DECENTRALIZED STABILIZATION AND CONTROL STRATEGIES FOR INTERCONNECTED POWER SYSTEMS

by
Dr. ATEIA A. ABDELMAGEED
- GENERAL DIRECTOR OF ELECTRIC MOTORS MANUFACTURE
- SHOUBRA COMPANY FOR ENGINEERING INDUSTRIES
- NATIONAL ORGANIZATION FOR MILITARY PRODUCTION

ABSTRACT

The paper considers the problem of stabilizing and control of a linear time invariant multivariable system, representing power system dynamics, using two techniques : The first technique adopts the decentralized stabilization approach, while the second depends upon the decomposition coordination approach. Both techniques are applied to an interconnected power system consisting of three synchronous machines. The simulation results proved the capability of both techniques in stabilization and control of the system under consideration.

1. INTRODUCTION

Economics in system design are achieved with large unit sizes, higher per unit reactance for generating and transmission equipment designs. These modern trends however reduce the dynamic stability of synchronous machines so that the phenomenon of their stability under small perturbations has received a great deal of attention. Previous work has been devoted to a study of the optimal control of multimachine power systems. This is done by controlling all the machines by one optimal controller called centralized controller [1-3,7]. However due to the exponential rise in power system interconnections, this centralized control is practically undesirable for large power systems due to :

1) Computational difficulties encountered in solving a single Riccati equation of large order.

2) High costs of the communication system need for transmitting all the state variables to the centralized controller.

3) The stability of the system may be lost if a fault occurs in the communication system.

The above difficulties can be alleviated by decomposing the original problem into several subproblems, which are much easier to solve. In the first part of this paper, a decentralized stabilization technique [8-10] is presented and examined through its application to an interconnected power system. The second part of this paper focuses on elaborating of decentralized control using decomposition-coordination technique. The later one is also examined by applying the elaborated control to the same system. The second technique is characterized by its simplicity of algorithm and its applicability for practical implementation.
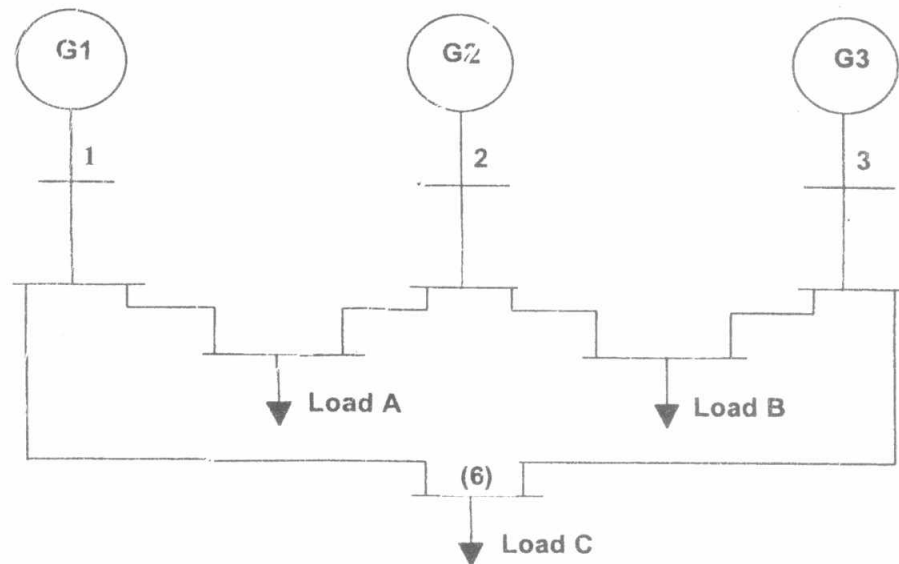
2. POWER SYSTEM MODEL DESCRIPTION

Figure (1)

Figure (1) shows the configuration of an interconnected power system, each subsystem is assumed to have one synchronous machine. This is used as an example in this styudy. The details of this system is found in appendix (1).

In [2], it is shown that the dynamics of the interconnected power system of Figure (1) may be described by the following state equation (for small disturbances about a given operating point).

$$\dot{x}(t) = \hat{A} \cdot x(t) + B \cdot u(t) \tag{1}$$

$$x(t_o) = x_o$$

Where :

x(t) is an n-dimensional composite state vector,

u(t) is an m-dimensional composite control vector, and

A and B are constant matrices of dimensions n x n and n x m respectively.

