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MILITARY TECHNICAL COLLEGE

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PRACTICAL IMPLEMENTATION OF DECENTRALIZED STABILIZERS FOR AN INTERCONNECTED POWER SYSTEM

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ABSTRACT

This paper deals with a problem of dynamic instability facing a real power system .Evidence of a problem arose in studies of a proposed generationexpansion of the system using a comprehensive non-linear dynamic simulation for the system.

The procedure followed to stabilize such non-linear system was to linearize the system into state space form and to use modal control approach and an optimization approach to design the stabilizers.Two alternative solutions are illustrated ; the first is based on the centralized approach in which a single stabilizer controlling the whole system is designed, and the second is based on a decentralized approach in which local-controllers are designed for the individual machines.

Dynamic simulation tests, again on the non-linear dynamic simulation confirm the effectiveness of the alternative approaches.

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I. INTRODUCTION

Stability is still one of the major problems encountered in power system operation. Several basic system design and control methods[1] have been developed to cope with these problems ;however they still remain in many systems and new methods may prove useful. In practice auxiliary stabilizing signals based on shaft speed or rotor angle measurements working into the excitation systems are emoployed to enhance the stability of individual machines. The successful application of the stabilization methods available has been somewhat "ad hoc". Modern optimal control and state feedback methods have been suggested[2,3] but have not been adopted by the industry largly due to the conputaional problems associated with handling multi-machine systems on-line and the reliability problems associated with the communication of state variables and control signals between individual machines and the centralized controller.

These difficulties imposed by centralized controller concept can be alleviated by treating the entire large system in terms of several interconnected subsystems in which the stabilization and interaction effects are considered succesively for each subsystem.

The stabilization techniques for large scale systems can be classified into two groups[4] termed the hierarchical approach and the decentralized aproach, respectively.

A. Hierarchical (multilevel) Stabilization Approach

The main function of the hierarchical control approach is to generate two signals; the first is to keep each subsystem as independent as possible, and the second is to stabilize each local subsystem using a decentralized controller. This appraach requires the transmission of state variables of each subsystem to the higher level controller however, so has the attendant disadvantages. These problems can be overcome using the completely decentralized stabilization approach.

B. Decentralized Stabilization Approach

The main idea behind the decentralized approach is to implement several decentralized (or local) controllers, each utilizing only locally measured states and applying control locally.

In this paper the decentralized stabilization problem for a real five plants infinite bus power system is presented and solved by formulating the stabilization problem into a functional minimization problem.

II. PROBLEM STATEMENT

2.1 Real Network Configuration

Figure 1 shows the essential feactures of a real 30 KV multi-machine power system. Load flow results indicate that most of the power delivered to the loads (8-14) is coming through the double-circuit underground cable (7-8). This is a weak link in the system and subject to frequent faults.

The generating units at all plants are identical and their excitation systems have the same voltage-response-ratios. The turbines, governors, and boilers are not modelled because of relatively large time constants associated with their dynamic responses. All of the power plants are equiped with rotating type excitation systems, represented by IEEE type 1, shown in Fig. 2.

