Output Feedback Grey Prediction System Regulator

C.C. Huang[1] Y.N. Lien[1] T.Y. Hwang[2] T.L. Huang[2] J.S. Liu.[2] Y.F. Liu[2] K.P. Hung[2]

[1]Computer Science Department, National Chengchi University

[2]Computer Science Department, National Taipei University of Education

Email:tsongliang@tea.ntue.edu.tw

Abstract: In this paper, we propose a new method to design a grey prediction system controller using output feedback. The optimal reduced order model will be used to retain the physical meaning of the output states. By using only the output states feedback, the control strategy can be implemented easily. The grey prediction method adopts the forecasting information from the output state variables to control system behavior. As a result, it reduces the oscillation and enhances the dynamic stability of the system. The advantages of the proposed method are verified through a detailed simulation of a multi-machine power system. Responses of the system with the proposed method and full state feedback optimal control are included for comparative analyses. In conclusion, the effectiveness of the grey prediction system controller in enhancing the dynamic performance stability is much better than the traditional optimal control methods.

Keyword: optimal reduced order model、grey prediction

1 Introduction

The work presented here is to design a grey prediction system controller using grey prediction output states feedback. The system stabilizers are added to the system to enhance the damping of the system. Recent interest in designing the system stabilizer, the stabilizer can be formulated as an optimal linear regulator control problem whose solution is a complete state control scheme [1]. But, the implementation requires the design of state estimators. These are the reasons that a control scheme uses only some desired state variables such as output states. Upon this, a scheme referred to as optimal reduced order model [2][3][4] whose state variables are the deviation of only output states . The approach retains the modes that affect the system most. The model is used to design an output states feedback controller. Since using only the output feedback the control strategy can be implemented easily.

The traditional system control strategies adopt the previous information of the system to decide the control signal so that it is hard to control the system before it is going to change. This paper presents a method that combines the grey theory [5][6][7] and the optimal reduced order model to develop a prediction system controller. By using a grey model to predict the system performances and using only the system output states to get the feedback gain, the control strategy can be implemented easily. As a result, the method reduces the oscillation and enhances the dynamic stability of the system.

2. Grey System Stabilizer

The structure of the grey prediction system stabilizer is shown in Fig. 1. It is composed of three units, we use the power system as an example:

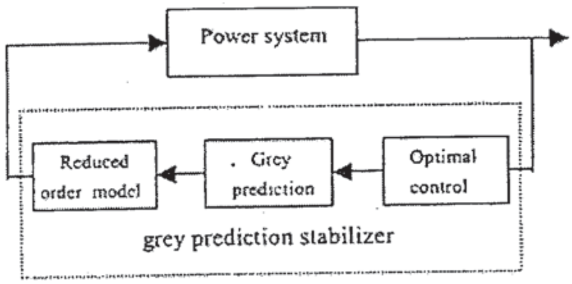

Fig.1. The structure of the grey prediction r system stabilizer

A. Reduced order model unit

This unit is used to reduce the order of the system; only the output variables (the deviation of torque angles($\Delta\delta$)and speeds ($\Delta\omega$))will be retained, variables information are fed to the grey predictor to be as the input data of the grey modeling process.

B. Grey prediction unit:

The grey predictor is used to predict the forecasting values $\Delta\hat{\delta}$ and $\Delta\hat{\omega}$, these values are provided for the optimal controller to obtain the feedback signals of the power system.

C. Optimal controller unit:

The control signals of the system are generated from this unit. The gains of the controller will be obtained by using the optimal reduced order model and grey prediction method. The feedback states will be the output states $\Delta\hat{\delta}$ and $\Delta\hat{\omega}$ only.

