High Performance Intelligent PID Control System and Application

MA Li-xin
College of Computer & Electrical Engineering
University of Shanghai for Science and Technology
Shanghai, 200093, China
E-mail: malixin_666@hotmail.com

CHEN Min-xuan
College of Optical & Electronic Information Engineering
University of Shanghai for Science and Technology
Shanghai, 200093, China
E-mail: chenminxuan1231@hotmail.com

ZHOU Tao
College of Computer & Electrical Engineering
University of Shanghai for Science and Technology
Shanghai, 200093, China
E-mail: zt739@163.com

Hiromi Miyajima
Department of Electrical and Electronics Engineering
Kagoshima University
1-21-40 Korimoto , Kagoshima,890-0065 Japan

***Abstract*—PID (Proportional Integral Derivative) controllers are widely used in industrial process control system.Tuning the parameters of PID controller is very important in PID control. Neural network algrithm is a massively parallel, distributed information processing system; it has self-learning, adaptive, non-linear mapping capabilities and fault-tolerance, and achieved certain results in the field of control.Ordinary BP neural networks PID controller was mentioned in document [1], it had a good robust performance. But its precision and performance can be improved by high-order BP neural networks which is introduced and used in this document.The simulation result shows that Frequency Control System Compared to regular high BP network convergence speed, high precision control, fast response, achieve the purpose of raising the quality and effectiveness of control.**

***Keywords*—PID, Higher order neural networks, BP algorithm**

I. INTRODUCTION

PID control is one of the earliest control strategies. It is widely used in industrial process control system because of its simple algorithm, high reliability. However, there are nonlinear, time-varying uncertainty conditions in the actual production process. Even if the mathematical models are established, they are sometimes very complex. The traditional control methods cost so much and the result is not satisfactory. Up to now, there are no satisfactory solutions about the tuning of PID parameters. Ordinary BP neural networks PID controller was mentioned in document [1], it had a good robust performance. But its precision and performance can be improved by high-order BP neural networks which is introduced and used in this document. The result show that high-order BP can improve system precision, reduce error remarkably. To solve this problem, a high-performance intelligent PID control strategy, high BP neural network control, is used for tuning PID parameters, and the PID control of frequency converter is taken as an example. There is nonlinear condition in Frequency Control System in practical application and the system model could not be fully described accurately because of the motor speed changes, outside interference. Therefore, traditional PID controller can not meet demand. Neural network is a massively parallel, distributed information processing system; it has self-learning, adaptive, non-linear mapping capabilities and fault-tolerance, and achieved certain results in the field of control. To solve this problem, high-order BP neural network is used for tuning parameters in frequency control system of fans and pumps. The results showed that it is better than traditional BP algorithm in the convergence speed, the accuracy and stability of control system. High-order BP neural network can improve the quality and effectiveness of the control system.

II. FREQUENCY CONVERTER CONTROL SYSTEM AND IT'S PID CONTROLLER BASIC STRUCTURE

A. *Frequency Converter Control System Structure*

The frequency converter control system provides the necessary driving signals for main circuit. The control system circuit is to generate kinds of gate and base driving signals for V/f or current control according to the control modes of frequency converter. In addition, it also includes the signal detection circuit of current, voltage, the motor speed, the protective circuit of the frequency converter and the motor, the control circuit of the external interface circuit and digital operational box.

The center of converter control circuit is a high-performance microprocessor, and PROM, RAM, ASIC chips, and other peripheral circuits necessary.

Through ADC, DAC other circuit detection circuit and external circuit signal sent by setting parameters and values using pre-prepared and the necessary software, and various other parts of the inverter control signal or that the necessary information. -- took control in a generic converter mainly perform the following tasks:

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(1) of the input signal processing input signals including frequency converter (speed) and signal operating instructions, stop being transferred and conversely operational control signal. There are two input signals in the frequency converter simulated instructions signals: and Digital Signal. D converters can be changed to read instructions simulated signals into digital signal microprocessor, after insulation amplifier and digital signal is being sent to the microprocessor.

(2) The rate of deceleration is the basic regulatory function for the general direction of modern signal changes According to the motor deceleration and acceleration time prior to the time set for acceleration and deceleration. To make the process more smooth acceleration and deceleration. New S-speed-up and slow-down converter is also functional.

(3) V control during this processing, a slowdown in exports and increase computational circuits regulate the output voltage signal corresponding to the signals, slip frequency control and vector control. According to the algorithms necessary for the selected control method, the corresponding voltage signal will output.

(4) The calculus PWM control of the converter, two PWM wave generation methods, using a dedicated circuit (or GAL PAL) calculated directly generated or generated by the CPU. Since the latter approach more flexible, as the CPU performance of the converter developed, the latter has gradually become the mainstream.