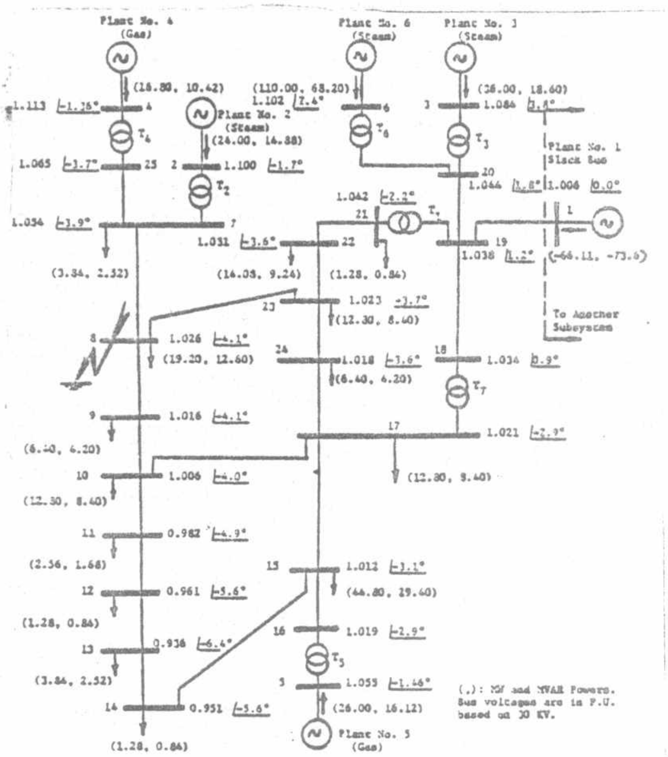

Fig. 1 Five Plants/Infinite bus 30 KV-Real System

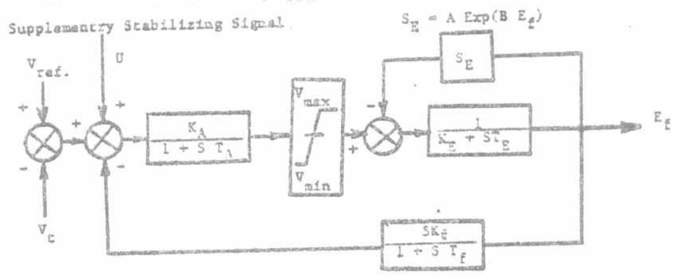

Fig. 2 IEEE Type 1 Rotating Excitation System

Data for the machines and their exciters are given in Tables I&II

Table I: Machine Data (In P.U. Based on 100 MVA)

Plant #	H	Ra $\times 10^{-4}$	R_f	X_f	X_{fd}	X_ℓ	X_d	X'_d	X_q	X'_q	T'_{do}	T'_{qo}	D	A $\times 10^{-4}$	B
1	10^7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	4.0	16	10	1.0	1.1	0.1221	1.4360	0.2363	1.4021	0.9611	6.60	0.20	2.0	4.92	7.1792
3	2.5	25	10	1.0	1.1	0.0550	0.8105	0.1428	0.7565	0.2779	6.10	0.30	2.0	1.12	7.30
4	1.13	32	10	1.0	1.1	0.3103	2.8946	0.5372	2.8251	1.6557	4.750	1.50	2.0	7.32	6.6891
5	1.10	23	10	1.0	1.1	0.070	1.20	0.20	1.20	0.30	6.30	0.250	2.0	2.0	7.20
6	2.80	27	10	1.0	1.1	0.1027	1.0533	0.180	1.0	0.18	4.40	1.50	2.0	2.346	6.0610

Table II: Excitation System Parameters (In P.U.)

Plant #	K_A	K_E	K_F	T_A	T_E	T_F	V_{max}	V_{max}	A	B
1	-	-	-	-	-	-	-	-	-	-
2	57.14	-0.0445	0.080	0.05	0.05	1.0	-1.0	1.0	0.0012	1.2096
3	25.0	-0.0582	0.105	0.20	0.6544	0.35	-1.0	1.0	0.0015	1.5833
4	400.0	1.0	0.030	0.02	0.253	1.0	0.0	7.30	0.0983	0.2972
5	400.0	1.0	0.030	0.02	0.253	1.0	0.0	7.30	0.0983	0.2972
6	225.0	1.0	0.75	0.05	0.952	0.02	-3.84	3.84	0.0322	0.8514

2.2 Network Reduction of System

To simulate the system dynamically, it is required to represent the power network by an equivalent admittance matrix seen by the generating units. Kron's technique was applied to eliminate all the interior buses and keep only the generator buses as shown in Fig.3. The equivalent admittance matrix is given in Table III.

