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DESIGN OF AN OUTPUT-FEEDBACK CONTROLLER FOR POWER SYSTEM GENERATOR

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Abstruct: We propose a new algorithm to obtain the output feedback controller 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 Astrom's algorithm for the integral calculation of quadratic form. Simulations on a one machine infinite bus system shows the effectiveness of this approach.

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], optimal output feedback contorollers [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, outputs of high order obsevers. 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 higher order system.

Here, we propose a new algorithm to obtain the output feedback contoller. 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 Astrom's algorithm for the integral calculation of quadratic form [7]. This approach to obtain the output feedback gains has the following properties:

(1) Conputational effort is small;
(2) The controlled system can inherit some good properties of reference model;
(3) This approach is applicable to any type of controllers which can be represented by the rational transfer functions.

In this paper, the optimal servo system is used for the reference model which has a robustness property and zero steady state differences between reference inputs and controlled outputs. Simulations on a one machine infinite bus system shows that the designed controller which uses only four measurable outputs from fifteen state variables has also a robustness property and zero steady state differences. This controller needs only two extra measurements compared with the trditional controller. Thus, practical realization of this system is very easy.

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 parapeters of controlled system are determined by minimizing the performance criterion shown in equation (1), concerned with output differences e(t) between reference model and controlled system.

$$J = \int_0^\infty e(t)^T Q e(t) dt \qquad (1)$$

Where $e(t) = \bar{y}(t) - y(t)$

$Q = \text{diag}(q_1, q_2, \ldots q_m) \quad q_i \geq 0$

$\bar{y}(t)$: outputs of reference model

$y(t)$: outputs of controlled system

m : number of outputs

This criterion is easily computed by the Astrom's algorithm without using the calculation of eigenvalues and/or matrix equations [7],[8]. Thus, the minimization of it is easily performed by usually used numerical optimization procedures [9]. 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.

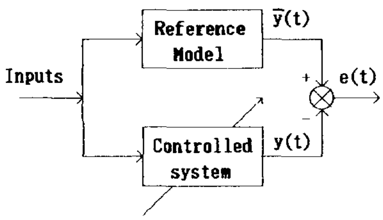


Fig. 1 Concept of design method

2.2 Reference model

Reference model should be determined by considering following conditions:

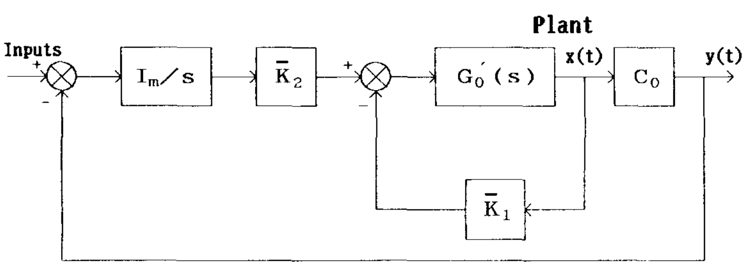
(1) Fast responsibility;

(2) Stability;

(3) Steady state characteristics;

(4) Robustness property; etc.

We choose the optimal robust servo system [10] as a reference model which satisfys 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 in Fig. 2.

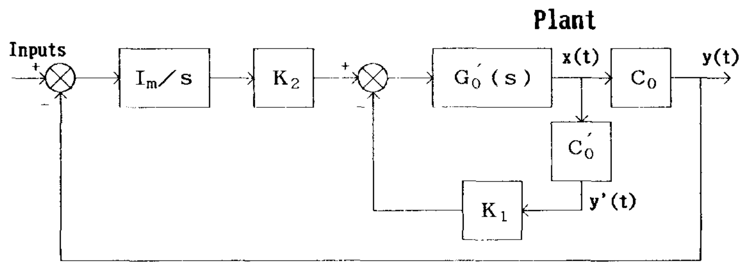


y(t) : Outputs to be controlled

Fig. 2 Optimal robust servo system

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, 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.



y(t) : Outputs to be controlled y'(t) : Observable outputs

Fig. 3 Controlled system

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 cxcitation system and governor control system. The dynamics of this system is represented by fifteenth order nonlinear differencial equations described below [11].

