'89 KACC 1989. 10. 27~28

# DESIGN OF A DYNAMIC OUTPUT FEEDBACK CONTROLLER FOR POWER SYSTEM GENERATORS

Mitsuaki Danjyo* Yukihiko Tanaka** Yoshihito Kominato ** and Setsuo Sagara**

* Department of Electrical Engineering, Niihama National College of Technology, Niihama 792, Japan
** Department of Electrical Engineering, Kyushu University, Fukuoka 812, Japan

Abstract : *We propose a new algorithm to obtain the output feedback controller, which contains one dynamic element, for power system generators. The performance criterion of this controller is the integral of quadratic form of output differences between reference model and controlled system. With this criterion, we can easily compute the output feedback gains using Åström's algorithm for the integral calculation of quadratic form.*

## 1. Introduction

With the growth of power systems, a well designed controller for a power system generator becomes quite important to maintain satisfactory performance of the system under all operating conditions. Many methods to design such a controller have been studied in recent years Various techniques, optimal regulators [1],[2],[3], pole assignment methods [4],[5], adaptive controllers [6], have been suggested. Development of such a controller requires an accurate model of the generator being controlled and such a model of the generator results in a high order mathematical model. Design of optimal controllers for high order mathematical systems is computationally cumbersome. Furthermore, the optimal controller needs all state measurements or, if it is not impossible, of high order observers. Thus, realization of the optimal controller is not practical. The pole assignment method requires calculation of eigenvalues and computation of eigenvalues of high order system is difficult. It is desirable to control the generator using output feedback only. But, the optimal output feedback control of the system with usually used quadratic criterion concerned with outputs and inputs requires iterative solutions of matrix algebraic equations the adaptive controller requires identification of plant parameters which is not easy for high order system.

In this conference of the last year, we proposed a new algorithm to obtain the output feedback controller[7]. The performance criterion of this controller is the integral of quadratic form of output differences between reference model and controlled system. With this criterion, we can easily compute the output feedback gains, using Åström's algorithm for the integral calculation of quadratic form. This approach to obtain the output feedback gains has the following properties:

(1) Computational effort is small;

(2) The controlled system can inherit some good properties of the reference model;

(3) This approach is applicable to any type of controllers which can be represented by the rational transfer function.

In this paper, we employ this algorithm to obtain the output feedback controller which contains one dynamic element. Simulation studies on a one-machine infinite-bus system show that output behaviors of the designed controller which uses only three measurable outputs (angular frequency, load angle, and terminal voltage ) from fifteen state variables are very similar to the reference model one, while the controller without dynamic element need four measurable outputs for comparable output behaviors.

## 2. Design method

2.1 Concept of design method

We consider an ideal model which has some good properties for design purpose as reference model. It is desired that the controlled system outputs should be as close as possible to the reference one. Then gain parameters of controlled system are determined by minimizing the performance criterion shown in equation (1), concerned with output differences $e(t)$ between the reference model and the controlled system.

$$J = \int_0^\infty e(t)^T Q e(t) dt \tag{1}$$

where

$$\begin{aligned} e(t) &= \overline{y}(t) - y(t) \\ Q &= \mathrm{diag}(q_1, q_2, \cdots, q_m) \quad q_i \geq 0 \end{aligned}$$

$\overline{y}(t)$ : outputs of reference model
$y(t)$ : outputs of controlled system
$m$ : number of outputs

This criterion is easily computed by the Åström's algorithm without using the calculation of eigenvalues and/or matrix equations [8],[9]. Thus, the minimization of it is easily performed by usually used numerical optimization procedures [10]. This approach can be applied to any type of controller which is represented by the rational transfer functions. The concept of this approach is shown in Fig.1.

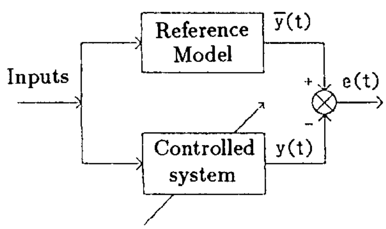



Fig.1 Concept of design method

2.2 Reference model

Reference model should be determined by following conditions:

(1) Fast responsibility ;
(2) Stability ;
(3) Steady state characteristics ;
(4) Robustness property ; etc.