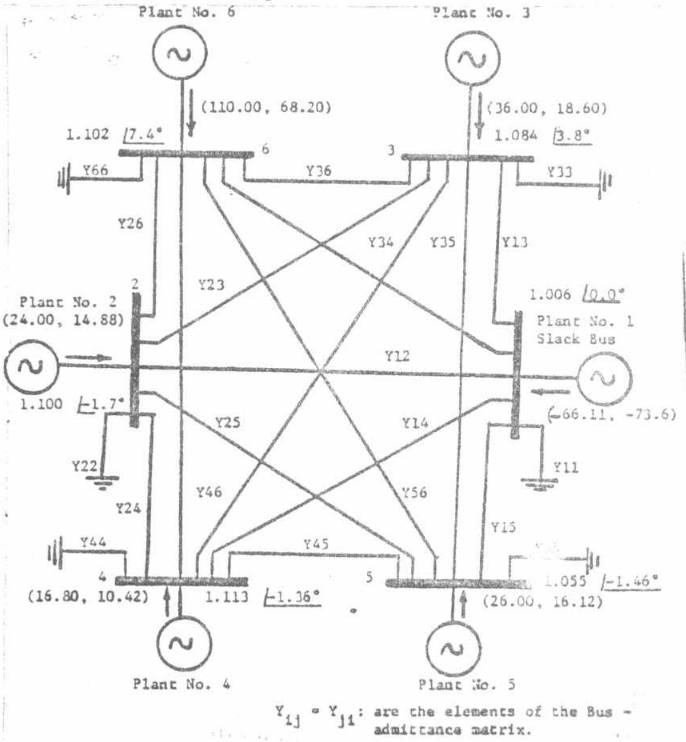

Fig. 3 Five Plants/Infinite-bus Reduced

Table III
Equivalent Generator Bus Admittance Matrix

1.5583 -J11.0398	-0.1429 +J0.6976	-0.3828 +J4.0486	-0.0933 +J0.3891	-0.2549 +J1.5058	-0.4113 +J4.3504
-0.1429 +J0.6876	0.4080 -J3.1117	0.0059 +J0.2459	0.1945 +J1.2456	-0.2026 +J0.6252	0.0064 +J0.2642
-0.3828 +J4.0486	0.0059 +J0.2459	0.2040 -J7.0337	-0.0009 +J0.1401	0.0327 +J0.5339	0.2192 +J2.1489
-0.0933 +J0.3891	0.1945 +J1.2456	-0.0009 +J0.1401	0.1845 -J2.2813	-0.1263 +J0.3525	-0.0010 +J0.1506
-0.2549 +J1.5058	-0.2026 +J0.6252	0.0327 +J0.5339	-0.1263 +J0.3525	0.9278 -J3.7439	0.0352 +J0.5737
-0.4113 +J4.3504	0.0064 +J0.2642	0.2192 +J2.1489	-0.0010 +J0.1506	0.0352 +J0.5737	0.2355 -J7.5919

The system is subject to a three-phase-to-ground fault at bus no. 8, for a time duration of three cycles (.05 sec.).

2.3 Simulation Results Without Supplementary Stabilizing signals

A simulation program has been developed [5] to study the effects of generators, excitation systems and turbine-governors on power system dynamic stability. Although the fault clearing time was relatively short, simulation results show that large swings in the rotating mases were developed, (Fig.4), and synchronism between the power plants was lost.

III PROBLEM SOLUTION

Developing stabilizing signals for the non-linear system is a very difficult task, therefore the dynamic performance of the system is approximated by a linearized model. The validity of the controller design based on the linearized model is checked by using it in the non-linear simulation.