$$\dot{x}(t) = f(x(t), u(t)) \qquad (2)$$

$$y(t) = g(x(t)) \qquad (3)$$

where $x(t)$: state variables

$u(t)$: inputs

$y(t)$: controlled outputs

f, g : nolinear functions

$u(t) = [u_e, u_g]^T$

u_e : exciter input

u_g : governor input

$y(t) = [\delta, V_t]^T$

δ : load angle of generator

V_t : terminal voltage of generator

other observable outputs

ω : angular frequency

E_{fd}: exciter voltage

First order approximation of these equations about nominal oprating values (x_o, u_o) are

$$\Delta\dot{x}(t) = A_o \Delta x(t) + B_o \Delta u(t) \qquad (4)$$

$$\Delta y(t) = C_o \Delta x(t) \qquad (5)$$

where $A_o = \partial f(x_o, u_o)/\partial x$, $A_o \in R^{15\times15}$

$B_o = \partial f(x_o, u_o)/\partial u$, $B_o \in R^{15\times2}$

$C_o = \partial g(x_o)/\partial x$, $C_o \in R^{2\times15}$

and Δ means deviations from nominal values. We consider these linearized system as the system to be controlled. Thus, the transfer function from Δu to Δx is

$$G_o'(s) = (sI - A_o)^{-1} B_o \qquad (6)$$

Since the function f, g are nonlinear, the coefficients A_o, B_o, C_o change its values when the operating conditions are changed.

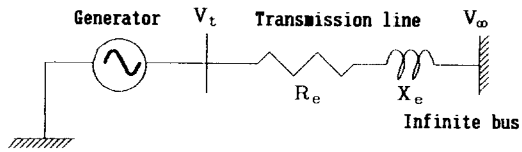
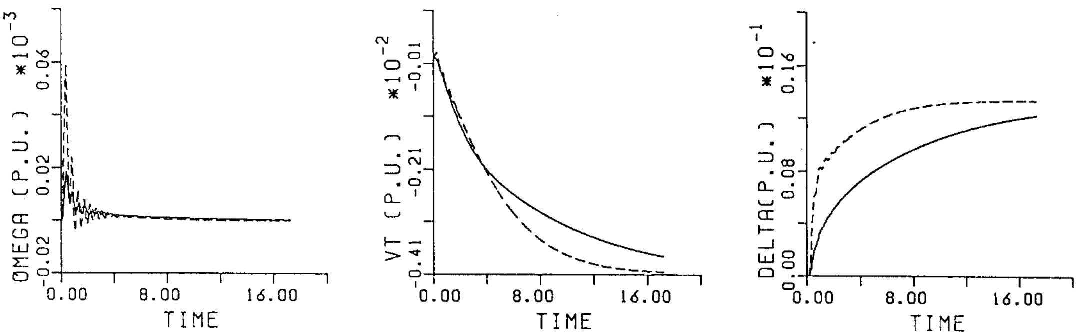
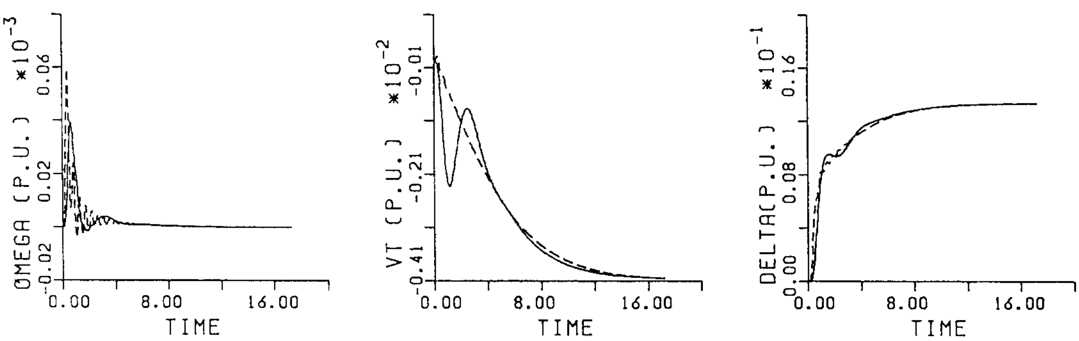


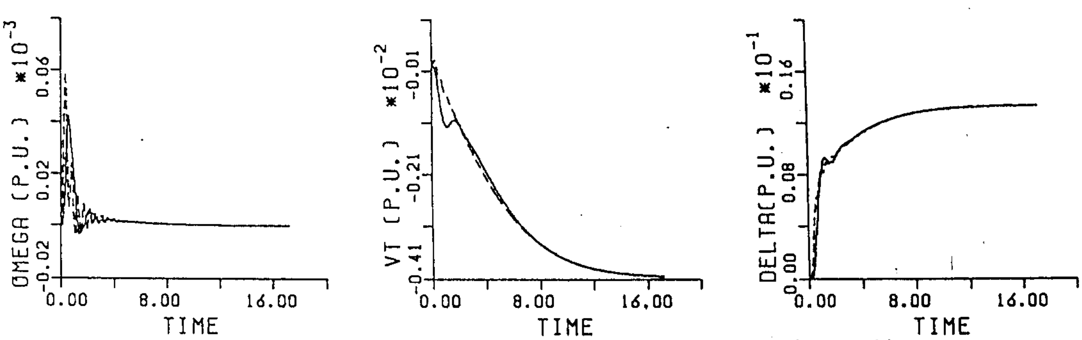
Fig. 4 One machine infinite bus system



(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])