3. Grey Prediction

Grey theory was initiated in 1982 by Prof. Deng [5], Cheng Biao proposed a grey prediction controller in 1986[7]. In this paper, we build a dynamic model called the grey model GM(n,h) [8][9] to approximate the system. GM(1,1) can be described as follows:

Suppose $y^{(0)}$ be a original data sequence, which is denoted as

$$y^{(0)}=(y^{(0)}(1), y^{(0)}(2),\ldots, y^{(0)}(n)),\quad n\leq 4 \qquad (1)$$

the accumulated generating operation (AGO) on $y^{(0)}$ is the first step in building grey model. AGO is denoted as

$$y^{(1)}(k) = AGO \bullet y^{(0)} = \sum_{m=1}^{k} y^{(0)}(m), \qquad k=1,2,\ldots,n \quad (2)$$

Let $z^{(1)}$ be as the data sequence obtained by the following MEAN generating operation $y^{(1)}$

$$z^{(1)}(k) = MEAN \bullet y^{(1)} = \frac{1}{2}[y^{(1)}(k)+y^{(1)}(k-1)], k=2,3,\ldots,n \qquad (3)$$

Then the grey differential equation of GM(1,1) is

$$y^{(0)}(k) + az^{(1)}(k) = u \qquad (4)$$

The grey differential equation is

$$\frac{dy^{(1)}}{dt} + ay^{(1)}(k) = u \qquad (5)$$

The parameters a and u can be solved by means of least-square method as follows

$$\hat{\theta} = \begin{bmatrix} a \\ u \end{bmatrix} = (B^T B)^{-1} B^T y_N \qquad (6)$$

where

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix} \qquad (7)$$

and

$$y_N=(y^{(0)}(2), y^{(0)}(3),\ldots, y^{(0)}(n)),\quad n\leq 4 \qquad (8)$$

Based on the solution of the whitening (4)is

$$y^{(1)}(t)=(y^{(0)}(1)-\frac{u}{a})e^{-at}+\frac{u}{a} \tag{9}$$

The GM(1,1) model with respect to the data sequence $y^{(1)}$can be expressed as

$$\hat{y}^{(1)}(n+p)=(y^{(0)}(1)-\frac{u}{a})e^{-a(n+p-1)}+\frac{u}{a}, \quad n\geq 4 \tag{10}$$

where the parameter p is the prediction step size and the up-script "Λ" means this value is a forecasting value.

The inverse accumulated generating operation (IAGO) is used to estimate the value of $y^{(0)}$, the corresponding IAGO sequence $\hat{y}^{(0)}$ is defined by

$$\hat{y}^{(0)}=IAGO\cdot\hat{y}^{(1)} \tag{11}$$

the forecasting value of $y^{(0)}(n+p)$ will be expressed as follows:

$$\hat{y}^{(0)}(n+p)=(y^{(0)}(1)-\frac{u}{a})(1-e^{a})e^{-a(n+p-1)}, n\geq 4 \tag{12}$$

4. Numerical Results

A. Full Order Model

The Two machine-infinite-us power system full order model given in [4][10]is

$$\dot{x}=Ax+Bu \tag{13}$$

where

$x=[\Delta\omega_1\ \Delta\delta_1\ \Delta e'_{q1}\ \Delta v_{F1}\ \Delta\omega_2\ \Delta\delta_2\ \Delta e'_{q2}\ \Delta v_{F2}]^T$

Δ denotes deviation from operation point

ω speed

δ torque angle

e'_q voltage proportional to direct axis flux linkages

V_{FD} generation field voltage

$$A=\begin{bmatrix} -0.244 & -0.0747 & -0.1431 & 0 & 0 & 0.0747 & 0.0041 & 0 \\ 377 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0.046 & -0.455 & 0.244 & 0 & 0.046 & 0.13 & 0 \\ 0 & -398.56 & -19498.8 & -50 & 0 & 398.58 & -3967 & 0 \\ 0 & 0.178 & -0.0433 & 0 & -0.2473 & -0.178 & -0.146 & 0 \\ 0 & 0 & 0 & 0 & 376.99 & 0 & 0 & 0 \\ 0 & & 0 & & & & & 0.149 \\ 0 & & & & & & & -50 \end{bmatrix}$$

$$B=\begin{bmatrix} 0 & 0 & 0 & 2500 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2500 \end{bmatrix}^T$$

The full model optimal controller is designed by solving the following linear regulator problem:

$$Minimize\ J=\frac{1}{2}\int_0^\infty\{x^T(t)Qx(t)+u^T(t)Ru(t)\}dt \tag{14}$$

Where

Q = *diagonal (1,1,10,10)*

R= *diagonal (1,1)*

The eigenvalues of the power system are given in Table 1.