This composite system, S, may be described as an interconnection of N subsystems $S_1, S_2, \ldots S_N$ [3].

$$\dot{x}(t) = [A + H] \cdot x(t) + B \cdot u(t) \tag{2}$$

Where :

$$x^T = \begin{bmatrix} x_1^T & x_2^T & \cdots & x_n^T \end{bmatrix} \qquad u^T = \begin{bmatrix} u_1^T & u_2^T & \cdots & u_n^T \end{bmatrix} \qquad \text{and}$$

$A = A + H$.

For subsystem S_i, $x_i(t)$ is an n_i-dimensional state vector with $n = \sum\limits_{i=1}^{N} n_i$

and $U_i(t)$ is an m_i-dimensional vector with $m = \sum\limits_{i=1}^{N} m_i$. Also,

A = block diagonal $[A_1, A_2, \ldots A_N]$,

B = block diagonal $[B_1, B_2, \ldots B_N]$, and

$$H = \begin{bmatrix} 0 & A_{12} & \cdots & A_{1n} \\ A_{21} & 0 & \cdots & A_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ A_{n1} & A_{n2} & \cdots & 0 \end{bmatrix} = \begin{bmatrix} H_1 \\ H_2 \\ \cdots \\ H_n \end{bmatrix}$$

is the interconnection matrix. Where A_i, A_{ij}, and B_i are $n_i \times n_i$, $n_i \times n_j$, and $n_i \times m_j$ constant matrices, All pairs (A_i, and B_i) are assumed controllable. All matrices B_i are assumed to be of full rank m_j.

Associated with each subsystem S_i is a performance index J_i of the form :

$$J_i = \frac{1}{2} \int_0^\infty (X_i^T Q_i X_i + u_i^T R_i u_i) dt \qquad (3)$$

Where Q_i is an $n_i \times n_j$ positive semidefinite matrix and R_i is an $m_i \times m_j$ positive definite matrix.

The problem is how to find the u_i ($i = 1, 2, \ldots , n$) which minimize J_i and guarantee the stability of the overall system S.

3. DECENTRALIZED STABILIZATION STRATEGY

Our objective is find the U_i of the form :

$$U_i = - K_i X_i , \quad i = 1, 2, \ldots , N. \qquad (4)$$

Which minimize equation (3) and guarantee the stability of the overall system S given by :

$$\dot{x}(t) = [A + H - BK] \cdot x(t) \qquad (5)$$

With K = block diagonal [K_1, K_2, ... K_N]. This is given in literature [3].

The regulators of equation (4) are called static controllers. The necessary condition for stabilization by local static regulators is that the decentralized fixed modes to be stable. These modes are the eigen-values of

the closed loop matrix (5) that are common with the eigen-values of A for any matrix K [4]. However, this condition is in fact necessary and sufficient for stabilization by local dynamic controller [4].

Sufficient conditions for solving this problem using local static controllers is derived [4], consider the decoupled subsystems $S_1, S_2, ... S_N$ in which the interaction matrix H is assumed, for a while, to be zero and described by :

$$\dot{x}(t) = A \cdot x(t) + \sum B_i \cdot u_i(t), \quad i = 1, 2, \ldots, N \quad (6)$$

Also, the notion of exponential stability is adopted [5] for the isolated subsystems of equation (6). i.e., the solution of equation (6) should satisfy $x_i e^{\alpha t} \to 0$ as $t \to \infty$ where $\alpha > 0$. In other words, the closed loop system poles will be to the left of $Re(s) = -\alpha$.

In this case, the system will be exponentially stable with degree α. Each subsystem S_i ($I = 1, 2, ... , N$) described by equation (6) can be exponentially stabilized with degree α and minimizes :

$$J_i = \frac{1}{2} \int_0^{\infty} (x_i^T Q_i x_i + u_i^T R_i u_i) e^{2\alpha t} dt \quad (7)$$

When the control vectors are given by :

$$u_i = - R_i^{-1} B_i^T P_i x_i, \quad i = 1, 2, \ldots, N \quad (8)$$

Where P_i is the symmetric positive definite solution of the algebraic matrix Riccati equation :

$$P_i (A_i + \alpha I) + (A_i + \alpha I)^T P_i + Q_i - P_i B_i R_i^{-1} B_i^T P_i = 0 \quad (9)$$

Using the control u_i of equation (8), the composite system represented by equation (2) is described by :

$$\dot{x}(t) = [A - B R^{-1} B^T P + H] \cdot x(t) \qquad (10)$$

Where R^{-1} = block diagonal $[R_i^{-1}]$, P = block diagonal $[Q_i]$, (I = 1, 2, ... , N). The response of the interaction will change the stability, and it is needed to obtain a sufficient condition to guarantee the stability of the overall systems. This is given in [3].