We choose the optimal robust servo system [11] as a reference model which satisfies above conditions (1) , (2) and has a robustness property for plant parameter change and zero steady state differences between reference step inputs and controlled outputs. The block diagram of this system is shown Fig.2 .

2.3 Controlled system

The controlled system is shown in Fig.3 . This system is very similar to the reference model. But, in this system the subfeedback loop is outputs feedback instead of states feedback in the reference model. Thus, practical realization of this system is easy. The feedback gains $K_1(s)$ ( or $K_1$ ) ,$K_2$ are the parameters to be determined so as to minimize the performance criterion. This system has zero steady state differences from its own structure if it is stable. Simulations on one machine infinite bus system reveals that this system has also the same properties as mentioned in section 2.2 ( condition (1) to (4) ) by suitable selection of observable outputs.

## 3. Simulations

We investigate the effectiveness of this approach by simulations on one machine infinite bus system, shown in Fig.4 . In this system, the generator has customary used excitation system and governor control system. The dynamics of this system is represented by 15th order nonlinear differential equations described below [12] .

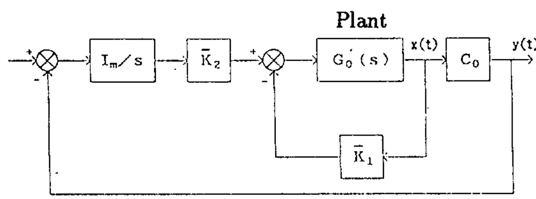
$$\dot{x}(t) = f(x(t), u(t)) \tag{2}$$
$$y(t) = g(x(t)) \tag{3}$$

where

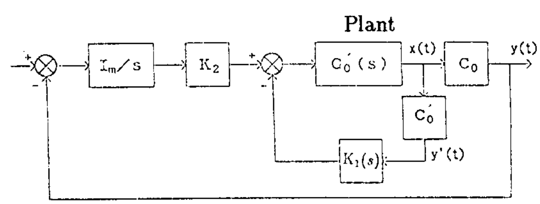
$x(t)$ : state variables
$u(t)$ : inputs
$y(t)$ : controlled outputs
$f, g$ : nonlinear functions
$u(t) = [u_e, u_g]^T$
$u_e$ : excitor input
$u_g$ : governor input
$y(t) = [\delta, V_t]^T$
$\delta$ : load angle of generator
$V_t$ : terminal voltage of generator

other observable outputs

$\omega$ : angular frequency
$E_{fd}$ : excitor voltage




$y(t)$ : Outputs to be controlled
Fig.2 Optimal robust servo system




$y(t)$ : Outputs to be controlled
$y'(t)$ : Observed outputs
Fig.3 Controlled system

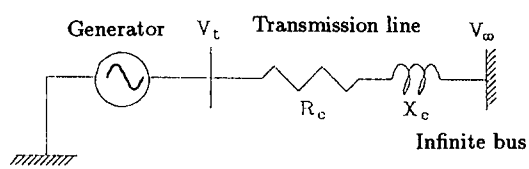



Fig.4 One machine infinite bus system

First order approximation of these equations about nominal operating values ($x_0$ ,$u_0$ ) are

$$\Delta \dot{x}(t) = A_0 \Delta x(t) + B_0 \Delta u(t) \quad (4)$$
$$\Delta y(t) = C_0 \Delta x(t) \quad (5)$$

