Fuzzy and Grey Forecasting Techniques and Their Applications in Innovative Design

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Abstract - In this Work, we proposed an effective method to design the power system stabilizers (PSS). The design of a PSS based on Grey Fuzzy PID Control (PSS+GFPIDC) can be formulated as an optimal linear regulator control problem; however, implementing this technique requires the design of estimators. This increases the implementation and reduces the reliability of control system. Therefore, we favor a control scheme that uses only some desired state variables, such as torque angle and speed. The grey PID type fuzzy controller (GFPIDC) designed in this paper, can predict the future output values of the system accurately. However, the forecasting step-size of the grey controller determines the forecasting value. When the step-size of the grey controller is large, it will cause over compensation, resulting in a slow system response. Conversely, a smaller step-size will make the system respond faster but cause larger overshoots.

***Key Words*:** PID Controller, Power System Stabilizer (PSS), On-line rule tuning, Grey Prediction, Grey Fuzzy PID Control

1.INTRODUCTION *(Size 11, Times New roman)*

A grey predictor with a small fixed forecasting step-size will make the system respond faster but cause larger overshoots. Conversely, the bigger step-size of the grey predictor will cause over compensation, resulting in a slow system response. In order to obtain a fast system respond with a little overshoot, the step-size of the grey predictor can be changed adaptively. In the literature of the grey system theory, there are some methods that tune the step-size of the grey predictor according to the input state of the system. In order to determine the appropriate forecasting step-size, some online rule tuning algorithms using a fuzzy inference system have been proposed for the control of an inverted pendulum, fuzzy tracking method for a mobile robot and non-minimum phase systems..

The power system stabilizers are added to the power system to enhance the damping of the electric power system. The design of PSSs can be formulated as an optimal linear regulator control problem whose solution is a complete state control scheme. But, the implementation requires the design of state estimators. These are the reasons that a control scheme uses only some desired state variables such torque angle and speed. Upon this, a scheme referred to as optimal reduced order model whose state variables are the deviation of torque angles and speeds will be used. The approach retains the modes that mostly affect these variables. In this paper, we adopt a grey model to predict the output states value. The PID controller is the master controller and the fuzzy control is the slave control to enhance the master one. Furthermore, we cannot make sure that the forecasting step size and PID parameters.

After the grey system theory was initiated by Deng in 1982, Cheng proposed a grey prediction controller to control an industrial process without knowing the system model in 1986. From that moment, more and more applications and researches of the grey prediction control were presented.

The essential concept of this paper is that the forecasting step size in the grey predictor can be tuned according to the input state of the system during different periods of the system response. To approach this object, we propose an on-line rule tuning mechanism so that it can quickly regulate an appropriate negative or positive forecasting step size. An on-line rule tuning algorithm using the concept of reinforcement learning and supervised learning is proposed to tune the consequent parameters in the fuzzy inference system such that the controlled system has a desired output.

This Work is proposed on-line rule tuning grey prediction fuzzy control system is described an inverted pendulum control problem is considered to illustrate the effectiveness of the proposed control scheme.

2. Body of Paper

Grey Fuzzy Theory

GM (1, 1) Model

GM (1, 1) type of grey model is most widely used in the literature, pronounced as “Grey Model First Order One Variable”. This model is a time series forecasting model. The differential equations of the GM (1,1) model have time-varying coefficients. In other words, the model is renewed as the new data become available to the prediction model. The GM (1,1) model can only be used in positive data sequences. In this paper, a non-linear liquid level tank is considered. It is obvious that the liquid level in a tank is always positive, so that GM (1, 1) model can be used to forecast the liquid level. In order to smooth the randomness, the primitive data obtained from the system to form the GM (1, 1) is subjected to an operator, named Accumulating Generation Operation (AGO), described above. The differential equation (i.e. GM (1, 1)) thus evolved is solved to obtain the n-step ahead predicted value of the system. Finally, using the predicted value, the inverse accumulating operation (IAGO) is applied to find the predicted values of original data. Consider a single input and single output system. Assume that the time sequence $X^{(0)}$ represents the outputs of the system) x.

$$X^{(0)} = \left(x^{(0)}(1), x^{(0)}(2), \ldots \ldots x^{(0)}(n)\right), n \geq 4 \quad (1)$$