However this technique solves the problem of design of decentralized of control laws which guarantee the stability of the system, it suffers from high computational effort and requirements.

In the next part, we shall offer simple algorithm to overcome the above mentioned drawbacks. The algorithm depends on decomposition coordination approach.

4. DECENTRALIZED CONTROL STRATEGY

In this case, the dynamic model must be represented in discrete form and it is assumed that the control structure is formed of N local agents, acting directly on the process [6]. Each of them (Which may present a mini or microcomputer) applies a part of control law. The process itself decomposed into subsystems, each is characterized by state X_{ik} evolving under the control and U_{ik} and interconnections V_{ik} due to the other subsystems is then :

$$X_{ik+1} = A_{ii} X_{ik} + B_{ii} u_{ik} + V_{ik} \qquad (11)$$

With :

$$V_{ik} = \sum_{j \neq i} A_{ij} X_{jk}$$

The criterion to be minimized is :

$$J = \frac{1}{2} \sum_k \sum_i (X_{ik+1}^T Q_i X_{ik+1} + u_{ik}^T R_i u_{ik} \qquad (12)$$

For simplicity, the matrices Q_i, R_i are blockdiagonal. The part of the global criterion affected by each agent is then [6] :

$$J = \frac{1}{2} [X_{ik+1}^T Q_i X_{ik+1} + u_{ik}^T R_i u_{ik} \tag{13}$$

So, the local optimization problem becomes :

$$\text{Min } C_{ik} = J_{ik} + \rho_{ik}^T U_{ik} \tag{14}$$

Subjected to $X_{i\ k+1} = A_{ii} X_{ik} + B_{ii} u_{ik} + V_{ik}$. This is true if J_{ik} is convex function. The local control law is simply given by :

$$u_{ik} = - [B_{ii}^T Q_i B_{ii} + R_{ii}]^{-1} [B_{ii}^T Q_i A_{ii} X_{ik} + B_{ii}^T Q V_{ik} + r_{ik}]$$

$$= G_i X_{ik} + Li V_{ik} + \mathcal{I}_i$$

ρ_{ik} : is called the coordination vector. For more details, see |6].

5. APPLICATION OF STABILIZATION AND CONTROL STRATEGIES TO POWER SYSTEMS

The above decentralized control and stabilization techniques are applied to an interconnected power system shown in figure (1). Each subsystem is assumed to be represented by one synchronous machine. The system model is described in the state variable form by the equations :

$$X = A\underline{X} + B\underline{u} \quad \text{and}$$
$$\underline{Y} = C\underline{X}$$

The vectors $\underline{X}$, $\underline{Y}$ and $\underline{U}$ are given by :

$\underline{X} = [\Delta\delta_1 \ \Delta\delta_2 \ \Delta\delta_3 \ \Delta\omega_1 \ \Delta\omega_2 \ \Delta\omega_3 \ \Delta i_{f1} \ \Delta i_{f2} \ \Delta i_{f3} \ \Delta v_{f1} \ \Delta v_{f2} \ \Delta v_{f3}]^t$,
$\underline{Y} = [\Delta\delta_1 \ \Delta\delta_2 \ \Delta\delta_3 \ \Delta\omega_1 \ \Delta\omega_2 \ \Delta\omega_3 \ \Delta v_{t1} \ \Delta v_{t2} \ \Delta v_{t3}]^t$, and
$\underline{u} = [u_{f1} \ u_{f2} \ u_{f3}]^t$.

The control u_{f1}, u_{f2}, and u_{f3} are field regulator stabilizing signals. The disturbance is assumed as an initial perturbation of 0.02 radians in $\Delta\delta_1$.