The system dynamics is represented in the state-space form as

$$\dot{X} = AX + BU \quad , \quad Y = CX \tag{1}$$

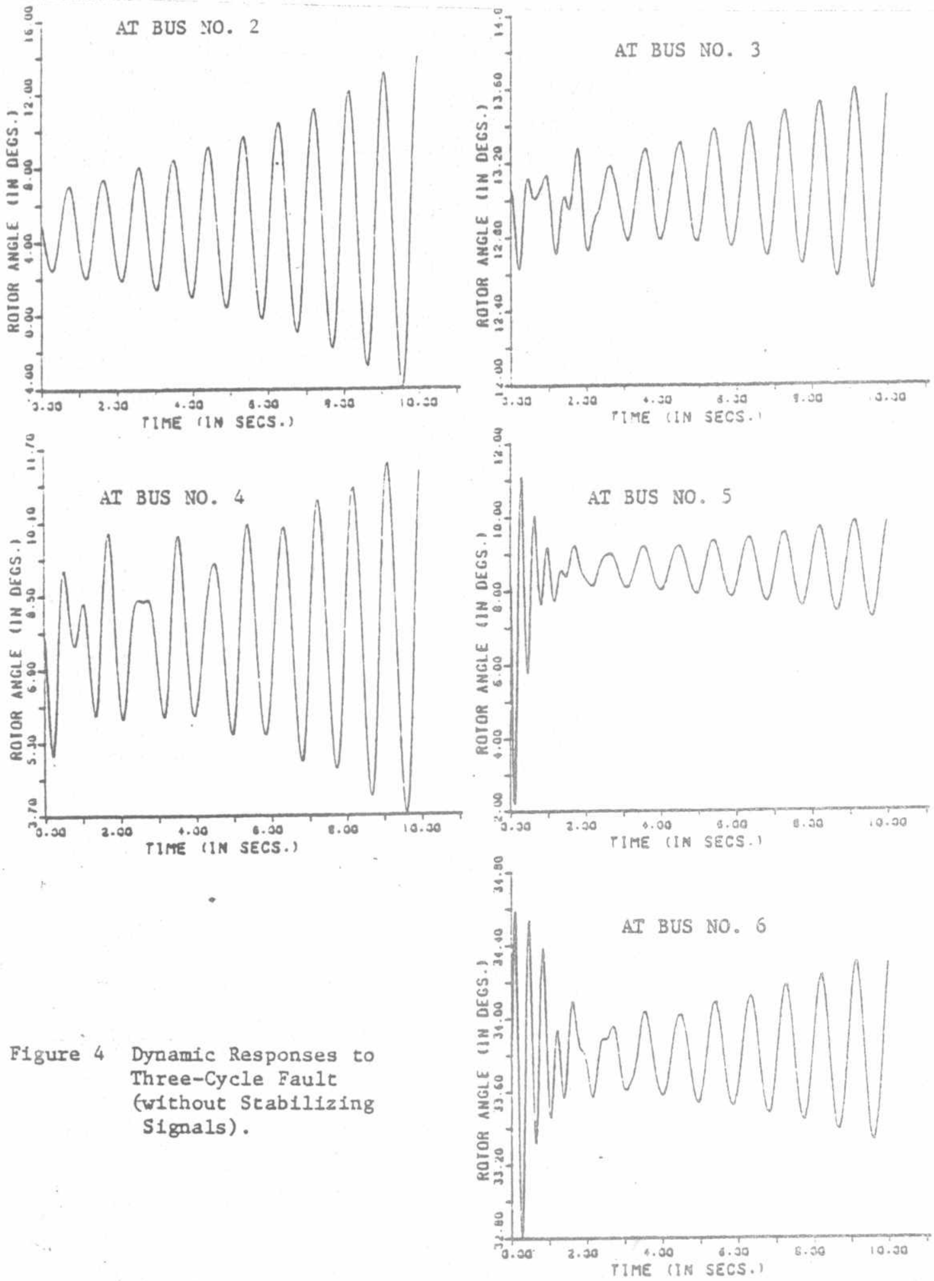

Figure 4 Dynamic Responses to Three-Cycle Fault (without Stabilizing Signals).

where $X = [X_2^T \dots X_6^T]^T$ is nxl state vector, the state vctor for machine i is $X_i = \Delta[\psi_f, \omega, \delta, E_f]^T$. The matrices A, B&C are of dimensions nxn, nxm &lxn respectively. The vectors U&Y are of dimensions m&l resp.

The nomenclature of the machine parameters have adequately been described in the referenced papers so that details will not be repeated here.

