DECENTRALIZE CONTROL FOR STABILIZING THE U.P.S. OF EGYPT

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ABSTRACT

This paper deals with the application of decentralized optimal model control for solving the problem of stabilization of the unified power system (U.P.S) of Egypt. The design technique of the decentralized control system is based modelling the interaction of each subsystem with the other ones, through the way of construction of a low-order model including the dominant modes only. Using an optimal-model control technique; a set of locally decentralized controllers are designed simply by shifting the dominant eigenvalues of each subsystem sequentially to their prescribed locations. An effective stability measure is introduced for testing the connective stability of the system on implementing the decentralized controllers by using the concept of weighted sum scalar Lyapunov functions on the decomposion-aggregation principle. A digital computer simulation for the dynamical response of the disturbed system are used to verify the effectiveness to the designed decentralized controllers.

INTRODUCTION

The U.P.S of Egypt is characterized by the growing size and complexity of the large number of generating units, loads, and transmission lines that are included in the system. The system is usually subjected to structural perturbations, i.e. changes in the interconnection pattern within the system during operation, and it is necessary to bring it back to a steady-state equilibrium condition without loosing the system integrity. This is the role of system regulators which include speed and voltage regulators.

Ideally, a full dynamic centralized feedback stabilizing control signals (supper imposed on the normal regulator error signals) would be needed with a known stability region convering all practical conditions. From any state in such a region the system under control would return, preferably in some optimal manner to its stable equilibrium state. This implies complete knowledge:

- of the state of the system (normally requires state estimation),
- of its stable equilibrium (normally requires a load flow computation), and
- of the availability of computing equipment ant time to find and apply controls.

However, developing such a control encounters severs constraints in the multimachine stability condition due to the followings:

a. Optimal control requires the feedback of all the states, and the transmission of state information between geographically scattered control ares cannot be obtained fast enough within the typical control areas cannot be obtained fast enough within the typical duration of a stability crisis of an integrated large-scale power system.

b. The frequency of oscillation ranges from 0.05 to 3 Hz, thus the control must act on a fractional second time-scale.

c. The control actions require load shedding of major remote load centers.

This situation effectively rules out centralized dynamic computer control based on full system model. thus providing impetus for a decentralized control structure to achieve system wide stabilitization.

This is the subject of second of two papers dealing with the use of decentralized control for solving the problem of stabilization of the U.P.S. of Egypt during contingencies. In the first paper [1], the method of formulating the decentralized dynamical simulating model of the integrated system is analyzed in detail.

In this paper, a design approach based on interaction modelling is suggested to compute a robust block diagonal feedback matrix which provides near optimal decentralized control for stabilizing the U.P.S of Egypt.

PROBLEM FORMULATION

The state-space simulation model of the li-multimachine system included in the ith subsystem is given in details in ref. [1] and the expressed here as:

$$x_i = Ai\ xi + Bi\ Ui + Ci\ zi\ ,\ i = 1,2,3,4$$

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2. PROBLEM FORMULATION

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$$x_i = Ai\ xi + Bi\ Ui + Ci\ zi\ , \qquad i = 1,2,3,4 \qquad (1)$$

However, the dominant modes which could affect the estimated process of the interaction variables are mainly the dominant mechanical modes. The simulation results has showed minimum error in the estimated trajectories using the dominant modes only compared with the complete interaction modes.