Several studies have to be investigated from the viewpoint of performance. Figures (2), (3), and (4) display the dynamic behavior of $\Delta\delta_1$, $\Delta\delta_2$, and $\Delta\delta_3$ respectively using the previous strategies given in sections (3) and (4).

The figures point to good damping and minimum steady state errors of the responses when using the proposed controllers.

CONCLUSION

The problem of stabilization and control of interconnected power systems has been considered in this paper. Two strategies are developed for constructing the required decentralized control laws. These techniques are useful for large scale power systems where the global solution is not possible either from computation or implementation view points.

It is evident that the second technique does not require high computational requirements and also more applicable than the first technique. Moreover, the control law obtained by the first technique is quasioptional in case of cutting the links between the two levels.
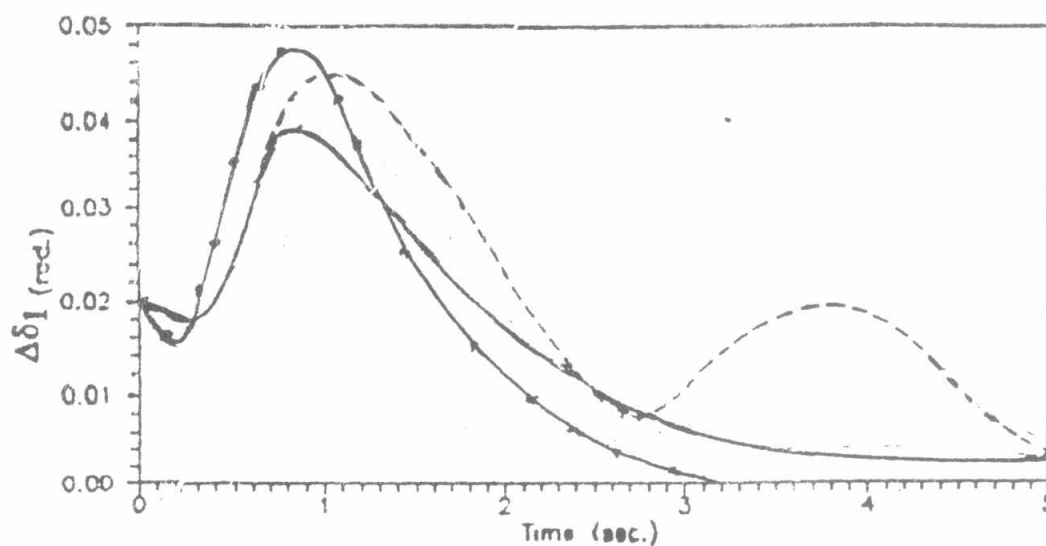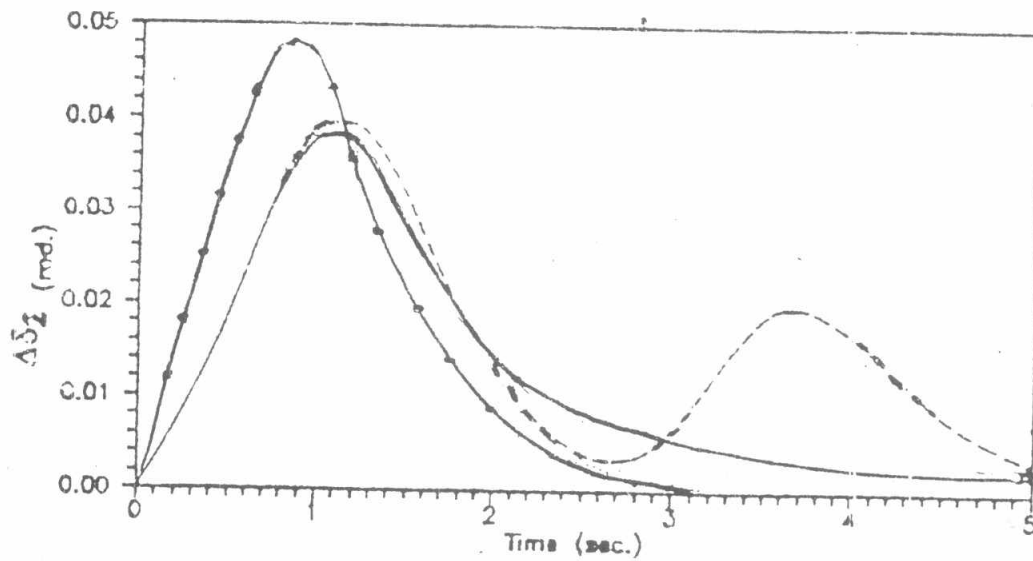
Figure (2) : Dynamic response $\Delta\delta_1$.
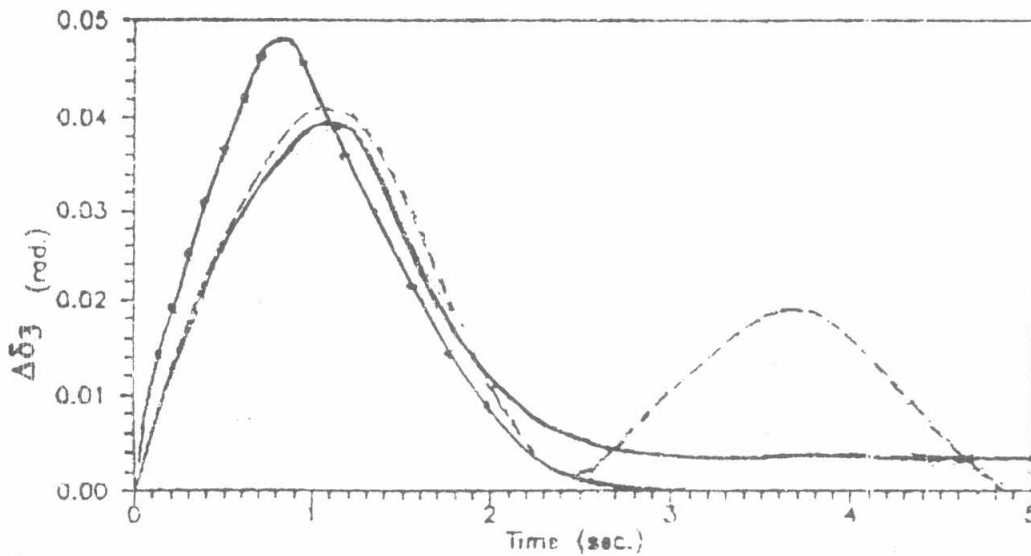
Figure (3) : Dynamic response $\Delta\delta_2$.