Where X(0) is a non-negative sequence and n is the sample size of the data. When this sequence is subjected to the Accumulating Generation Operation (AGO), the following sequence X(1) is obtained. It is obvious that X(1) is monotone i0)(n)) , n ≥ 4

$$X^{(1)} = \left(\left(x^{(1)}(1), x^{(1)}(2), \ldots \ldots x^{(1)}n\right)\right), n \geq 4 \quad (2)$$

Where

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), k = 1,2,3, \ldots . . n \quad (3)$$

The generated mean sequence Z(1) of X(1) is defined

- $z^{(1)} = \left(z^{(1)}(1), z^{(1)}(2), \ldots \ldots z^{(1)}(n)\right)$

(4)

Where z(1)(k) is the mean value of adjacent data, i.e.

$$z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1), k = 2,3, \ldots \ldots n \quad (5)$$

The least square estimate sequence of the grey difference equation of GM (1,1) is defined as follows:

$$x^{(0)}(k) + az^{(1)}(k) = b \quad (6)$$

The whitening equation is therefore as follows:

$$\frac{dx^{1}(t)}{dt} + ax^{1}(t) = b \quad (7)$$

In above, $[a, b]^T$ is a sequence of parameters that can be found as follows:

$$[a, b]^T = (B^T B)^{-1} B^T Y \quad (8)$$

Where

$$Y = \left[x^{(0)}(2), x^{(0)}(3), \cdots \cdots \cdots, x^{(0)}(n)\right]^T \quad (9)$$

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(2) & 1 \\ \cdot & \\ \cdot & \\ \cdot & \\ -z^{(1)}(n) & 1 \end{bmatrix} \quad (10)$$

According to equation (8), the solution of x(1)(t) at time k:

$$x_p^{(1)}(k+1) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-ak} + \frac{b}{a}$$

To obtain the predicted value of the primitive data at time (k+1), the IAGO is used to establish the following grey model.

$$x_p^{(0)}(k+1) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-ak}(1 - e^{a}) \quad (12)$$

And the predicted value of the primitive data at time (k+H):

$$x_p^{(0)}(k+H) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-a(k+H-1)}(1 - e^{a}) \quad (13)$$

The parameter (a) in the GM (1,1) model is called “development coefficient” which reflects the development states of X(1)p and X(0)p . The parameter b is called “grey action quantity” which reflects changes contained in the data because of being derived from the background values.

3. Grey Fuzzy PID Type Controller (GFPIDC)

During the development of fuzzy controller two variables, error (e) which is the difference between rotor speed deviation and stabilized voltag

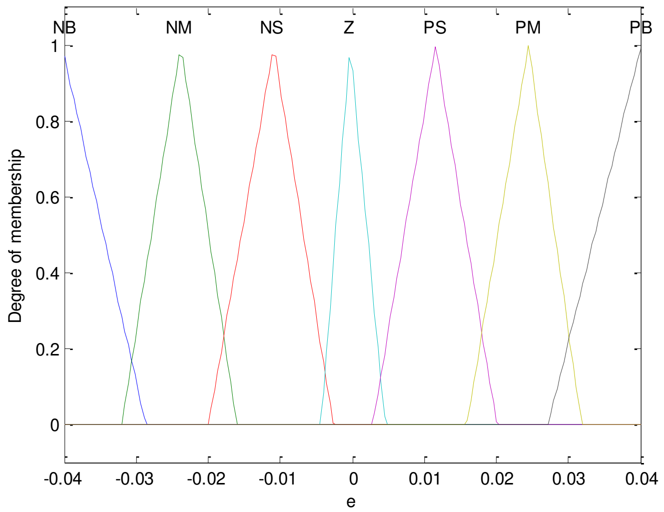


Fig.1 (a) the membership functions of error (e) e (both in pu) has been used as first input variable for designing of fuzzy controller. On the same time the rate of change of error signal ($\dot{e}$) has been taken as the second input variable for the fuzzy controller.