Table 1.system eigenvalues

-0.0904± j9.843	-25.1741± j67.8187
-0.0006	-25.2392± j30.3072
-0.2443	

B. Reduced Order Model

The modes that should be retained are the mode-0.0904±j9.843, -0.0006,, -0.2443 and retained state variables are $\Delta\omega_1\ \Delta\delta_1\ \Delta\omega_2\ \Delta\delta_2$, **Using the optimal reduced order method[2][3], the following reduce order model is obtained as::**

$$\dot{Z}=FZ+Gu$$

where

$Z=[\Delta\omega_1\ \Delta\delta_1\ \ \Delta\omega_2\ \Delta\delta_2]^T$

$$F=\begin{bmatrix} 0 & 0 & 377 & 0 \\ 0 & 0 & 0 & 377 \\ -0.07 & 0.073 & -0.237 & -0.007 \\ 0.18 & -0.184 & -0.059 & -0.188 \end{bmatrix}$$

$$G=\begin{bmatrix} -0.15 & 0.11 \\ 0.23 & -0.35 \\ -0.022 & 0.007 \\ 0.009 & -0.029 \end{bmatrix}$$

The reduced order optimal controller is designed by solving the following linear regulator problem gotten from the reduced order model:

$$\text{Minimize } J=\frac{1}{2}\int_0^\infty \left\{Z^T(t)QZ(t)+u^T(t)Ru(t)\right\}dt \tag{15}$$

where

Q = *diagonal (1,1,10,10)*

R = *diagonal (1,1)*

Table 2 shows the values of the feedback control gains calculated from the reduced order model and the full order model :.

Table 2. Feedback gains

	Full order		Reduced order	
	u1	u2	u1	u2
$\Delta\delta_1$	0.98	0.49	1.232	0.16
$\Delta\omega_1$	205	34.6	196.5	32.51
$\Delta\delta_2$	0.35	-0.03	0.103	0.038
$\Delta\omega_2$	58.53	40.56	59.3	39.53
Δe_{q1}	-0.33	-0.03		
ΔV_{F1}	0.002	0.0001		
Δe_{q2}	0.038	-0.138		
ΔV_{F2}	0.0001	0.0004		

C. Grey predictor

From the (12) ,we choose the forecasting step size p=10 for each forecasting value ($\Delta\omega_1$,$\Delta\delta_1$,$\Delta\omega_2$,$\Delta\delta_2$,).

D. Simulation results

The transient responses of the angular frequencies with a 5% change in the mechanical torque of machine 1 are shown in Fig/ 2. The transient responses of the angular frequencies with a 5% change in the mechanical torque of both machines at the same time are shown in Fig. 3

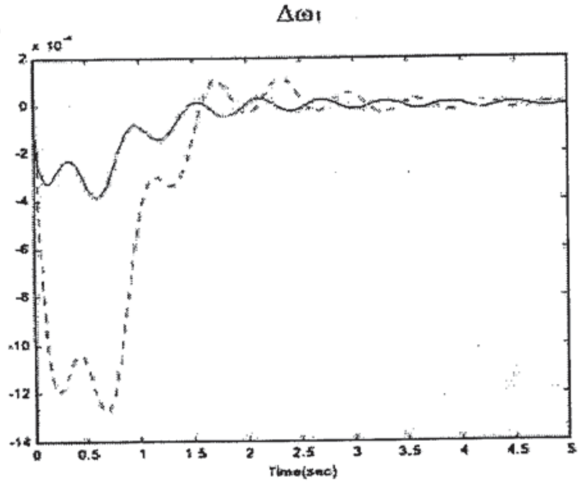

Fig.2(a)The angular frequency response of machine 1.