3. THE DECENTRALIZED CONTROLLER DESIGN

The control laws for the individual subsystems equations are design 'ed by an optimal modal control technique developed originally by Solhem in [4] and improved later [5], [6], which minimizes a quadratic performance index

Sub-system No. "i"	Machine Circuit	Dominant Eigenvalue Of The Uncontrolled Subsystem Matrix Ai	Preassigned Locations For The Dominant Eigenvalues
1	(ΔW1)mode	-0.063	-0.156
	(ΔB2, ΔW2)mode	-0.027 + j 8.487 (ζ = 0.003)	-1.2 +j 7.86 (ζ= 0.15)
	(ΔB4, ΔW4)mode	-0.382 + j 3.86 (ζ = 0.09)	-1.2 +j 3.55 (ζ= 0.51)
	(ΔB5, ΔW5)mode	-0.292 + j 3.13 (ζ = 0.094)	-1.56 +j 3.0 (ζ = 0.46)
2	(ΔB7, ΔW7)mode	-0.155 + j 9.657 (ζ = 0.016)	-1.56 +j 8.81 (ζ= 0.267)
	(ΔB9, ΔW9)mode	-0.022 + j 8.797 (ζ = 0.0025)	-0.947+j 8.55 (ζ =0.101)
	(ΔB10, ΔW10)mode	-0.132 + j 8.00 (ζ = 0.016)	-0.895+j 7.98 (ζ =0.11)
	(ΔB11, ΔW11)mode	-0,067 + j 7.192 (ζ = 0.009)	-0.986+j 7.14 (ζ =0.13)
3	(ΔB13, ΔW13)mode	-0.166 + j 11.52 (ζ = 0.01)	-0.946+j 9.87 (ζ =0.1)
	(ΔB14, ΔW14)mode	-0.0624 + j 8.243 (ζ = 0.008)	-1.10 +j 7.98 (ζ =0.14)
	(ΔB15, ΔW15)mode	-0.161 + j 7.67 (ζ = 0.02)	-2.46 +j 7.46 (ζ =0.31)
	(ΔB16, ΔW16)mode	-0.048 + j 7.83 (ζ = 0,006)	-1.35 +j 6.84 (ζ =0.19)
4	(ΔB18, ΔW18)mode	-0.066 + j 9.46 (ζ = 0,005)	-0.96 +j 9.21 (ζ = 0.11)
	(ΔB19, ΔW19)mode	-0.025 + j 8.22 (ζ = 0,003)	-1.35 +j 8.00 (ζ =0.13)
	(ΔB20, ΔW20)mode	-0.273 + j 6,30 (ζ = 0,04)	-1.5 +j 6.3 (ζ =0.23)

* ζ : is the damping ratio

Table 1. Preassignment for the eigenvalues of the closed-loop subsystem matrix Ai.

eqn. (3) subject to the dynamical constraints eqn. (4) and, at the same time, insures that the closed-loop system (A_{ri} + BYi GYi) has a prescribed set of eigenvalues; typically they are the ridominant eigenvalues of the closed-loop matrix (A_i + Bi Gxi) and the and the stable eigenvalues of A_{zi}.

The weighting control matrices R_i, 1,2,3,4, are chosen t be unity matrices and the gain feedback matrices for a subsystems are calculated using the procedure describe in [5], [6] so that the closed-loop matrix (A_i + Bi Gxi obtains a set of prescribed dominant eigenvalues (Table 1 at a minimum va;lues of quadratic performance index.

To improve the estimated dynamical response of th crude interaction model, the dominant mechanical mode are shifted by using artificial damping coefficients so as t increase the damping of the dominant modes to the leve of the assigned values in the design procedures.

4. STABILITY OF THE INTERCONNECTED POWE SYSTEM

The concept of weighted sum Lyapunov function utiliz the decomposition-aggregation method [7] is introduce in this paper to where Xi is the n_i dimensional augmented state vector of the i-th subsystem, U_i is the mi-dimensional control vector, and z_i is the q_i -dimensional interaction vector. And,

$x_i = [x^i_m, E^i_{fd}, P^i_m]^T$, $U_i = [Ua^i, Ugi]T$

$z_i = [X_{1s}, X2s, ..., Xjs. ..., Xs4]T, j \neq i$

$X = [1^j, E'j_{q1}, ..., m\ jj, E'\ jqmj]\ T$; m_j are the number of units in the j-th subsystem.