3.1 Inplementation of a Centralized Controller

The necessary and sufficient condition for finding a state-feedback matrix, G, to assign the eigenvalues of the closed loop (A + B K), is that systen(1) be controllable. The state feedback G is chosen to have the dyadic form $G = fd^T$. The desired poles are:

$-1.2\pm j28.6, -1\pm j17.6, -1.7\pm j10.1, -.91\pm j8.9, -1\pm j4.9, -2.9\pm j1.2, -.87\pm j.7, -.99\pm j.5, -1., .84, -.8, -.7$
and the "G"matrix has been obtained, using modal control theory[6] such that the controller feeds one stabilizing signal to plant 2.

G=[-47.5, 5.6, -37.6, -2.1, -5.9, 3, 54.1, 1168.8, -64., 4.3, -71.9, -20.7, 185.2, 3.4, 129.4, 32.6, -66.8, -1.8, -32.9, -55.6]

To check the effectiveness of this procedure, this stabilising signal was applied in the nonlinear simulation model. Simulation results (Fig.5) indicate that the controller is quite effective in pushing the dominant eigenvalues to the desired location with a degree of stability .7 .

Although the centralized controller was effective in damping the system oscillations, there are some difficulties (cost, reliability) which stand against its application in the field. Therefore, it is essential to look for an alternative solution to overcome these difficulties.

3.2 Designing of a Decentralized Controller

The system described by (1) can be decomposed into N interconnected subsystems as follows:

$$\begin{bmatrix}\dot{X}_1\\ \vdots \\ \dot{X}_N\end{bmatrix} = \begin{bmatrix}A_{11} & A_{12} & \cdots & A_{1N}\\ \cdots & \cdots & \cdots & \cdots\\ A_{N1} & A_{N2} & \cdots & A_{NN}\end{bmatrix}\begin{bmatrix}X_1\\ \vdots \\ X_N\end{bmatrix} + \begin{bmatrix}B_1 & & \\ & \ddots & \\ & & B_N\end{bmatrix}\begin{bmatrix}U_1\\ \vdots \\ U_N\end{bmatrix} \qquad (2)$$

The problem is to design decentralized state feedback controller

$$U_i = K_i X_i \qquad i=1\ldots N \qquad (3)$$

Such that the overall system $\dot{X} = (A + BK)X$ is stable. Where

$$K = \text{block diag}[K_1 \ldots K_N] \qquad (4)$$

The necessary and sufficient condiction for solving such problem is that the system must be free from unstable decentralized fixed poles[7].

3.2.1 Minimization Algorithm

From [8], the negativity of the functional (see nomenclature)

$$J = \| \gamma I + A + BK \|_E \qquad \text{for } \gamma > 0 \qquad (5)$$

represents a sufficient condition for stability of system (1). If the functional (5) can be reduced below zero, then the closed-loop system is stable. However, the eigen-value theorem indicates that :

$$\max_i [\text{Re}\ \lambda_i (A + BK)] \leq \lambda_{\max_i} \frac{(A+BK)+(A+BK)^T}{2} \qquad (6)$$

Thus the system degree of stability canbe improved by reformulating equation (5) as follows;

$$J = \left\| \gamma I + \frac{(A+BK)+(A+BK)^T}{2} \right\|_E - \gamma \quad \text{for } \gamma > 0 \qquad (7)$$

Hence, the stabilization problem can be formulated as follows; find the matrix K of the controller parameters which minimizes the functional(7). This is an optimization problem the solution of which yields the required design.

For the sake of accuracy and speed, a minimization algorithm which utilizes the functional J and its gradient was used . The functional J is given by(7) and its gradient with respect to the gain K is computed as follows

Define $D = \gamma I + ((A+BK) + (A+BK)^T)/2$ (8a)

$$J = \|D\|_E - \gamma = \sqrt{tr(DD^T)} - \gamma \qquad (8b)$$

thus $\Delta J = tr(D^T \cdot \Delta D)/2\sqrt{tr(D.D^T)}$

or $\Delta J = tr(D^T.B.\Delta K + D^T(B.\Delta K)^T)/4\sqrt{tr(DD^T)}$ (9)

Hence, $\partial J/\partial K = B^T(D+D^T)/4\sqrt{tr(DD^T)}$ (10)

The negativity of the functional(7) is a sufficient condition for stability, consequently it gives unnecessarily high gains for the matrix K. To overcome this difficulty, the functional is reduced iteratively and in each iteration, stability is checked by a standerd subroutine.

