Research on the Three-phase Voltage Aviation Rectifier Based on Neural Network PID Control

Shutuan ZHANG, Lingshun LIU, Yan LI, Zhengyin SHENG
Department of Control Engineering, Naval Aeronautical and Astronautical University, Room 305, No. 188, Twoma Road, Zhipu District, Yantai City, Shandong Province, 264001, China
E-mail: shutuanzhang@163.com

Received: 11 March 2014 /Accepted: 30 April 2014 /Published: 31 May 2014

Abstract: Aimed to the selection of the PID parameters are very difficult in the rectifier design, and can’t realize the online self-turning function of the PID parameters, the three phase voltage source PWM aviation rectifier based on neural network PID control is designed in this paper. This paper analyzes the principle of the voltage source PWM rectifier based on traditional SVPWM, and improves the control algorithm, and completes the hardware design. In addition, the control algorithm, and the circuit are verified through actual experiments. In this rectifier, the PID parameters can realize the function of the online self-turning. The experimental results show that the three-phase PWM rectifier based on neural network control can decrease the harmonic distortion and the power factor reaches to 0.991, which can supply help for the design of the three-phase voltage high power factor aviation rectifier.

Keywords: Aviation rectifier, SVPWM control, Neural network, PID.

1. Introduction

In recent years, with the continuous development of electron device with high power and frequency, high voltage direct current transmission becomes the trend of the development of aviation power system, the new aviation rectifier of high power factor rectifier and digital implementation is the research hotspot. In order to improve the power factor of the voltage rectifier, the harmonic pollution of power electronic equipment and low power factor need solve in research, therefore, the research of the new rectifier or its control strategy has become very important. The three-phase voltage source PWM rectifier, which has the characters of steady output voltage and unity power factor and so on, becomes the focus. The direct current control methods have the advantages of fast dynamic response. In the three-phase voltage source PWM rectifier control strategy study, the current control methods of current loop mainly include the one cycle control [3], the PWM current control with fixed switching frequency [4], the predicted current control [5-8], the direct power control method [9], and so on.

Compared with the traditional sine pulse width modulation (SPWM), the three-phase voltage source rectifier with space vector PWM (SVPWM) control not only has high DC voltage utilization, fast dynamic response characteristics, but also has the characteristic of easy digital realization, so this type rectifier has been widely studied. The study found, the incremental PID controller has the character of algorithm simple and easy to be realized, but the control parameters of the PID controller tuning online has certain difficulty. So, the new Neural network PID controller, which combine the neural network with PID control, can achieve on-line PID controller parameter tuning through the online
learning, and achieve good control effect. In paper [9], the direct power control [10] of the rectifier based on SVPWM control, the feasibility and effectiveness of the control scheme have been verified. The incremental PID algorithm is studied in paper [11-13], the simulation results shown that this controller has high control precision compared with traditional PID controller. While, the BP neural network PID controller scheme by using DSP has been realized and achieved good results [14].

2. The Three-phase Voltage Source Rectifier Based on SVPWM Control

The schematic diagram of the three-phase voltage source rectifier based on SVPWM control is shown in Fig.1, it works by using the reference frame theory that transfer the three-phase static coordinate system into a two-phase rotating coordinate system. Then the six PWM control signal can be generated by using the space vector control algorithm, which can achieve the precise control of the switch. At last, the rectifier can afford the desired DC voltage. Double-achieve the precise control of the switch. At last, the rectifier can afford the desired DC voltage. Double-achieve the precise control of the switch. At last, the rectifier can afford the desired DC voltage. Double-achieve the precise control of the switch. At last, the rectifier can afford the desired DC voltage. Double-achieve the precise control of the switch. At last, the rectifier can afford the desired DC voltage. Double-achieve the precise control of the switch. At last, the rectifier can afford the desired DC voltage. Double-achieve the precise control of the switch.

![Fig.1. Schematic diagram of three-phase VSR based on SVPWM control.](image)

The rectifier based on the traditional SVPWM control algorithm used the PID control is simple and easy to implement, but the control parameters of the PID controller can not realize the function of the online self-turning and obtain the satisfy results, which needs to be further improved.