The approach requires the introduction of a crude interaction model of the from; Z_i = Azi zi (2)

where Z_i is the q_i-dimensional estimated interaction vector. The rules based on the choice of the model matrix Azi by Hassan [2] was to pick up the dominant in the rows of the global matrix of the interconnected system.

Now, the standard procedure for the design of the optimal linear emulator can be modified to the augmented from:

$$J = \Sigma^4_{i=1} \int^{\infty} [\ \|Y_i\|^2_{Qi} + \|U_i\|^2_{Ri}\ ]\ dt \qquad (3)$$

Subject to : $Y_i = y_i + B_{yi} U_i$, i=1,2,3,4 (4)

where $y_i = [x_i, Z_i]^T$

investigate the dynamical stability of the global system on implementing the decentralized controllers. such an approach involves decomposition of the composite N-multimachine system into N-isolated (free) subsystems plus the interconnections between the subsystems. We take the n-th machine as the comparison machine and decomposes the system into (n-1) Lur'e-Postnikov type subsystems as:

$$X_i = \begin{bmatrix} 0 & 1 \\ 0 & -\lambda \end{bmatrix} x_i + \begin{bmatrix} 0 \\ -1 \end{bmatrix} f_i(\sigma\ i)(x)$$

$$,\ i = 1,2,..,N \qquad (7)$$

where: $x_i = \sigma in - \sigma\ in(0),\ \omega\ in]^T = [x_{1i}, x_{2i}]^T$

$\sigma i = [1\ \ 0]\ x_i$

$$fi(\sigma\ i) = \sqrt{u^{2}_{1i} + \mu^{2}_{2i}}[\sin(\sigma_i + \sigma_{in}(0) + \psi_\epsilon) - \sin(\sigma_\epsilon(0) + \psi_\epsilon)]$$

$$hi(x) = \begin{pmatrix} 0 \\ \sum_{=1,\neq n}^{N} (M\,n^{-1}\,Bnj\,fnj\,Mi^{-1}\,Bij) \end{pmatrix}$$

$\sigma_{in} = \sigma_i - \sigma_n$, $\omega_{in} = \omega_i - \omega_n$, $B_{ij} = E_i\ Ej\ Yij$

C_{ij} = Bij in(θij), Dij = Bij cos (θij)

f_{ij} = Bij [cos (σij - θij) cos (σij(0) - θij)], i,j = 1,2,..,N

μli = (M n-1 + Mi-1) Cin , μ 2i = (Mi-1 - M n-1) Din

tan Ψin = μ 2i/ μ 1i

The construction of Lyapunov function of each isolated subsystem involves two conditions.

1. Uniform damping condition (λ = Di.Mi; i = 1,2,..,.N)
2. The nonlinearity f_i (σ_i) satisfy the sector condition; i.e $.f_i$ (σ_i) is in the first and third quadrant in an interval around the origin defined by;
   $- \pi - 2 (\sigma_{in\,(0)} + \Psi) < \sigma i < \pi - 2 (\pi_{in}(0) + \Psi_{in})$

If Mn is chosen as the machine with the largest inertia, this condition is likely to be satisfied.

The Lyapunov function for each isolated subsystem is

$$V\ i\ (xi) = 1/2\ (\lambda^{2}\ X1i2 + \lambda\ x1i\ x2i + x2i2) + \int_0^{x\ 1i} fi\ (\sigma_i)\ d\ \sigma$$

i (8)

The weighted sum scalar Lyapunov function is then defined for the composite system as:

$$V\ (x) = \Sigma_{i=1,=n}^{N}\ \alpha\ i\ V\ i\ (xi),\ \alpha_i\ 0\ (\ i= 1,2,..,N) \qquad (9)$$

Theorem [8] : The equilibrium x - o of the composite system (7) is asymptotically stable in the large (a.s.i.1) if the following conditions are satisfied:

i. Each free subsystem is a.s.i.1.
ii. A real N x N matrix D = $[d_{ij}]$ is an M-matrix,