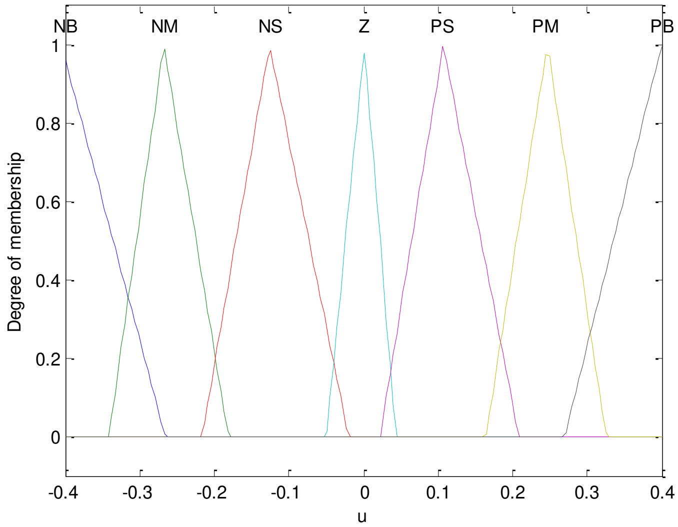


Fig.1 (b) the membership functions of rate of change of error ($\dot{e}$)

The linguistic terms chosen for this controller are seven. They are negative large (NL), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM) and positive large (PL). After assigning the input, output ranges to define fuzzy sets, mapping each of the possible seven input fuzzy values of error (e), rate of change of error ($\dot{e}$) to the seven output fuzzy values is done through a rule base. The rule base designed and employed in this paper for the fuzzy PID type controller are given as

1. If (e is NB) and (edot is NB) then (u is NB) (1)
2. If (e is NB) and (edot is NM) then (u is NB) (1)
3. If (e is NB) and (edot is NS) then (u is NB) (1)
4. If (e is NB) and (edot is Z) then (u is NB) (1)
5. If (e is NB) and (edot is PS) then (u is NM) (1)
6. If (e is NB) and (edot is PM) then (u is NS) (1)
7. If (e is NB) and (edot is PB) then (u is Z) (1)
8. If (e is NM) and (edot is NB) then (u is NB) (1)
9. If (e is NM) and (edot is NM) then (u is NB) (1)
10. If (e is NM) and (edot is NS) then (u is NM) (1)

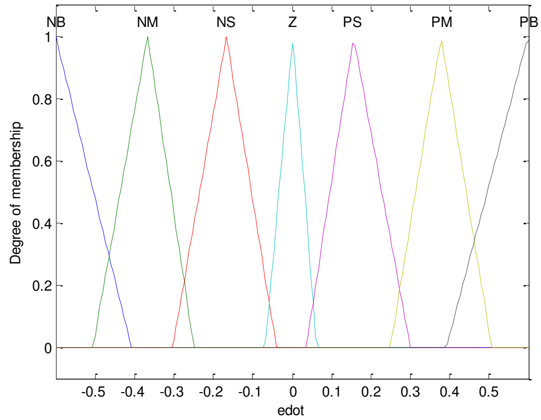


Fig.1 (c) the membership functions of output control signal u

11. If (e is NM) and (edot is Z) then (u is NM) (1)

and (edot is Z) then (u is NM) (1)

12. If (e is NM) and (edot is PS) then (u is NS) (1)
13. If (e is NM) and (edot is PM) then (u is Z) (1)
14. If (e is NM) and (edot is PB) then (u is PS) (1)
15. If (e is NS) and (edot is NB) then (u is NB) (1)
16. If (e is NS) and (edot is NM) then (u is NM) (1)
17. If (e is NS) and (edot is NS) then (u is NM) (1)
18. If (e is NS) and (edot is Z) then (u is NS) (1)
19. If (e is NS) and (edot is PS) then (u is Z) (1)
20. If (e is NS) and (edot is PM) then (u is PS) (1)
21. If (e is NS) and (edot is PB) then (u is PM) (1)
22. If (e is Z) and (edot is NB) then (u is NM) (1)
23. If (e is Z) and (edot is NM) then (u is NM) (1)
24. If (e is Z) and (edot is NS) then (u is NS) (1)
25. If (e is Z) and (edot is Z) then (u is Z) (1)
26. If (e is Z) and (edot is PS) then (u is PS) (1)
27. If (e is Z) and (edot is PM) then (u is PM) (1)
28. If (e is Z) and (edot is PB) then (u is PM) (1)
29. If (e is PS) and (edot is NB) then (u is NM) (1)
30. If (e is PS) and (edot is NM) then (u is NS) (1)
31. If (e is PS) and (edot is NS) then (u is Z) (1)
32. If (e is PS) and (edot is Z) then (u is PS) (1)
33. If (e is PS) and (edot is PS) then (u is PM) (1)