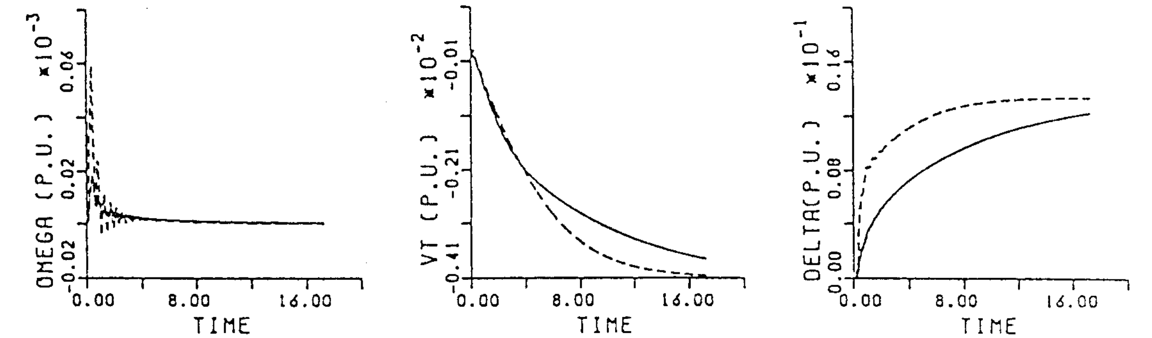
where

$$A_0 = \frac{\partial f(x_0, u_0)}{\partial x}, \quad A_0 \in R^{15\times15}$$
$$B_0 = \frac{\partial f(x_0, u_0)}{\partial u}, \quad B_0 \in R^{15\times2}$$
$$C_0 = \frac{\partial g(x_0)}{\partial x}, \quad C_0 \in R^{2\times15}$$

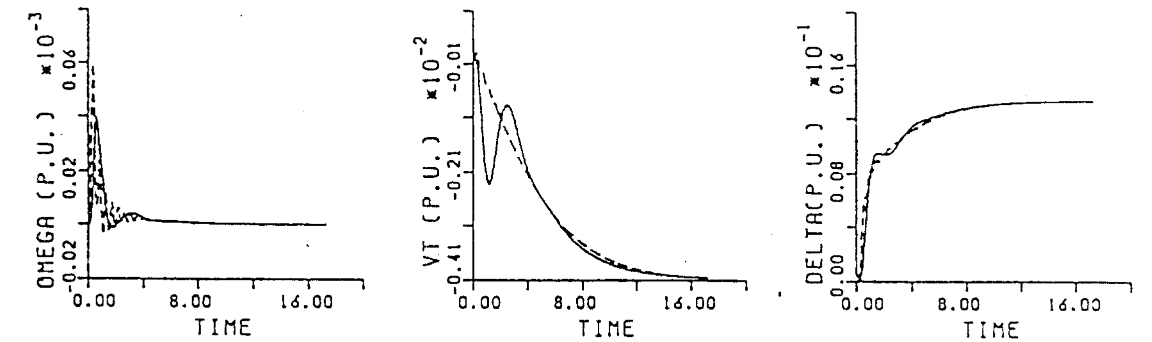
and $\Delta$ means deviations from nominal values. We consider these linearlized system as the system to be controlled. Thus, the transfer function from $\Delta u$ to $\Delta x$ is

$$G_0'(s) = (sI - A_0)^{-1} B_0 \quad (6)$$

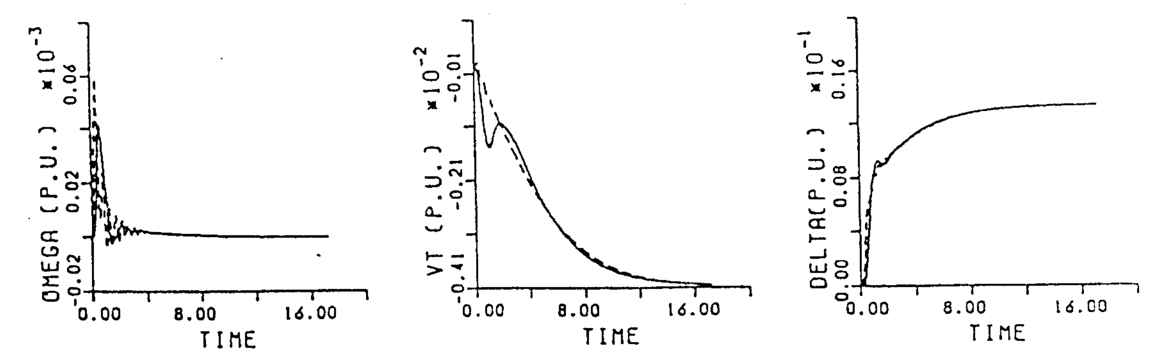
Since the function $f$ , $g$ are nonlinear, the coefficients $A_0$ ,$B_0$ , $C_0$ change its values when the operating conditions are changed. Thus, the robustness property of controlled system is very important. We select observable outputs from physical meanings as follows.