For the proof, the reader is referred to Michel [8], where

Table 2. Elements of D-matrix (D = $[d_{ij}]$); d_{ij} x 10^{-5}

5.324	-.739	-1.961	-1.400	-1064	-.287	-1.483
-10.130	14.508	-1.673	-.954	-.905	-.244	-1.262
-10.364	-709	-10.617	-1.546	-1.519	-.397	-2.069
-10.151	-.647	-2.123	30.991	1.370	-.343	-1.733
-10.229	-.559	-2.293	-1.536	39.582	-.405	-1.972
-10.301	-.582	-2.505	-1.566	-1.615	-.451	35.659
-10.099	-.613	-1.337	-1.076	-1077	-.301	-1.564
-10.429	-.721	-2.374	-1.910	-1.008	-.643	-1.860
-10.040	-.603	-1.668	-.969	-.931	-.260	-1.304
-10.227	-.556	-2.255	-1.445	-1.549	-.463	-2.023
-10.064	-.609	-1.733	-1.22	-1015	-.285	-1.387
-10.214	-.640	-2.101	-1.190	-1.389	-.405	-1.905
-10.056	-.506	-1.707	-.984	-.974	-.271	-1.361
-10.137	-.537	-2.005	-1.256	-1.204	-.347	-1.753
-10.121	-.525	-1.906	-1.138	-1.131	-.318	-1.625
-10.082	-.516	-1.796	-1.067	-1.032	-.287	-1.474
-10.117	-.625	-1.393	-1.129	-1.116	-.312	-1.604
-10.041	-.604	-1.679	-.986	-.910	-.256	-1.317
-10.029	-.600	-1.636	-.947	-.896	-.244	-1.251
-10.141	-.633	-.972	-1.194	-1.131	-.333	-1.707

Table 2. Contd.

-.396	-2.142	-.189	-1.067	-.267	-.486	-.197
-.337	-1.822	-.162	-.908	-.277	-.400	-.167
-.548	-2.943	-.260	-1.488	-.371	-.677	-.272
-.461	-2.536	-.236	-1.308	-.331	-.491	-.233
-.533	-2.904	-.251	-1.556	-.382	-.754	-.273
-.386	-2.134	-.189	-1.087	-.271	-.505	-.196
-.671	-3.388	-.292	-1.675	-.415	-.857	-.318
42.724	-2.248	-.197	-1.119	-.278	-.563	-.213
-.818	37.967	-.411	-2.295	-.568	-1.203	-.426
-.352	-1.927	37.948	-.959	-.241	-.413	-.177
-.571	-3.181	-.278	38.561	-.890	-1.291	-.406
-.377	-2.064	-.183	-1.504	38.262	-.583	-.219
-.561	2.956	-.225	-2.063	-.495	35.370	-.606
-.374	-2.004	-1.177	-1.112	-.279	-.733	34.555
-.494	-2.572	-.241	-1.401	-.359	-.660	-.369
-.452	-2.377	-.208	-1.234	-.308	-.697	-.284
-.402	-2.146	-.192	-1.093	-.275	-.524	-.231
-.440	2.341	-.204	-1.188	-.295	-.628	-.252
-.353-	1.908	-.1741	-.958	-.242	-.396	-.186
-.336	-1.852	-.166	-.911	-.230	-.412	-.172
-.472	2.498	-.219	1.277	-.319	-.687	-.281

Table 2. Contd.