Figure (4) : Dynamic response $\Delta\delta_3$.

-------   *Decentralized standard controller without coordination*

_____   *Decentralized standard controller with coordination*

•▲•▲••   *Decentralized stabilization*

APPENDIX (1)

machine parameters are :

Network and loads :

$R_{12} = 0.025$	$X_{12} = 0.25$	$R_{13} = R_{23} = 0.05$
$X_{13} = X_{23} = 0.5$	$P_{b1} = 0.5$	$Q_{b1} = -0.2$
$P_{b2} = 0.5$	$Q_{b2} = 0.3$	$V_{D3} = 1.0$
$V_{Q3} = 0.0$	$P_{11} = 0.5$	$Q_{11} = 0.0$
$P_{12} = 0.5$	$Q_{12} = 0.5$	$P_{13} = 1.0$
$Q_{13} = 0.5$		

Machine and regulators :

The three machines are identical and their parameters are given by :

$X_d = 1.2$	$X_q = 0.8$	$X_{md} = 1.0$	$X_f = 1.1$
$r_a = 0.02$	$r_f = 0.001$	$H = 5$ sec.	$K_d = 0.01$
$f = 50$ c/s	$T_e = 0.5$ sec	$\mu_e = 1.0$	

Note :

All quantities are in p.u. unless otherwise stated.

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Nomenclature

i	Subscript refers to subsystem No. i.
o	Subscript denotes an infinite condition.
r	Subscript denotes a reference condition.
p. u.	per unit.
δ_i	Rotor angle, radians.
$\Delta\delta$	Rotor angle deviation, radians.
$\Delta\omega$	Angular velocity deviation, rad/sec.
ω_o	Rated angular velocity, rad/sec.
V_{ti}	Magnitude of machine terminal voltage.
P_{ti}	Active power output of the machine.
Q_{ti}	Reactive power output of the machine.
P_{bi}, Q_{bi}	Active and reactive power at network bus.
P_{li}, Q_{li}	Active and reactive power of a load.