With the development of semiconductor technology, the new inverter control circuit and a high-performance microprocessor for the user customized LSI has DDC control become mainstream, and further improve the performance, enhance the function and reliability. To meet the special needs converter. Inverter current major manufacturers have their own specialized ASIC chip. These chips will be needed for the inverter control function together (some of the functions include DSP), thereby achieving enhanced functions, smaller, improve reliability purposes. Moreover, in order to increase microprocessors performance, many of the past by the hardware circuit functions are now replaced by software to complete, thus greatly reducing costs. and enhancing the reliability. In addition, to further enhance the operational capacity of the converter. In some vector control inverter has adopted a dual-CPU, Vector Control CPU with a special need for the various terms.

B. The Basic Structure of PID Controller.

Figure 1 is an inverter control basic component circuit; feedback signal can be detected by detection circuit. PID control for the la: can be

$$u(t) = K_p(e(t) + \frac{1}{T_i}\int_0^t e\,dt + T_d\frac{de}{dt}) + u_0$$

Written in the form of a transfer function

$$G(s) = \frac{U(s)}{E(s)} = K_p(1 + \frac{1}{T_i s} + T_d s)$$

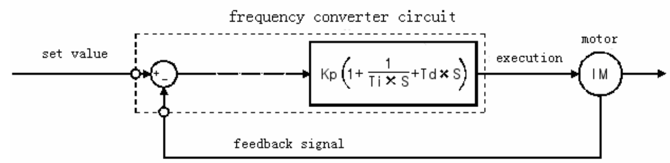

Figure 1. Diagram of PID controller basic tenets

In figure 1: K_p——Proportion parameter；

T_i——Integral time；

S——Calculus unit；

T_d——Differential Time.

Incremental digital PID control algorithm is

$$\Delta u(k) = k_p[error(k) - error(k-1)] + k_i error(k)$$
$$+ k_d[error(k) - 2error(k-1) + error(k-2)]$$
$$u(k) = u_0 + \Delta u(k) \quad (1)$$

Kp、Ki、Kd——Proportion, integral, differential parameters ；

u(k)——Sampling time of the k-th computer output

error(k)——K-th input sampling time deviation

Figure 2 is a schematic diagram used conventional PID control method.

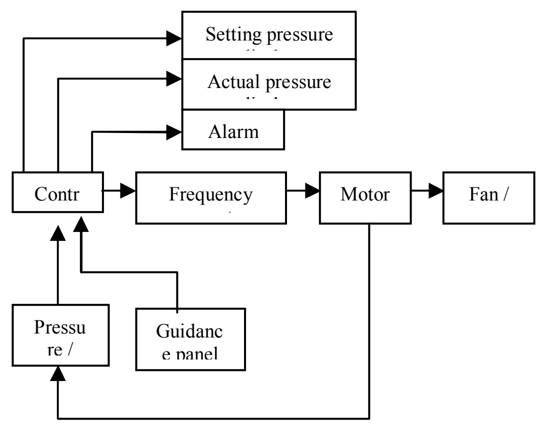

Figure 2. The schematic diagram of frequency control

When the variable frequency works, the data acquisition controller will be used in order to process control and speed. Controller parameters sent, or when the actual flow pressure below the set value, According to data errors and set the PID parameters, issued instructions through the DAC. Output increased frequency converter to enable increased speed; otherwise, the reduced speed. The operational advantages of the system according to need, Working point better than the bumper or when there has been a marked change in control valves. According to the power and speed is proportional to the third power, we can see that frequency converter is used to make power declined significantly. Improve efficiency and reduce waste, the system's power consumption dropped; drawback is the need to target testing in accordance with PID control parameters, the system slow to respond, the high precision of a larger oscillation.

III. SELF-TUNING PARAMETERS BASED ON BP NEURAL NETWORK CONTROLLER

A. PID Controller Structure of the neural Network System

When the control system parameters change, the need for real-time adjustment of PID parameters, this is difficult to achieve in actual operation. ANN's strong and adaptive self-learning ability, Real-time neural network training and learning to adjust PID control parameters. It will be quite satisfactory control effect. Control system block diagram shows in Figure 3.

