5 \\ 36.2 & -26. & 4.6 & 8.9 \end{bmatrix}$$

The feedback gain matrices are found to be

$$K_1 = [\ -62.4876 \quad -2.1124 \quad 149.5602 \quad 151.5222\ ]$$

$$K_2 = [\ -30.6228 \quad -1.0015 \quad 593.3848 \quad 130.4662\ ]$$

$$K_3 = [\ -1.7447 \quad -0.0498 \quad 16.1768 \quad 5.8418\ ]$$

The coupled system responses in this case are shown in Figs. 7 and 8, it can be seen that important system variables are will regulated, convergences to the steady state values is fast, and the overshoots are in within acceptable bounds.

The results clearly show the applicability of the proposed control scheme to a multimachine power system.

Conclusions

A direct method for governing the damping of a multimachine system in a decentralized fashion has been given. The effect of increasing the overall damping in the value of the feedback gains has been demonstrated and the results show the superiority of such approach over the known optimal method.

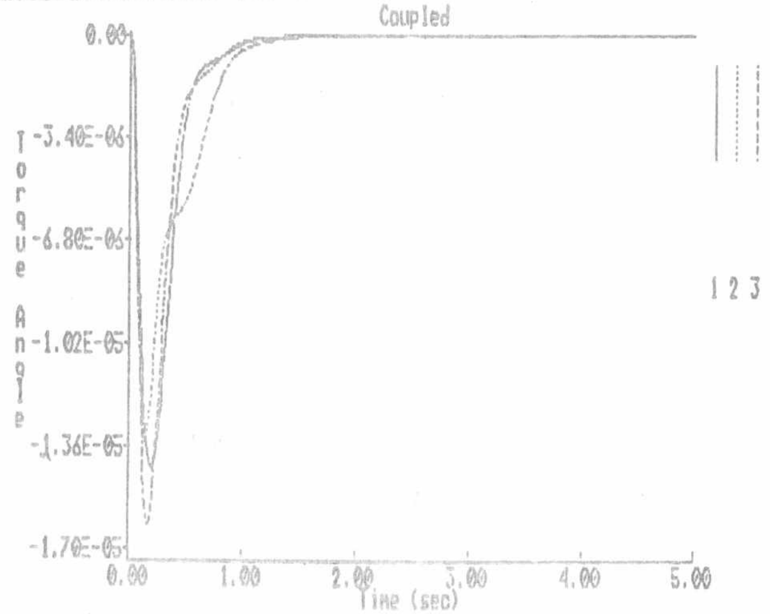

Fig. 7

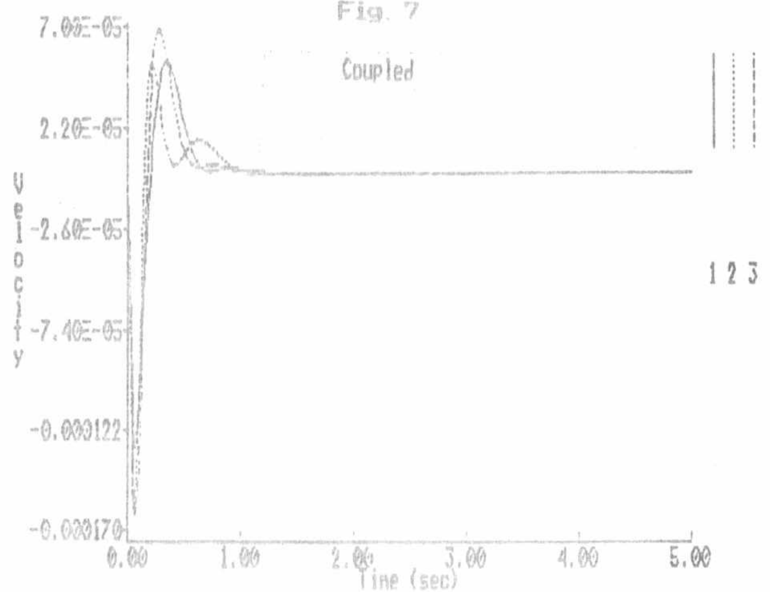

Fig. 8

References

1- Y.N. Yu, K. Vongsuriya, and L.N. Wedman,"Application of an Optimal Control Theory to a Power System", IEEE Trans. Power App. & Sys., Vol. PAS-89, pp. 55-62, Jan. 1970.

2- E.J.Davison and N.S.Rao,"The Optimal Output Feedback Control of a Synchronous Machine", IEEE Trans. Power App. & Sys., Vol. PAS-90, pp. 2123-2134, Oct. 1971.

3- B.S.Habibullah,"Optimal Governor Control of a Synchronous Machine", IEEE Trans. on Automatic Control, Vol. AC-26, No.2, pp. 391-395, April 1981.

4- H.A.M.Moussa and Y.N.Yu,"Optimal Power System Stabilization Through Excitation and/or Governor Control", IEEE Trans. Power App. & Sys., Vol PAS-91, pp. 1166-1174, 1972.

5- M.M.Fahmy and J.O'Reilly,"On Eigenstructure Assignment in Linear Multivariable Systems", IEEE Trans. Automatic Control, Vol. AC-27, pp. 690-693, June 1982.

6- V.H.Chow and J.J.Sanchez-Gasca,"Pole Placement designs of Power Stabilizers", IEEE Trans. on Power Sys., Vol. 4, No 1, Feb. 1989.