(a) Response curves of traditional control system




(b) Response curves of proposed controller ( Case 1 )




(c) Response curves of proposed controller ( Case 2 )

Fig.5 Response curves of outputs for step input at $u_g$
( Nominal operating condition [ 100 % loaded ] )

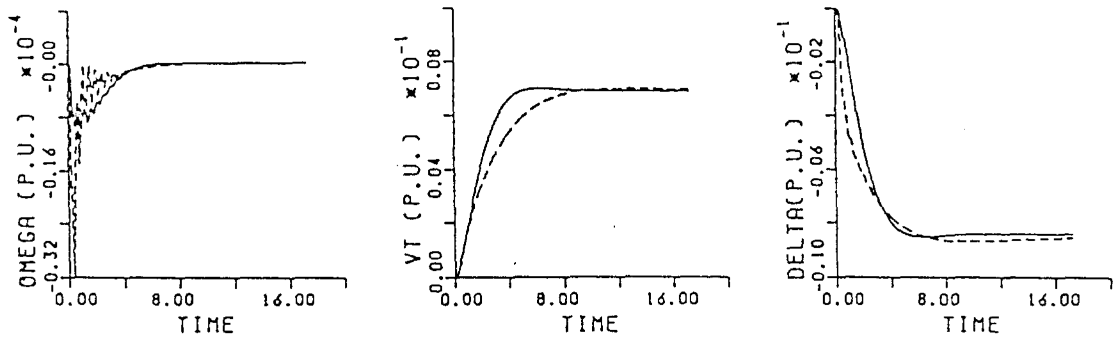
Case 1 : $y'(t) = [y(t)^T, \omega, E_{fd}]^T$

Case 2 : $y'(t) = [y(t)^T, \omega]^T$
including one dynamic element
($V_t \rightarrow u_e$)

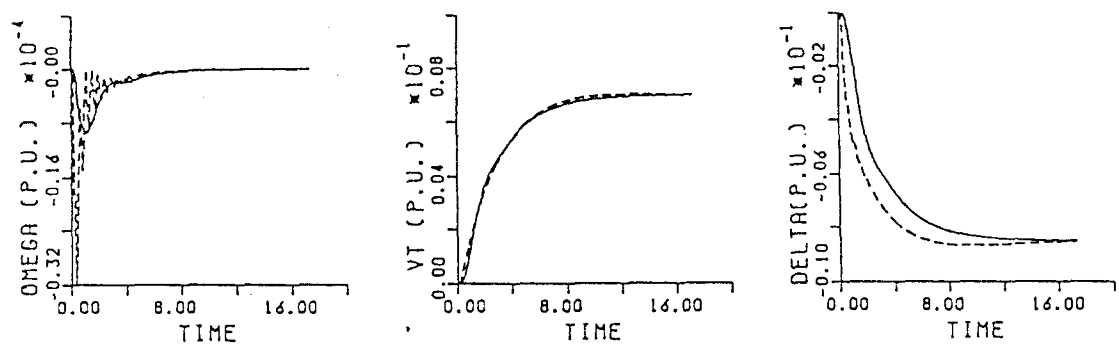
As the dynamic element, we used the second order element such as

$$\frac{cs + d}{s^2 + as + b} \quad (a, b, c, d : \text{parameters to be determined})$$