3. The Incremental PID Controller Based on Neural Network

The traditional incremental PID refers to realize the output of digital controller to control the incremental \( \Delta u(k) \). When the implementing agencies need the incremental of control, we should use the incremental PID control.

According to the associated references on PID control, we know that the formula of PID controller is:

\[
u(k-1) = K_p e(k-1) + K_i \sum_{j=0}^{k-1} e(j) + K_d [e(k-1) - e(k-2)]
\]

where \( K_p, K_i, K_d \) is the proportional coefficient, the integral coefficient and the differential coefficient respectively; \( e(j) \) is the input deviation value of the \( j \)th sampling; \( u(k-1) \) is the output of the \((k-1)\)th sampling. The incremental of the PID control algorithm for the corresponding is:

\[
\Delta u(k) = K_p [e(k) - e(k-1)] + K_i e(k) + K_d [e(k-1) - 2e(k-1) + e(k-2)]
\]

In the traditional incremental PID controller, \( K_p, K_i, K_d \) the three parameters is difficult to adjust, it increases the difficulty of system design. However the neurons have the characteristics of self-learning, adaptive ability and easy to calculate, so the improved neural network incremental PID control algorithm can be implemented the control parameters online setting. It can effectively solve the problem that the traditional PID controller parameters tuning difficult.

The input of neurons can be defined as follows:

\[
\begin{align*}
x_1(k) &= e(k) - e(k-1) = \Delta e(k) \\
x_2(k) &= e(k) \\
x_3(k) &= e(k) - 2e(k-1) + e(k-2)
\end{align*}
\]

The corresponding single-output function is:

\[
u(k) = u(k-1) + \alpha_1 x_1(k) + \alpha_2 x_2(k) + \alpha_3 x_3(k),
\]

where \( \alpha_1, \alpha_2, \alpha_3 \) are the weighting coefficient corresponding the \( x_i(k) \) (i = 1, 2, 3). The above three parameters using supervised learning rules and the learning algorithm is defined as follows:

\[
\begin{align*}
\alpha_1(k) &= \alpha_1(k-1) + \eta_1 e(k-1) u(k-1) x_1(k-1) \\
\alpha_2(k) &= \alpha_2(k-1) + \eta_2 e(k-1) u(k-1) x_2(k-1) \\
\alpha_3(k) &= \alpha_3(k-1) + \eta_3 e(k-1) u(k-1) x_3(k-1)
\end{align*}
\]
where $\eta_p, \eta_i, \eta_d$ are using three kinds of learning rate. Therefore, the neural network incremental PID control can adjust the weighting coefficients to realize parameter tuning. So we can reduce the difficulty of selection proportion, integral and differential coefficient, and improve the efficiency of design system.

4. The Rectifier Design Based on Neural Network PID Control

The schematic diagram of three-phase voltage source PWM rectifier based on neural network PID control is shown in Fig. 2. The rectifier is controlled mainly by the 6 switch on and off, let the net side current track the net voltage well, so as to achieve high power factor. The traditional SVPWM control, the VSR upper bridge power switch needs to switch 6 times in one switching period, so result greater switching losses. In order to reduce the switching frequency and decrease the switch loss, five SVPWM control [12, 13] was used in this paper. Therefore, in a switching period, the VSR upper bridge power switch only need to switch 4 times. The harmonic is mainly in integer multiples of the switching frequency, due to the switching function waveform symmetry. In the SVPWM control rectifier use dual-loop control structure. The outer voltage loop is mainly used for the control of three-phase rectifier DC output voltage. The inner current loop is used for the control of current that according to the instruction current of outer voltage loop PID controller. The control circuit diagram is shown in Fig. 2. The PID controller of the three loops are using neural network PID control, which is beneficial to the learning process to realize the PID parameter, so as to obtain satisfied control effect.

It is shown that the three-phase current of the net side transfer from CLARK and PARK to acquire the two-phase current $i_d$ and $i_q$ in the rotating frame in Fig. 2.