Thus, the robustness property of controlled system is very important. We select observable outputs from physical meanings as follows.

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

Case 2 : $y'(t) = [y(t)^T, \omega, E_{fd}]^T$

Response curve of outputs (δ, Vt, ω) 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.

4. Conclusion

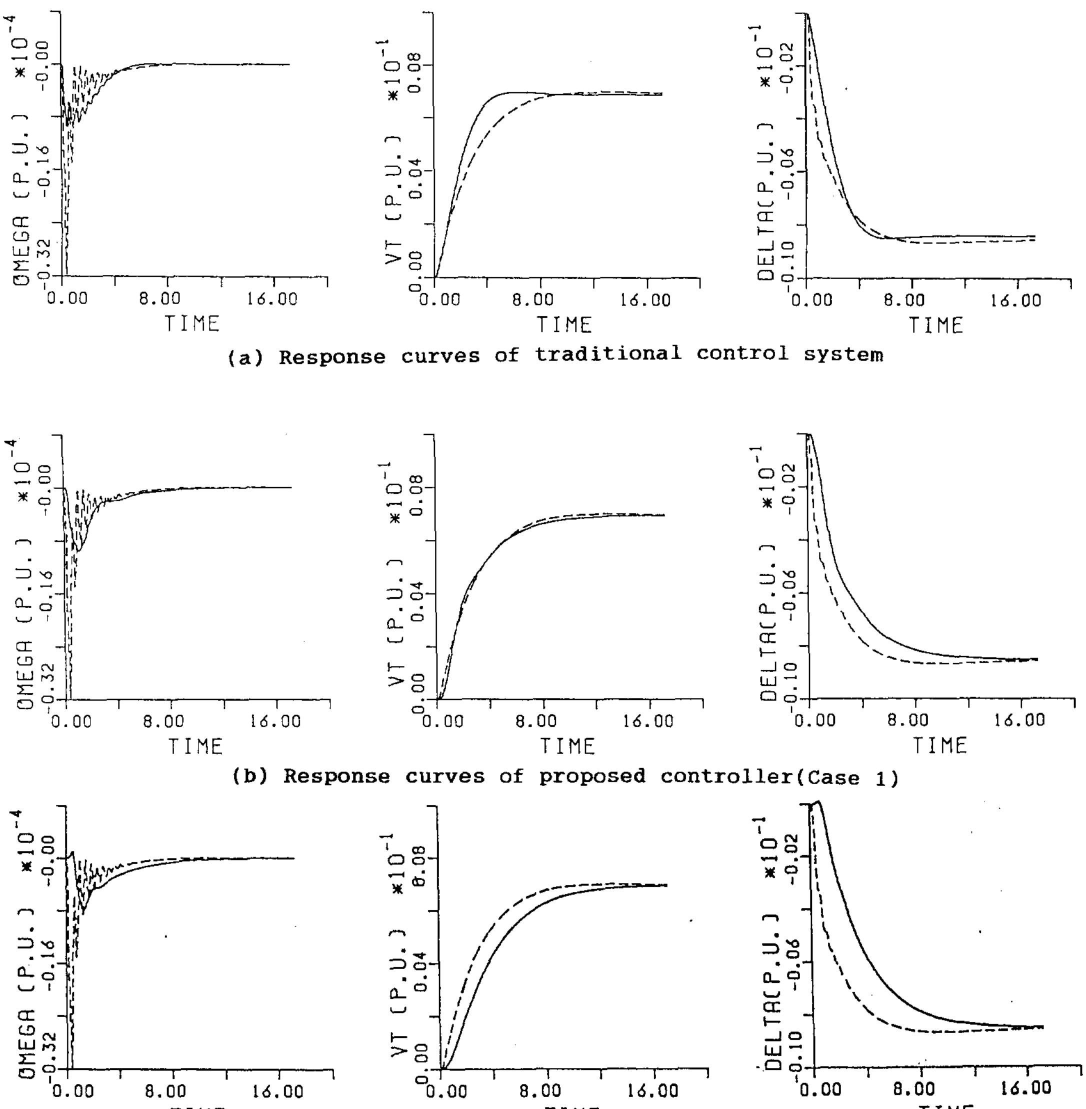
We propose a new algorithm to obtain the output feedback controller. This approach has the following properties:

(1) Computational effort is small;

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

(3) This approach is applicable to any type of controllers represented by the rational transfer functions.