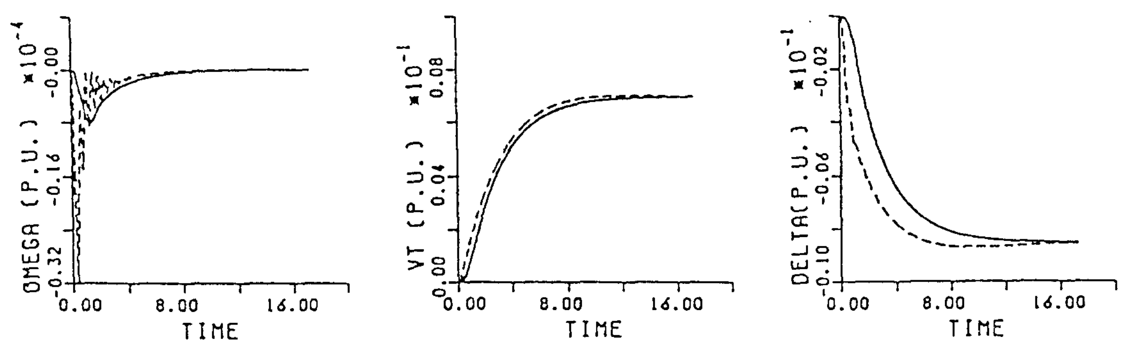
Response curve of outputs ($\delta$ , $V_t$ ,$\omega$ ) are shown in Fig.5 ,Fig.6 for different inputs and in Fig.7, Fig.8 for different operating conditions where the dot lines mean the reference model outputs. From these curves we can see the outputs of the proposed system are very close to that of reference model compared with the traditional control system and the case 2 has good robustness property.




(a) Response curves of traditional control system




(b) Response curves of proposed controller ( Case 1 )




(c) Response curves of proposed controller ( Case 2 )
Fig.6 Response curves of outputs for step input at $u_e$
( Nominal operating condition [ 100 % loaded ] )

## 4. Conclusion

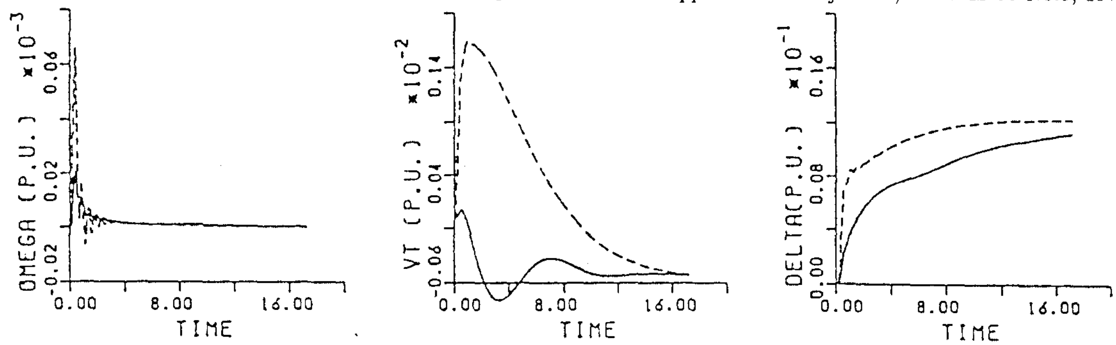
We proposed a new algorithm to obtain the output feedback controller in the conference of the last year. We employ this algorithm to obtain the output feedback controller which contains one dynamic element. Simulation studies on a one-machine infinite-bus system show that output behaviors of the designed controller which uses only three measurable outputs (angular frequency, load angle, and terminal voltage ) from fifteen state variables are very similar to the reference model one, while the controller without dynamic element need four measurable outputs for comparable output behaviors.