-.882	-.524	-.403	-.469	-.252	-.175	-.525
-.755	-.445	-.344	-.396	-.225	-.151	-.530
-1.210	-.718	-.551	-.641	-.358	-.239	-.854
-1.074	-.609	-.477	-.533	-.320	-.215	-.719
-1.152	-.697	-.525	-.626	-.334	-.222	-.829
-.852	-.506	-.386	-.452	-.294	-.166	-.601
-1.394	-.843	-.636	-.757	-.403	-.268	-1.002
-.937	-.559	-.422	-.498	-.259	-.179	-.562
-1.753	-1.059	-.795	-.950	-.500	-.132	-1.256
-.794	-.463	-.357	-.410	-.235	-.157	-.549
-1.367	-.795	-.587	-.691	-.364	-.239	-.919
-.374	-.510	-.388	-.449	-.249	-.166	-.600
-1.373	-.883	-.593	-.765	-.322	-.207	-.995
-.971	-.550	-.408	-.470	-.255	-.168	-.629
29.167	-1.325	-.931	-.912	-.555	-.335	-1.259
-1.803	34.282	-1.416	-1.453	-.727	-.417	-2.040
-1.373	-1.417	37.747	-1.316	-.733	-.418	-1.879
-1.434	-1.533	-1.419	36.399	-1.170	-.719	-1006
-1.013	-.785	-.764	-.991	33.540	-.407	-1.568
-.864	-.579	-.518	-.673	-.460	22.376	-.872
-1.702	-1.959	-1.855	-2.797	-1.705	-.796	38.577