The voltage error signal through the neural network PID controller can obtain the active current command value, at the same time the reactive current instruction value is set to zero. Then the command voltage of three-phase rectifier is obtained through decoupling. Last, the control signal of three-phase rectifier is obtained by SVPWM algorithm, and then realized the control of rectifier switch.

![Fig. 2. Schematic diagram of three-phase VSR based on neural network PID control.](image)

5. Neural Network PID Algorithm and the Flowchart of SVPWM Algorithm

In this paper, the neural network PID algorithm of the paper [10] was used. The realization of the algorithm is as follows:

1) The initialization parameter (K=2), such as $\eta_p, \eta_i, \eta_d$ and the inertia coefficient;

2) Obtain the values $r(k)$ and $y(k)$, and calculate the deviation $e(k) = r(k) - y(k)$ and $\Delta e(k)$;

3) Calculate $x_1(k), x_2(k)$ and $x_3(k)$, as the input of neural network;

4) Calculate the neural network input, output, then define the output parameters of the output layer as $k_p, k_i, k_d$;
5) Calculate the output of the controller \(\Delta u(k) + U(k)\);  
6) Limit the output value;  
7) Adjust the weighting coefficients by using neural network learning;  
8) Define \(k = k + 1\) and return to step (2).

So, the values \(x_1(k), x_2(k)\) and \(x_i(k)\) can be obtained, and they are as neural network inputs. The three output parameters respectively as three output parameters of the PID, and realize the on-line tuning.

In the design process of three-phase voltage source rectifier, the digital signal processor adopt the TMS320F2812, it’s the core part of the whole control system, which is mainly used to complete the calculation procedures, and output the calculation result. In the calculation process, the PID tuning is a difficult; the voltage loop and current loop are using neural network PID controller parameter tuning. Then use the improved algorithm to obtain the results after the corresponding transform to SVPWM subroutine. The SVPWM subroutine [13] is an important part of the software, the program flow diagram is shown in Fig. 3.

![Flowchart of SVPWM algorithm.](image)

This subroutine first according to the given \(u_{ao}\) and \(u_{bo}\) to determine the reference voltage vector \(V^*\) located sectors, then calculation \(X, Y, Z\); then according the reference voltage vector \(V^*\) located sectors to determined \(T_1\) and \(T_2\), then judge if there is over-modulation, if it exists, the new \(T_1\) and \(T_2\) should be calculated accord to the equation (3):

\[
\begin{align*}
T_1 &= \frac{T_1}{T_1 + T_2}, \\
T_2 &= \frac{T_2}{T_1 + T_2}.
\end{align*}
\]

Finally determine the vector switching points and will produce the output signals of the PWM wave.

6. The Hardware Circuit Design of the Control System

In the design process of rectifier, the hardware circuit design [13] of control system is very important. The digital control circuit use TMS320F2812 as the core processor, which is mainly used to achieve the acquisition and processing of data. It is shown in Fig. 2, the voltage and current signal that sampling from the voltage sensor and the current sensor. The output single after a condition circuit conditioning the amount of voltage 0-3 V to the TMS320F2812 AD port, and then enter the TMS320F2812 core processor. In the processor we through programming to realize the three-phase static coordinate system to two-phase rotating coordinate system and improve the function of PID regulator. At last the TMS320F2812 event manager A output a series of PWM switch signal, and after isolation drive the switch signal to the drive circuit to drive the power device of main power board, so as to realize the control of the rectifier switches.