## References

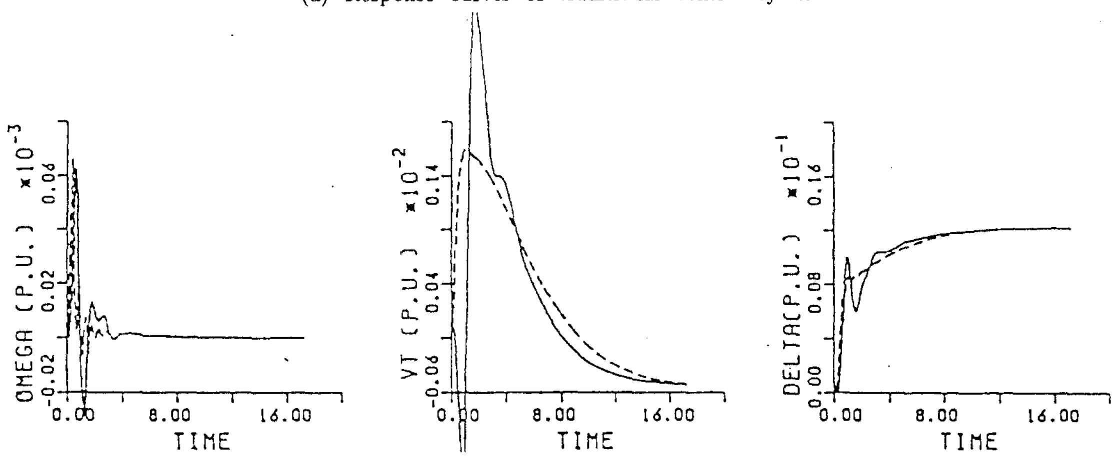

[1] Yao-Nan Yu : Electric power system dynamics, Academic Press, 1983

[2] K.Ohtsuka et al : Multivariable Optimal Control for Generator Excitation and Governor System, Trans. IEEJ Vol.104-B No.11, 1984

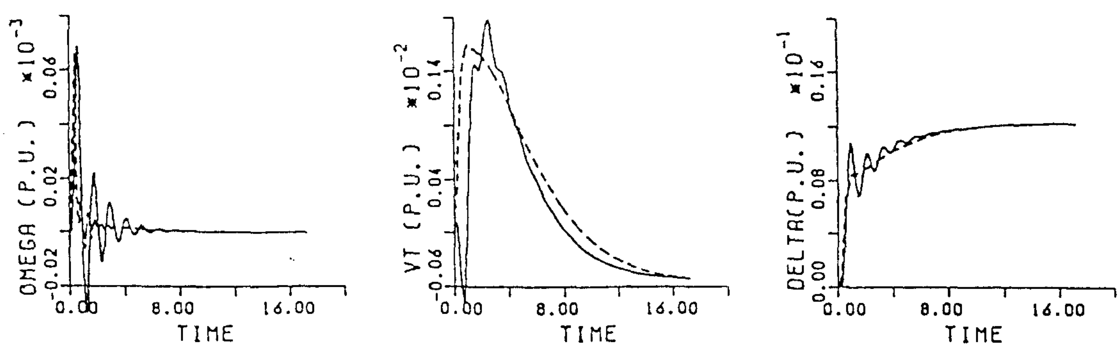
[3] V.H.Quintana : On the Design of Output Feedback Excitation Controlled of Synchronous Machine, IEEE Trans. Power Apparatus and Systems, Vol.PAS-95 No.3, 1976


(a) Response curves of traditional control system




(b) Response curves of proposed controller ( Case 1 )




(c) Response curves of proposed controller ( Case 2 )

Fig.7 Response curves of outputs for step input at $u_g$
( Non nominal operating condition [ 60 % loaded ] )

[4] A.B.R.Kumer and E.F.Richard : An Optimal Control Low by Eigenvalue Assignment for Improved Dynamic Stability in Power System, IEEE Trans. Power Apparatus and Systems, Vol.PAS-101 No.6, 1982

[5] K.Komai,J.Jin and Y.Sekine : Stabilization of Power System by Eigenvalue Control, Trans. IEEJ Vol.104-b No.11, 1984

[6] H.Tanaka et al : Real System Test of Adaptive Multivariable Generator Control System (TAGEC-I) for Hydro Power Plant, Proc. National Meeting of IEEJ, No.1000, 1987

[7] M.Danjyo et al : Design Of An Output-feedback Controller For Power System Generator. KACC International Session, 1988

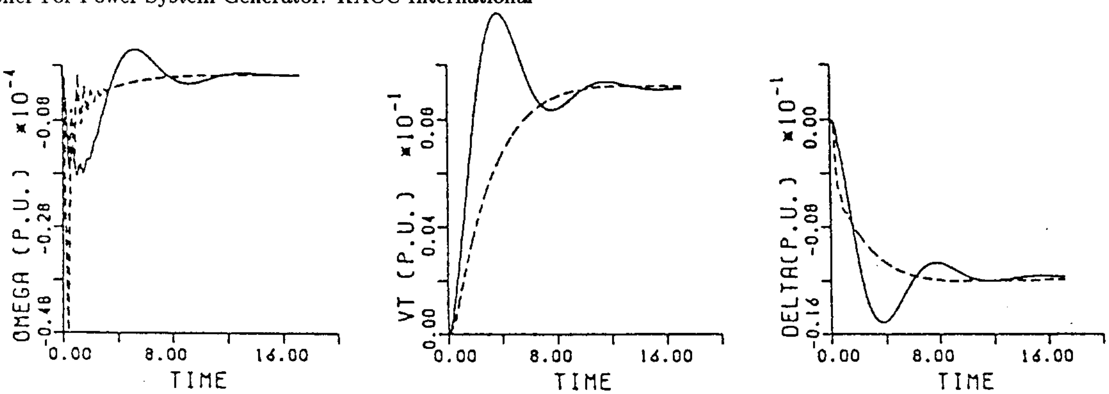
[8] K.J.Åström : Introduction to Stochastic Control Theory, Academic Press, 1970