Simulations on the one machine infinite bus system shows that only a few extra measurements improve the outputs responce of the system considerably.



(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])

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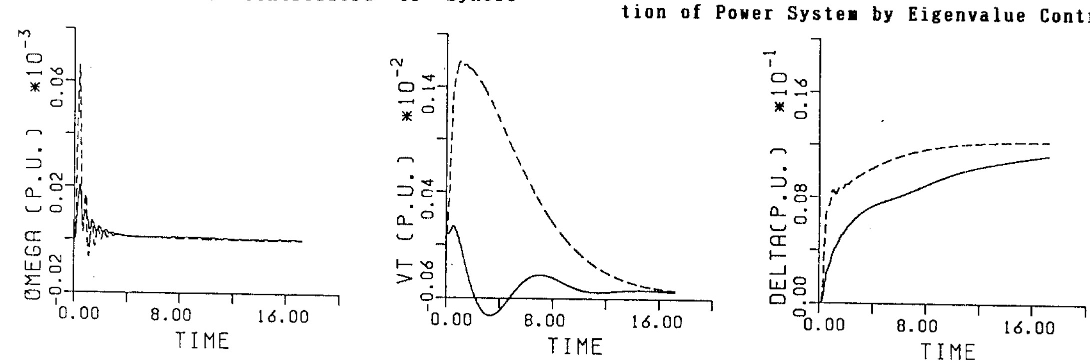
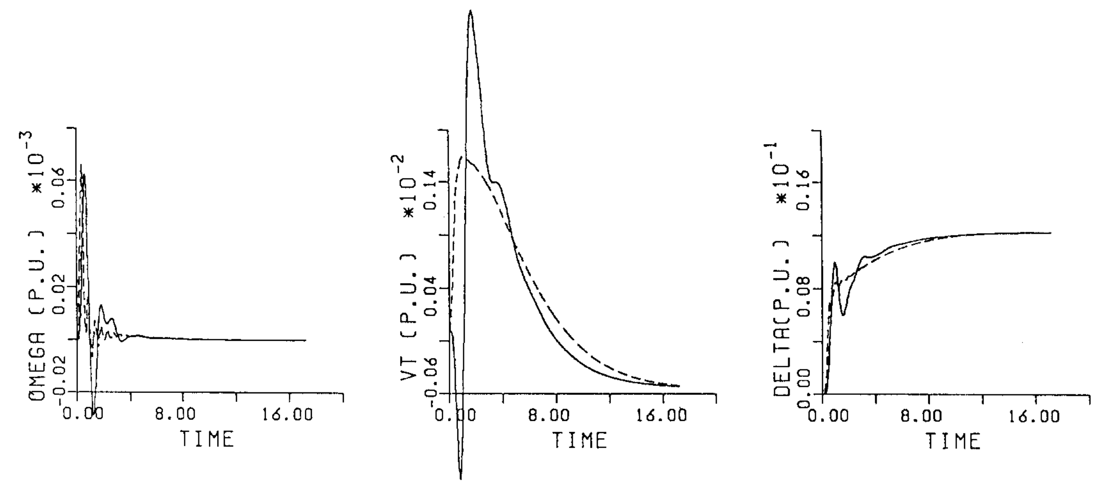
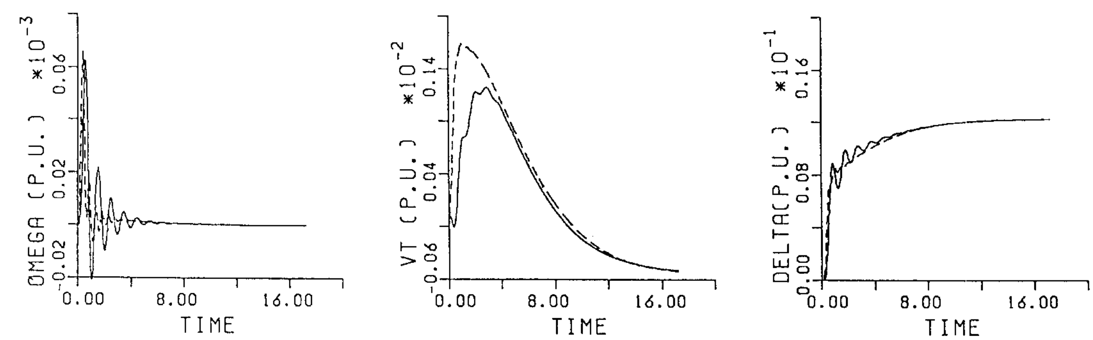