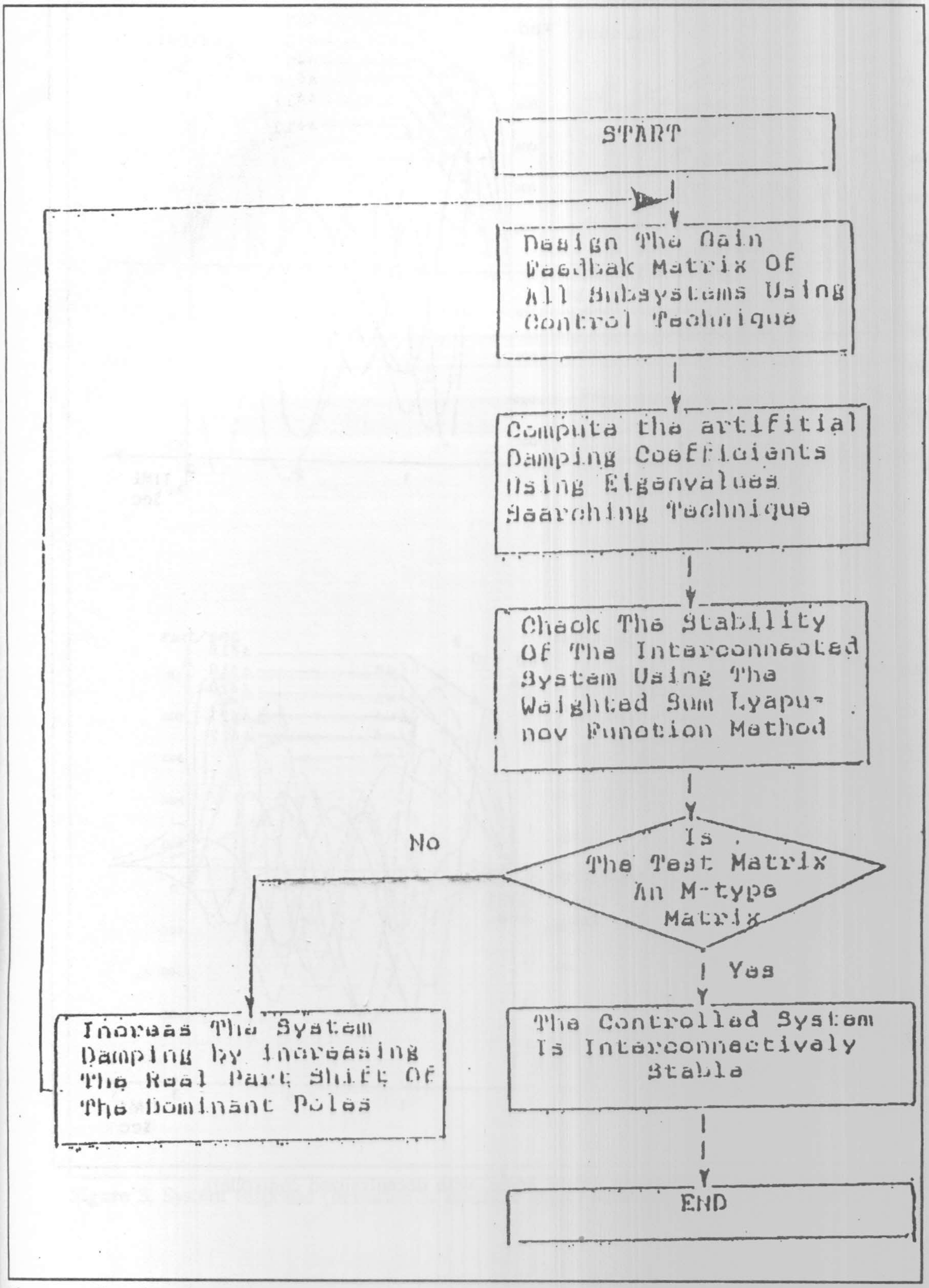

Figure 1. Flowchart for design procedures.