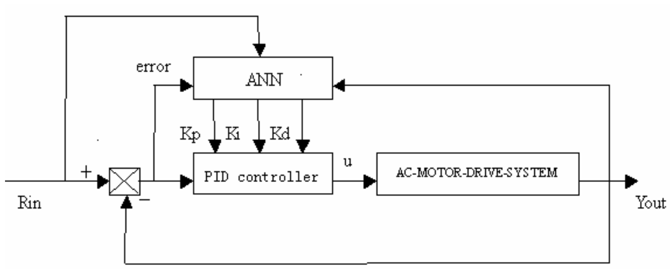

Figure 3 PID controller based on BP neural network architecture

PID controller structure of the neural network system, Classic PID controller and neural network composed of two parts, which is directly responsible for the classic PID closed-loop process control object, and three parameters Kp and Ki. Kd fixed for the entire line; NN system will be based on neural networks and operations, PID controller parameters, to achieve certain performance targets optimization The output neuron output layer corresponding to the state of the PID controller three adjustable parameters Kp, Ki, Kd. Self-learning neural network, weighting adjustments Controller corresponding to a certain stability so that optimal control law is under the parameters of a PID controller.

B. Higher-BP Sself-tuning Algorithm Parameters

- PID controller using high BP 4-4-3 structure, the input is
- $O_j^{(1)} = x(j) \quad j = 1,2,3,4$ (2)
- x (1), x (2), x (3) for a given input values (Rin). Output (Yout), and deviation (error), x (4) amendments to the Radio Network, the general set to 1.

  The input and output for the hidden layer:
- $net_i^{(2)}(k) = \sum_{j=1}^{4} w_{ij}^{(2)} O_j^{(1)}$ (3)
- $O_i^{(2)}(k) = f(net_i^{(2)}(k)) \quad (i = 1,2,3,4)$

  $w_{ij}^{(2)}$ ——Hidden layer weighting coefficients
- Hidden layer neuron activation function in the sigmoid function with Symmetrical:
- $f(x) = \tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}}$ (4)
- Input to output layer:
- $net_l^{(3)}(k) = \sum_{i=1}^{3} w_{li}^{(3)} O_i^{(2)}(k) + \sum_{i=1}^{3} \sum_{p=i+1}^{3} w_{lip}^{(3)} O_i^{(2)}(k) O_p^{(2)}(k)$ (5)

  $w_{lip}^{(3)}$ represents weight between the output layer l and the product of the i-th and p-th hidden layer

  Output to output layer:
- $O_l^{(3)}(k) = g(net_l^{(3)}(k)) \quad (l = 1,2,3,)$
- $O_1^{(3)}(k) = Kp$
- $O_2^{(3)}(k) = Ki$
- $O_3^{(3)}(k) = Kd$
- Three adjustable output layer corresponding output node Kp, Ki, Kd, not a negative parameter. Therefore, the output neuron activation functions of non-negative function of the Sigmoid:
- $g(x) = \frac{1}{2}(1 + \tanh(x)) = \frac{e^x}{e^x + e^{-x}}$ (6)

  the performance function:
- $E(k) = \frac{1}{2}(rin(k) - yout(k))^2$ (7)
- the gradient method in accordance with the weighting function network:
- $\Delta w_{li}^{(3)}(k) = -\eta \frac{\partial E(k)}{\partial w_{li}^{(3)}} + \alpha \Delta w_{li}^{(3)}(k-1)$ (8)

  η ——learning rate;

  α ——inertia coefficient;
- The output layer weighting coefficients can be derived for the learning algorithm:
- $\Delta w_{lip}^{(3)}(k) = \eta \delta_l^{(3)} O_{ip}^{(2)}(k) + \alpha \Delta w_{lip}^{(3)}(k-1)$ (9)
- $O_{ip}^{(2)}(k)$ ——the output of the product of the i-th and p-th hidden layer
- $\delta_l^{(3)} = error(k) \operatorname{sgn}\left(\frac{\partial y(k)}{\partial \Delta u(k)}\right) \frac{\partial \Delta u(k)}{\partial O_l^{(3)}(k)} g'(net_l^{(3)}(k))$
- $(l = 1,2,3)$ (10)
- $\frac{\partial \Delta u(k)}{\partial O_1^{(3)}(k)} = error(k) - error(k-1)$ (11)
- $\frac{\partial \Delta u(k)}{\partial O_2^{(3)}(k)} = error(k)$ (12)
- $\frac{\partial \Delta u(k)}{\partial O_3^{(3)}(k)} = error(k) - 2error(k-1) + error(k-2)$ (13)

- Similarly, the weighting coefficients can have hidden learning algorithm:
- $\Delta w_{ij}^{(2)}(k) = \eta\delta_i^{(2)} O_j^{(1)}(k) + \alpha\Delta w_{ij}^{(2)}(k-1)$ (14)
- $\delta_i^{(2)} = f'(net_i^{(2)}(k)) \sum_{l=1}^{3} \delta_l^{(3)} w_{li}^{(3)}(k)$
- $(i = 1,2,3,4,5)$ (15)
- $g'(\cdot) = g(x)(1 - g(x))$
- $f'(\cdot) = (1 - f^2(x))/2$ (16)
- Above the ordinary high BP neural network algorithm is derived on the basis of the algorithm, the algorithm to compare the results Higher-order neural network structure using 4-3-3, 4-6-3 ordinary BP neural network structure. This gives the right number of values of the same algorithm. BP algorithm's main difference algorithm with high-ranking is in the output layer. BP and the rest of the general algorithm is basically the same. The input of each layer of higher-order NN is $\sum w_{ijl} x_i x_j$, and the ordinary NN is $\sum w_{il} x_i$.