Executing the above optimization problem, a full matrix K , is obtained, not a block diagonal form(4) as required decentralization.

To satisfy this constraint, the method of feasible directions [4] was used as follows:

a) Start the minimization iteratively with K of the form(4), (called a feasible form). Arrange K column-wise containing non-zero elements corresponding to that of the block diagonal matrices(4) and zeros elsewhere.

b) The direction d (gradient(10) arranged column-wise) needed for minimization has to be modified to the feasible form. This can be done by premultiplying d by a matrix H, where H is a diagonal matrix of entries either 1's or 0's so as to reflect the block diagonal constraint in the minimization algorithm.

A proof given in [4] shows that if d is replaced by Hd , this minimizes J also, i.e. the algorithm still works.

3.3 Implementation of a Decentralized Controller

The control strategy described above was applied to stabilize the five plants/infinite bus system of Fig.1. The stability check was satisfied after seven iterations, and the closed loop eigenvalues with the decentralized control are;

-541.4, -535.9, -1.2±j28.6, -.2±j17.6, -14.4, -11.9, -1.7±j10.7, -.1±j10.1, -.8±j5.8, -7.8, -2.2, -.6, -.43, -.41, -.396

The diagonal rows in the controller matrix were found to be:

$K_2 = [-47.99, 5.4, -38.6, -2.4]$

$K_3 = [-1.8E-3, 9.3E-6, -1.1E-3, 2.96]$

$K_4 = [2.5E-4, 4.9E-4, -2.8E-2, -9.02e-2]$

$K_5 = [2.4E-2, 5.7E-4, 1.98E-2, -8.6]$

$K_6 = [-.28, 8.1E-4, -.36, -10.6]$

The dynamic responses from the non-linear simulation, for the same fault, with implementation of the obtained decentralized signals are shown in Fig.6. Figure 6 illustrates the success of the designed controllers in improving the damping of the multi-machine system.

IV. CONCLUSION

A simple algorithm has been developed for solving the problem of constructing static decentralized controllers to stabilize an interconnected power system. The degree of stability which can be achieved and the speed of solution of the problem depend mainly upon the number of iterations and on the chosen initial condition. Besides the advantage of applicability, decentralized controllers are more reliable and less costly than the centralized ones, since they don't require extra installations for information exchange . It is obvious from Fig. 6, that the decentralized controllers have imposed additional damping by reducing the amplitude of the first swings and the fast decay of the low frequency oscillations.

V. NOMENCLATURE

$\|(.)\|_E$	the Euclidean norm of the matrix (.), which is the square root of the sum of the squares of the elements of (.).
$\rho(.)$	the spectral radius of (.) i.e. the eigenvalue of (.) having the largest absolute value.
tr(.)	the trace of (.) i.e. the sum of its diagonal elements.
T	Superscript denoting matrix transpose.

VI. REFERENCES

1. Byerly, R.T. and Kinbark, E.W(eds)"Stability of Large Electric Power Systems"IEEE Press, New York, (1974)
2. Yu, Y.N. and Siggers, C"Stabilization and Optimal Control Signals for a Power System" IEEE Trans. Power Appar.Syst., 90, 1469-81 (1971)
3. Yu, Y.N. and Moussa, H.A.M."Optimal Stabilization of a Multi-Machine System" ibid, 91, 1174-82 (1972)
4. Soliman, H.M. and Fleming R.J."Minimal Order Decentralized Stabilizers for Interconnected Power Systems" Int. J.Sys.Sci. 14, 765-76 (1983)
5. Podmore, R"Power System Dynamic Simulation Program-User's Manual"Department of Elect.Engg., University of Saskatchewan Canada (1974)
6. Porter, B. and Crossly, R"Modal Control-Theory&Applications" Taylor and Francis Ltd., London (1972)