[9] M.Danjyo and S.Sagara : A Simplified Model of the Synchronous Machine for the Power System Analysis, Trans. IEEJ Vol.105-B No.2, 1985

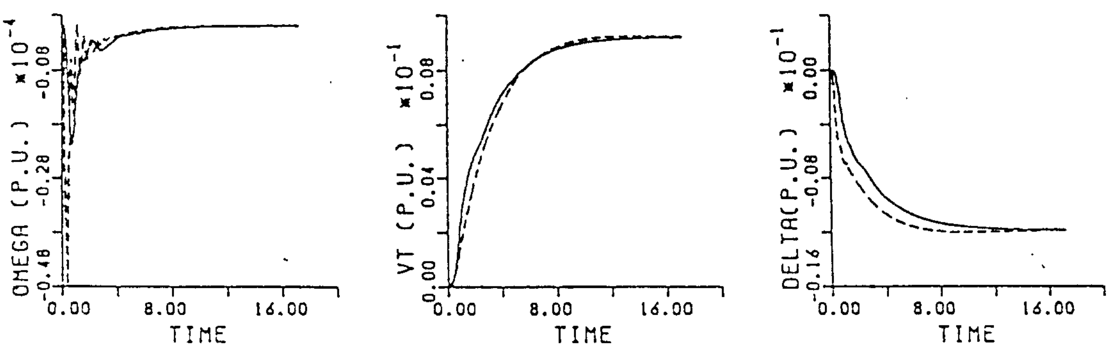
[10] R.Flecher and C.M.Reeves : Function Minimization by Conjugate Gradient, Computer j.No.7, 1969

[11] K.Furuta et al : Mechanical System Control ( in Japanese ) , Ohm Co. ,1984

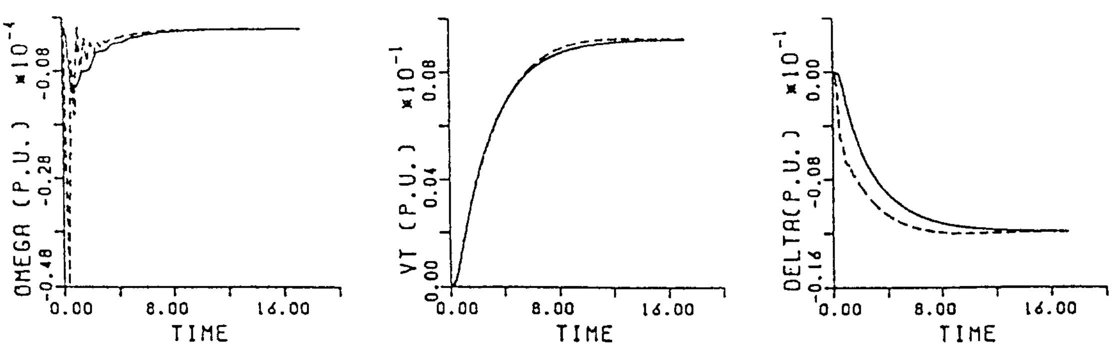
[12] Anderson and Fouad : Power System Control and Stability, Iowa State University Press, 1977




(a) Response curves of traditional control system




(b) Response curves of proposed controller ( Case 1 )




(c) Response curves of proposed controller ( Case 2 )

Fig.8 Response curves of outputs for step input at $u_e$
( Non nominal operating condition [ 60 % loaded ] )