IV. Model Design and Simulation of Control System

Variable Speed System control the mathematical model can be simplified to:

$$Y_{out}(k) = \frac{a(k)[0.49Y_{out}^2(k-1) - 0.53Y_{out}^2(k-2)]}{1 + 1.2Y_{out}^4(k-1) - 0.9Y_{out}(k-2)} + u(k-1)$$

$a(k)$ ——Slowly - varying coefficient reflects the system to simulate the load changes

Matlab7.0 is used for simulation of BP neural network which the ordinary is 4-6-3 structure, and higher BP neural network is 4-3-3 structure. Learning rate $\eta = 0.28$, inertia coefficient $\alpha = 0.04$, weight coefficient is a random from[-0.5,0.5].Input directive is step signal.

For ordinary BP neural network and several high-ranking neural network simulation results show that: For the initial weights in the high-speed neural network algorithm for the convergence of higher learning in neural networks.

TABLE 1. THE COMPARISON BETWEEN BP ALGORITHM AND HIGHER BP ALGORITHM

	BP		HOBP	
	t_{up} /s	$\delta\%$	t_{up} /s	$\delta\%$
	0.049	4.7	0.051	2.0
	0.052	4.4	0.045	2.5
	0.057	5.0	0.053	2.2
	0.060	5.3	0.047	3.1
	0.051	4.3	0.050	4.0
	0.053	4.2	0.042	1.9
	0.056	5.1	0.043	3.2
	0.048	3.0	0.044	4.5
	0.047	4.5	0.039	1.5
	0.050	4.1	0.041	2.1
average	0.052	4.46%	0.045	2.7%

Table 1 data for the simulation of the five groups, said the rise time, said that over-regulation. The error can be seen than ordinary high BP results improved significantly.

Figure 4 is a high BP algorithm and the learning curve of the step response. Figure 5 is the learning stage with the classic PID control more response curve. Among them, the more bands HOBP-- high BP response curve. BP bands bp-pid-- more general response curve; pid-- stage more classic PID control algorithm response curve. It can be seen from the simulation results. Neural networks can be effective tuning PID control parameters to achieve the desired control objectives. By comparison, we can see and, BP PID control method based on high-order neural network system to enable relatively stable, the ability to adapt to change more, robustness, improved quality control.

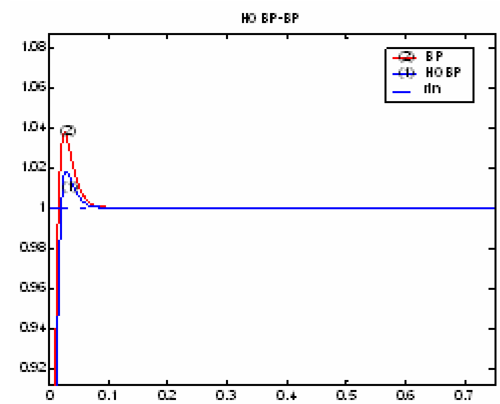

Figure 4 Step response curve of BP algorithm and higher-order BP algorithm

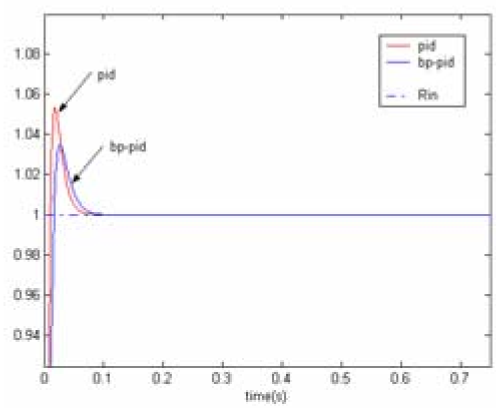

Figure 5 Step response curve of BP algorithm and traditional PID algorithm

BP neural network simulation is that the ordinary neural networks use 4-6-3 structure and 4-3-3 structure is used by higher-order BP neural network, thus the algorithm weights the same number. In comparison, under the same conditions and the general high BP network, through high-order neural networks and ordinary BP neural networks, the conclusion of simulation is: Frequency Control System Compared to regular high BP network convergence speed, high precision control, fast response, achieve the purpose of raising the quality and effectiveness of control.

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