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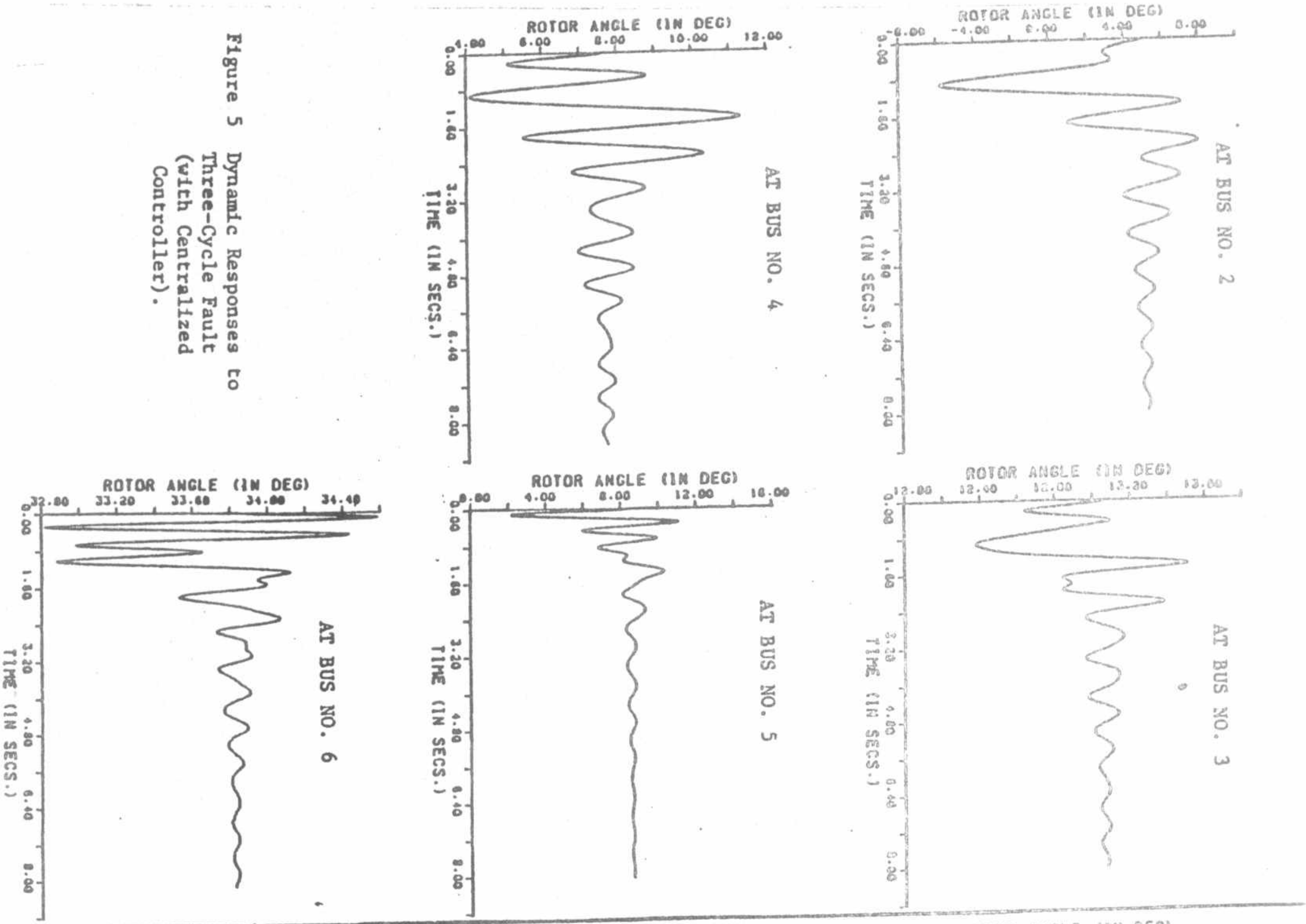

Figure 5 Dynamic Responses to Three-Cycle Fault (with Centralized Controller).