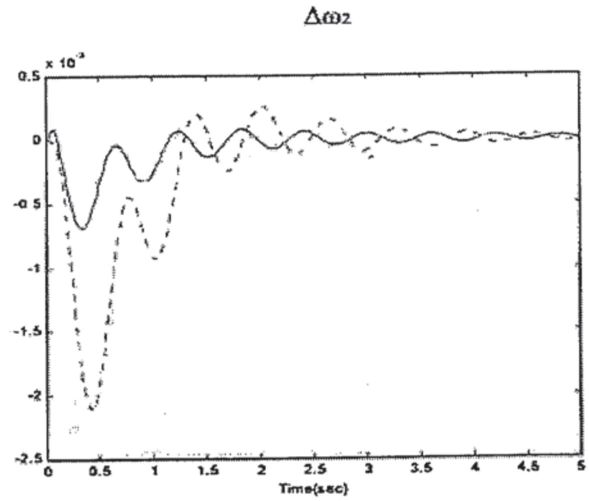

Fig. 2(b)The angular frequency response of machine 2.

Fig. 2. The transient responses of the angular frequencies with a 5% change in the mechanical torque of machine 1

Proposed ————

Full states ....

$\Delta\omega_1$

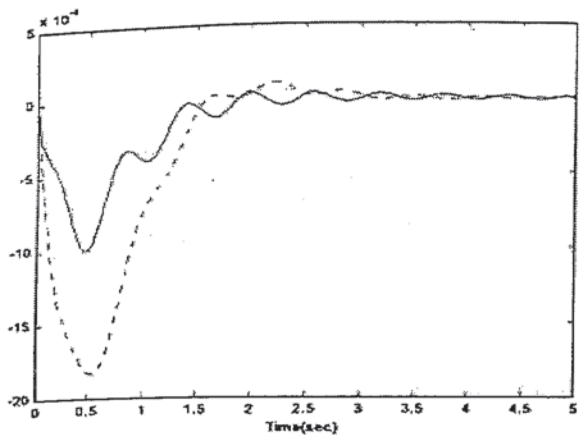

Fig.3(a) The angular frequency response of machine 1

$\Delta\omega_2$

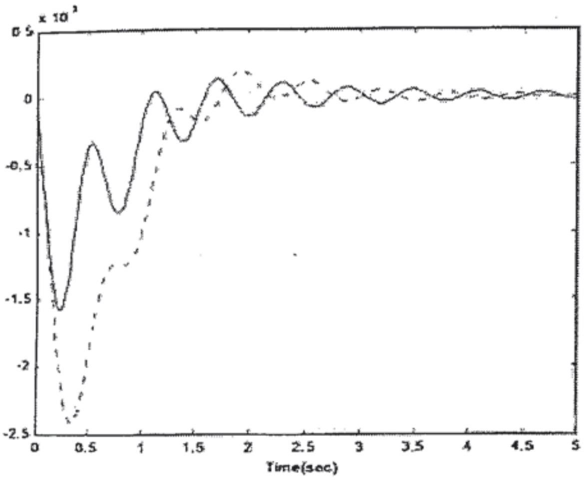

Fig.3(b) The angular frequency response of machine 2

Fig. 3. The transient responses of the angular frequencies with a 5% change in the mechanical torque of both machines

Proposed ————————

Full states ....

5. Conclusions

In this paper we suggest a new design method for the system stabilizer. The proposed method combines the optimal reduced order method and the grey prediction theory to replace the traditional full order method .This method retains the physical meaning of the output states. By using the output feedback only, this method reduces the implementation cost and increases the reliability of the system. The grey prediction method makes the next-step prediction of the states behavior of the system. An example of two-machine infinite-bus power system has been considered in this paper.

Comparison of proposed method with the traditional optimal control method is simulated and shown. The effectiveness of the grey prediction power system stabilizer in enhancing the dynamic performance stability is also verified from the simulation results. The proposed method reduces the oscillation and enhances the dynamic stability of the system and the control strategy can be implemented easily.

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