34. If (e is PS) and (edot is PM) then (u is PM) (1)
35. If (e is PS) and (edot is PB) then (u is PB) (1)
36. If (e is PM) and (edot is NB) then (u is NS) (1)
37. If (e is PM) and (edot is NM) then (u is Z) (1)
38. If (e is PM) and (edot is NS) then (u is PS) (1)
39. If (e is PM) and (edot is Z) then (u is PM) (1)
40. If (e is PM) and (edot is PS) then (u is PM) (1)
41. If (e is PM) and (edot is PM) then (u is PB) (1)
42. If (e is PM) and (edot is PB) then (u is PB) (1)
43. If (e is PB) and (edot is NB) then (u is Z) (1)
44. If (e is PB) and (edot is NM) then (u is PS) (1)
45. If (e is PB) and (edot is NS) then (u is PM) (1)
46. If (e is PB) and (edot is Z) then (u is PB) (1)
47. If (e is PB) and (edot is PS) then (u is PB) (1)
48. If (e is PB) and (edot is PM) then (u is PB) (1)
49. If (e is PB) and (edot is PB) then (u is PB) (1)

The FIS editor and the surface plot of the fuzzy controller are shown in figure (3) (a) and (b).

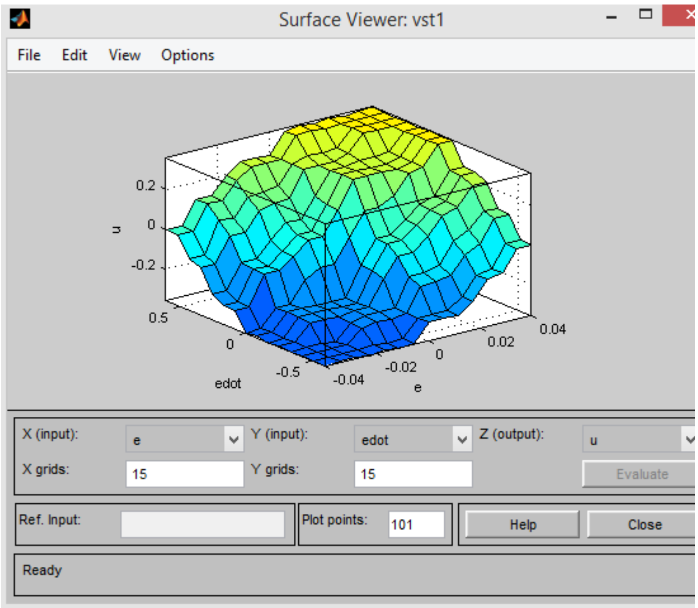
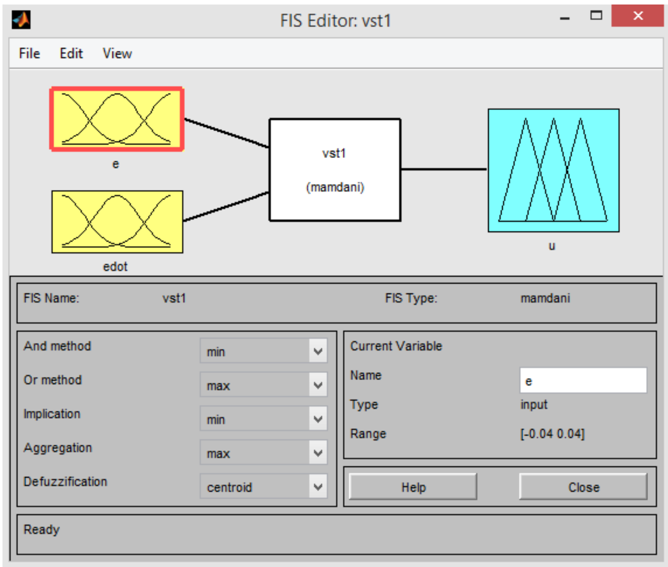


Figure (2)(a) FIS editor of developed Fuzzy Controller.