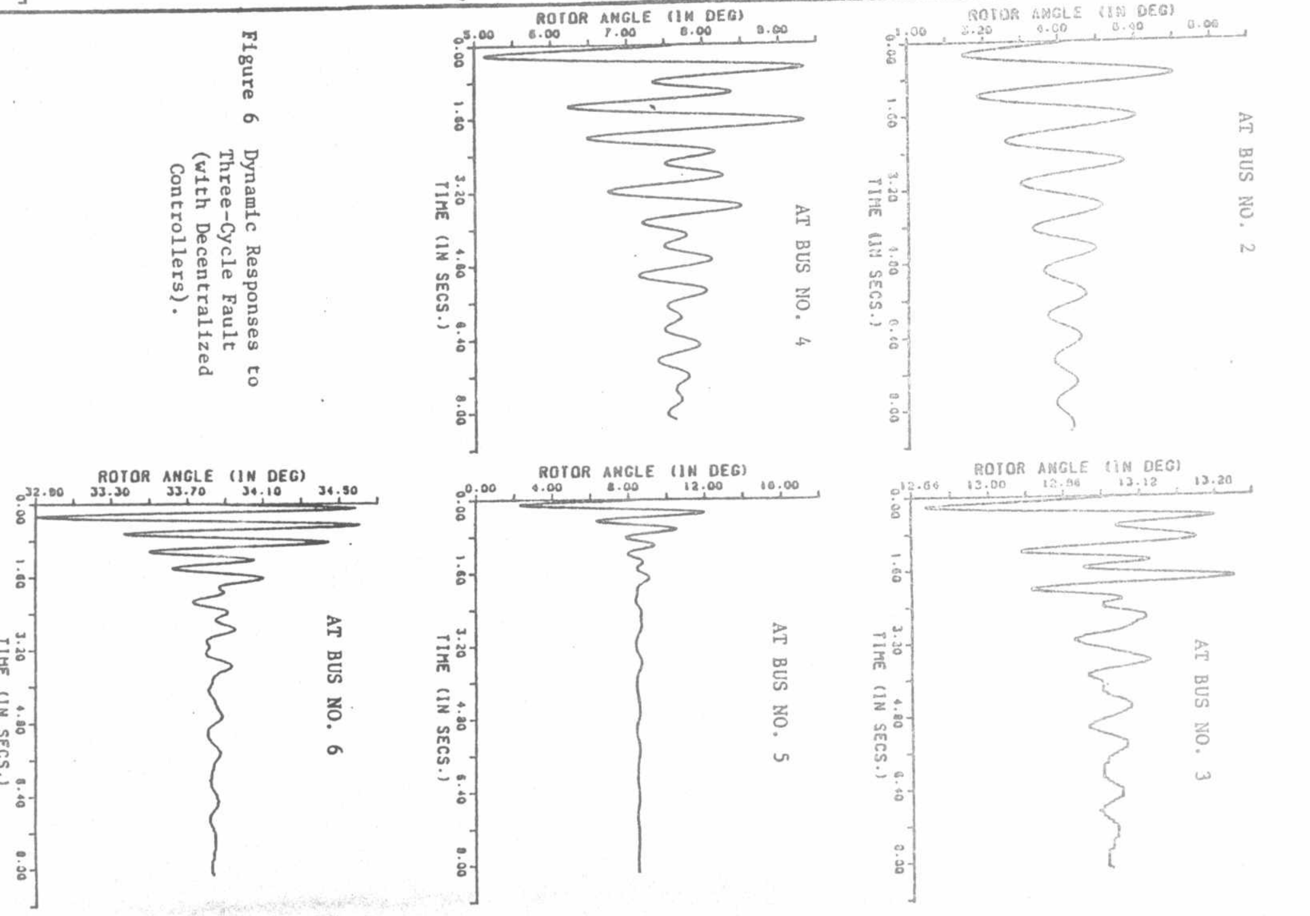

Figure 6 Dynamic Responses to Three-Cycle Fault (with Decentralized Controllers).

7. Wang, S.W. and Davison, E.J" On the Stabilisation of Decent. Control Systems"IEEE trans on Autom. Cont., 18, 473-78, 1973
8. Miller, L.F"Output Feedback Stabilisation by Minimization of a Spectral Radius Functional"Int. J. Cont. 27, 455-62, 1978