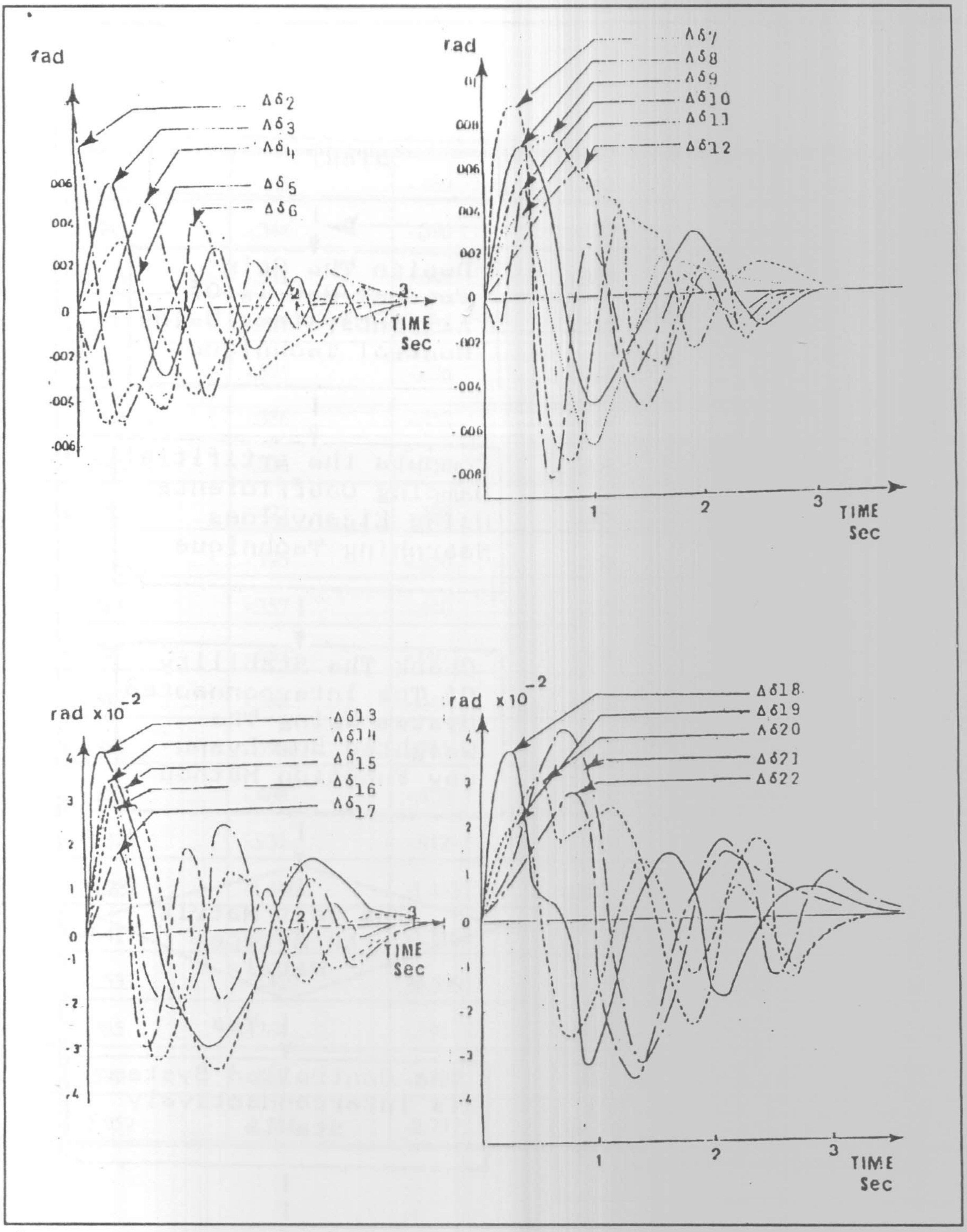

Figure 2. System response (deviation in torque angle) with decentralized controllers.