4.Design of Adaptive Grey Fuzzy PID Type Controller (GFPIDC)

In most control applications, the control signal is a function of the error present in the system at a prior time. This methodology is called as "delay control". In grey systems theory, prediction error is used instead of current measured error. In similar lines,



during the development of the grey PID type fuzzy controller, the prediction error is considered as the error of the system.

Figure (2) (b) Surface plot of developed Fuzzy Controller.

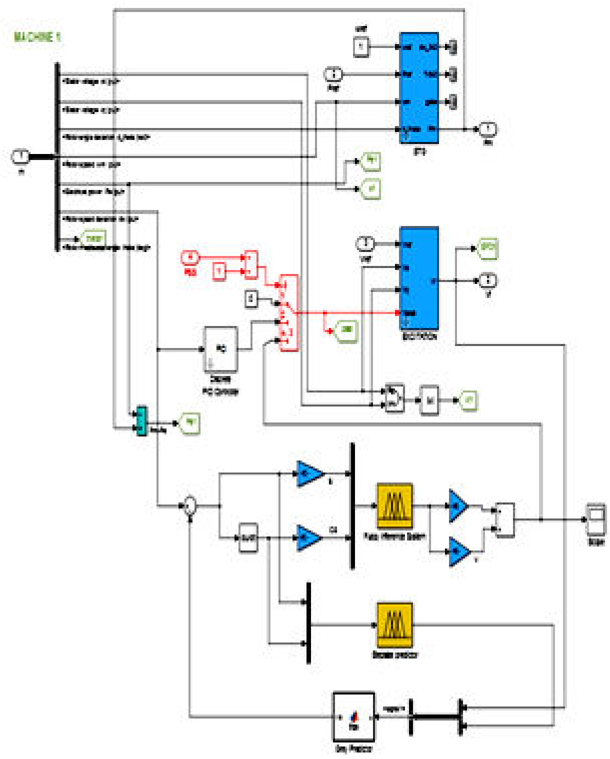


Fig.3 Internal configuration of area 1(subsystem)

To investigate the developed two-area four-machine system performance the following disturbances were considered in the simulation studies

i. Steady state operation (ie Without fault)

4.1 Steady state operation (ie without fault)

Various performance such as terminal voltage (Vt), speed deviation (dω), active power

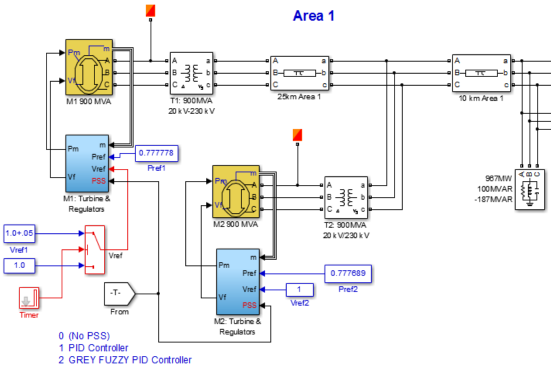


Fig.4 Internal configuration of Turbine and regulator (subsystem)

deviation (Pa) and active power transfer from bus 1 to bus2 (P) of the proposed grey fuzzy PID controlled power system stabilizer (GFPIDC) is compared with conventional PID controller based power system stabilizer and system without PSS for steady state operations. Figure (4) to figure(6) shows the various results obtained after simulation of steady state operation of the proposed power system.