(a) Response curves of traditional control system



(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])

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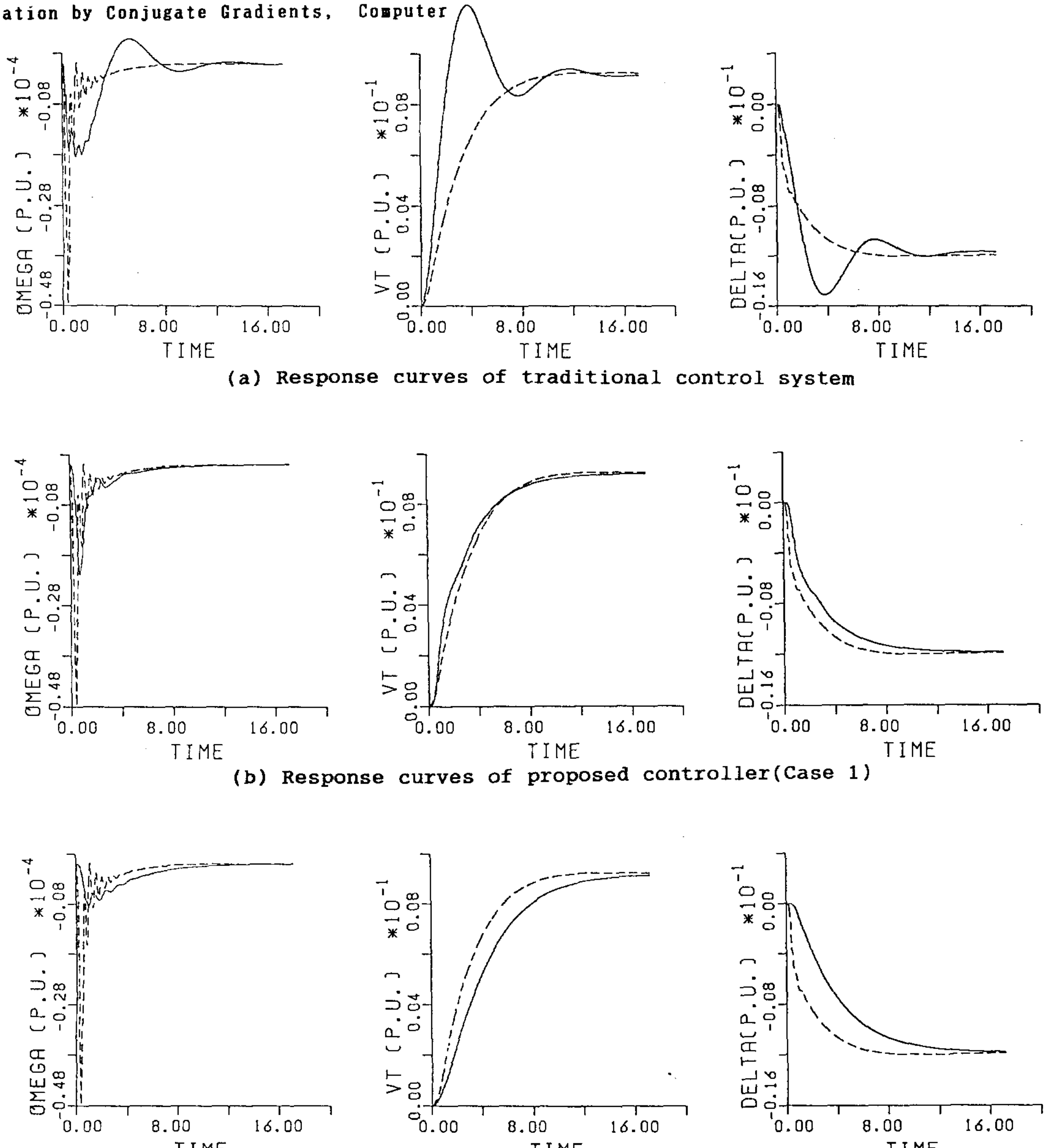

(a) Response curves of traditional control system

(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])