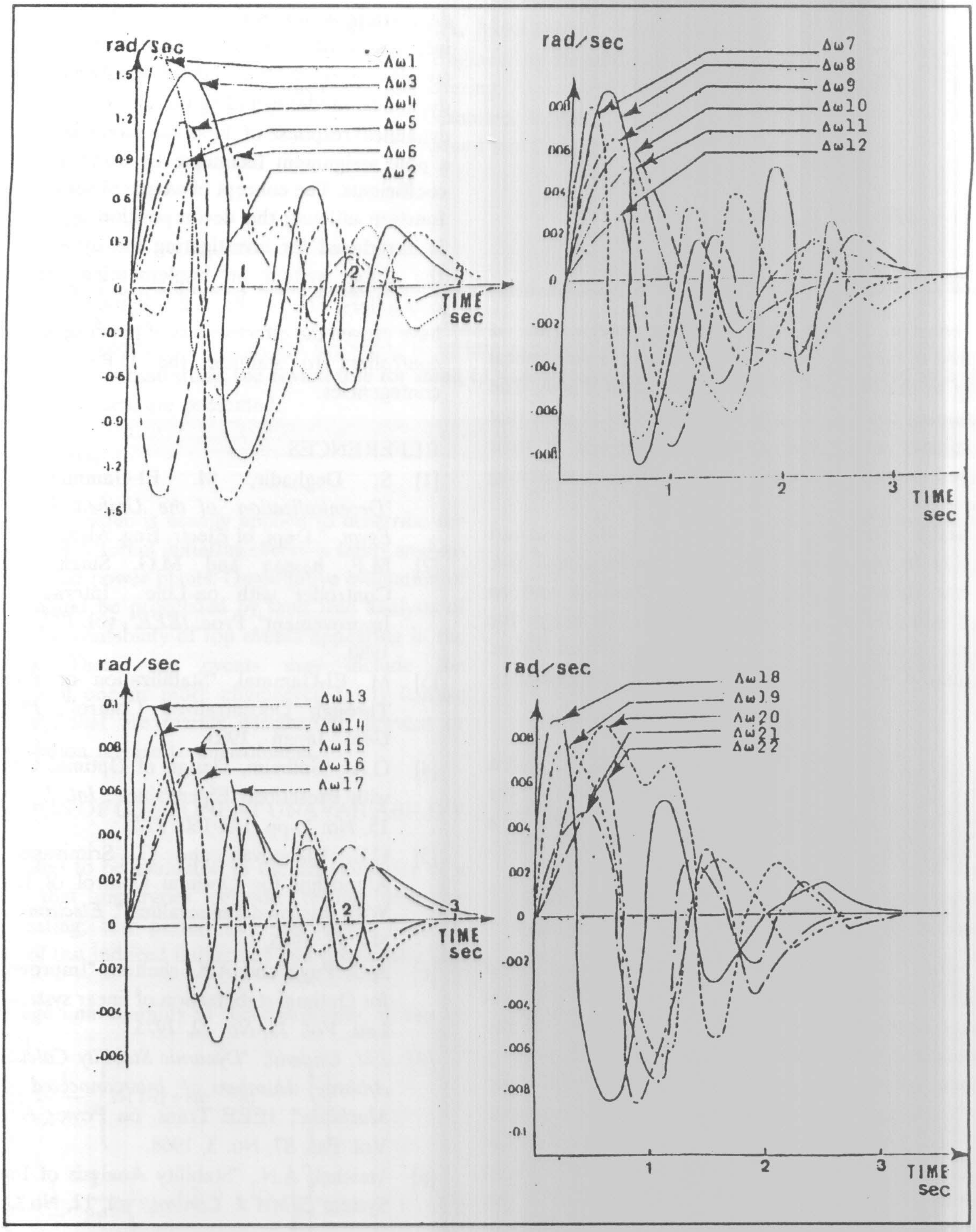

Figure 3. System response (deviation in machine angle) with decentralized controllers.

$$a_{ii} \frac{1 + \lambda/2}{M_i} \sum_{j=1,\neq,n}^{N} B_{ij} \sin(\sigma_{ij}(0) - \theta_{ij})$$

$$a_{ij} = (1 + \lambda/2) [M^{-1} B_{nj} [\sin (\sigma_{nj} (0) - \theta_{nj})]$$

$$\sigma_i = m_{in} (\lambda\beta/2_{,+ M\, n} \lambda[\sin (\sigma_{ij} (0) - \theta_{nj})`;` i \neq j$$

The concept of artificial damping coefficients is introduced to take into account the increase in mechanical damping by the effect of local feedback control laws. The new damping coefficients could be evaluated in such that the dominant mechanical modes are assigned in their prescribed region by using an eigenvalue searching technique.

The design procedures are illustrated in the flowchart Figure (1) In the design procedures machine no.1 (i.e. n=1) was chosen as the comparison machine and an average value for λ = 0.01 was sufficient to assign the dominant mechanical modes near their prescribed region. We assume β = 0.1, and the results of the test D-matrix

are listed in Table 2. It may be verified for the D-matrix that: (i) $d_{ij} < 0$; i=j and (ii) all determinants of the principal minor matrices, are positive, and therefore it is an M-matrix type.

5. the result of the digital computer simulation

To verify the effectiveness of the decentralized controllers designed in the previous sections, a digital computer simulation for the dynamical response of the interconnected system with the decentralized controllers has been carried out using the explicit fourth-order Runge-Kutta algorithm with a step time increment equal to 0.01 sec. The results evolving the time history of the deviation in rotor angles, and machine speeds, are plotted in Figures 3 to 4 to a step increase disturbance in the torque angle of machine 2 by 0.1 radians.

CONCLUSION

The problem of stabilizing the U.P.S of Egypt during contingencies has been solved via the design of locally optimal model controllers. The design technique of the decentralized controllers is based on modelling the interaction of each subsystem with the other weakly coupled ones by the way of constructing a low-order dynamical model including the dominant modes only. The dynamical response of the crude model is improve through a pole assignment technique by using artificial damping coefficients. The concept of weighted sum scalar Lyapunov function utilizing the decomposition aggregation method is introduced for investigating the dynamical stability of the global system on implementing the decentralized controllers. The results of the digital computer simulation have proved the effectiveness of the designed decentralized controllers to stabilize the U.P.s of Egypt during contegencies.

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