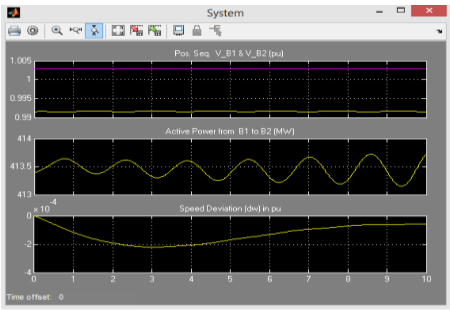


Figure (4) (a) System Response without PSS

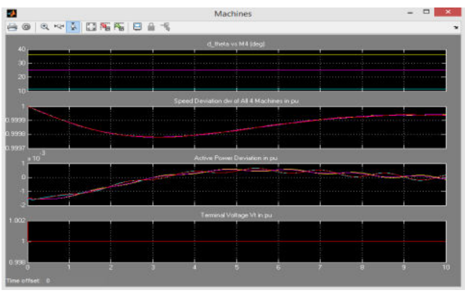


Figure (4) (b) System Response without PSS

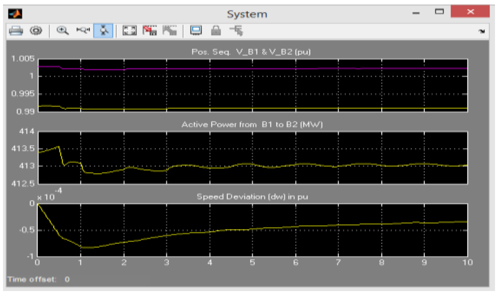


Figure (5) (a) System Response with PID Controller

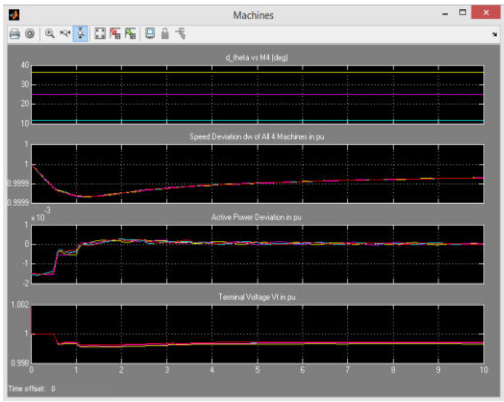


Figure (5) (b) System Response with PID Controller

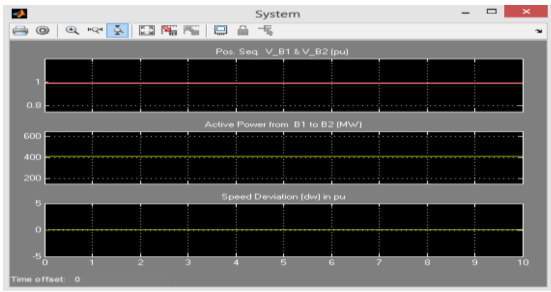


Figure (6) (a) System Response with Grey Fuzzy PID Controller

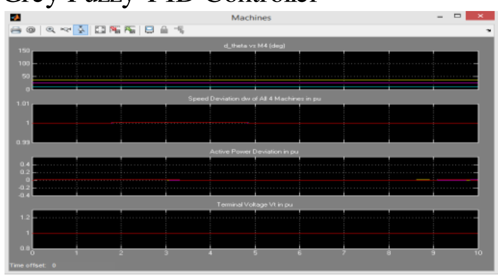


Figure (6) (b) System Response with Grey Fuzzy PID Controller

5. CONCLUSIONS

This paper proposes a grey Fuzzy PID Controller (GFPIDC) with a variable prediction horizon for power system stability control. The simulation results show that the proposed method not only reduces the overshoot and the rise time but also maintain a better disturbance rejection. In real life, there are always some uncertainties because an accurate mathematical model of a physical system cannot generally be defined. Noise that exists in various stages of the system is an additional problem. The proposed adaptive grey GFPIDC has the ability to handle these difficulties.
An on-line rule tuning mechanism is constructed to provide an appropriate forecasting step size to the grey predictor. An on-line rule grey fuzzy PID control system structure with an appropriate positive or negative forecasting step size is present so that the system controlled by the proposed structure has a good overall performance. Observing the result of simulation, it is obvious that the GFPIDC controller based PSS stabilizer (PSS-GFPIDC) can stabilize the mentioned synchronous generator. It is also observed that the system turned back to its stabilizer mode after disturbance, due to the three phase short circuit, to compensate the bad impact of disturbance

REFERENCES

1. 1. Anderson P. M. and Fouad A.A., “Power system control and stability’ Ames, 1owa: lowa state university press, 1977.
2. Deng J., "Control problems of grey system," Systems & Control Letters, Vol. 1, No. 5, pp. 288-294, 1982.
3. Deng J., "Grey Systems Control," Huazhong University of Science and Technology Press, Wuhan, 1985. (in Chinese)
4. Cheng B., "The Grey Control on Industrial Process," Journal of Huangshi College, Vol. 1, pp. 11-23, 1986. (in Chinese)
5. Deng J. L., “Introduction to grey system theory”, *The Journal of Grey System*, Vol. 1, pp. 1-24, 1989.