6.1. TMS320F2812 DSP Introduction

TMS320F2812 is the 32 bit fixed-point digital signal processor that is a new generation of low price, high performance introduced by American TI Company. It is one of the best DSP chip for digital control field performance. The DSP maximum process speed can up to 150 MIPS. It can be completed 32×32 bit multiply-accumulate operations in a single instruction cycle. It integration of the flash memory 128K/64K×16 bits (Flash), an external RAM can be expanded according to the needs. There are abundant peripheral resources on TMS320F2812, it mainly include the analog-to-digital conversion module (ADC), the event manager module (EV), serial peripheral interface module (SPI), serial communications interface module (SCI), CAN controller module (eCAN) and so on. In terms of software, the integrated development environment of Code Composer Studio3.1 that TI company provide could realize C/C++ compiler, assembler, linker and debugging Windows programs based on the user. And it can be analyzed DSP targets by the host computer and real-time analysis tools.
6.2. The Voltage Adjust Circuit Design

If the TMS320F2812 want to realize the AC voltage real-time accurate sampling and processing, it requires to condition the obtain voltage signals to DSP within the allowed range. In the design, the system given the three-phase input voltage is 115 V/400 Hz, sampling by selecting the ratio for 10:1 transformer.

We can obtain the sine signal is about 11.5 V of the effective value and then through the conditioning circuit conditioning voltage signal to 0~3 V. The conditioning circuit consists of a voltage follower, addition and reverse circuit, as is shown in Fig. 4. The selected chip is LM324N, the concrete realization of the process are as follows: the acquisition of the voltage signal conditioning to ±1.5 V through appropriate filter attenuation circuit, and then through an adder circuit can get a -3~0 V voltage signal, last through a inverter converts the signal into voltage signal between 0~3 V, into the AD interface and DSP.

![Fig. 4. Voltage adjust circuit.](image)

6.3. The Current Adjust Circuit Design

Acquisition and conditioning of the AC side current signal is a prerequisite to achieve current double closed loop control. In this design we choice a LA28-NP current sensor that is produced by LEM Company. It is a closed loop compensation current sensor using a Holzer effect, has the characteristics of linear excellent accuracy, good reliability and strong anti-interference ability. Part parameters of the current sensors: the primary side rated effective value is 25 A, the secondary side rated effective value is 25 mA, the response time is less than 1μs, the linear degree is less than 0.2 % and the room temperature 25°C, accuracy is ± 0.5 %. The conditioning circuit is similar to voltage regulator circuit, we will not be described.

6.4. The DC Voltage Adjust Circuit Design

In the design process of rectifier, the DC voltage signal acquisition and use optcoupler isolation, and then feedback to the control circuit. The reference voltage value (the design for given values is 350 V) difference after neural network PID control into the current loop given value, so as to realize the real-time tracking control of DC side voltage. For the DC side voltage output is 350 V, so we design double input amplification circuit consists of operational amplifier. And we will be the output DC voltage conversion to 0-3 V range by choosing reasonable parameters values. Then send it to the AD interface of TMS320F2812. So the high and low voltage isolation purposes on. Collecting and conditioning circuit for DC voltage consist of two operational amplifiers that with two input single output circuit and the operational amplifier use the OP07 general-purpose amplifier. The positive terminal of the DC side is connected to the negative terminal of the first operational amplifier. And the negative terminal of DC voltage is connected to the in-phase input terminal of the operational amplifier. The output signal of the first operational amplifier through reverse then it is delivered to the AD interface of the TMS320F2812.

7. The Experiment Verification

In order to verify the feasibility and correctness of the control algorithm, a prototype is developed and conducted related experiments. For the prototype, the part of the hardware includes the main circuit and control circuit, digital signal processor TMS320F2812, the net side inductance is designed by the output power requirements, and select the three phase inductance value of 4 mH, the DC side capacitor value is 2200 μF; the software includes the main program, interrupt service subroutine etc. According to the design requirements, the output power is 3 kW, the three-phase input power is 115 V/400 Hz, the switching frequency is 5 kHz, the DC output voltage is 350 V. Test of network side C phrase input voltage is similar to the C phrase input waveform as shown in Fig. 5, and the load of DC output voltage waveform is shown in Fig. 6, the
DC output voltage stability in the vicinity of 350 V. It can be seen from Fig. 5 that the C phrase input voltage is basically the same phase as the input current.

![Fig. 5. Voltage and current waveforms of C phase.](image)

In order to measure the total harmonic content determination of the rectifier and power factor of the design of rectifier, we use the laboratory existing aircraft electric parameter test system module for corresponding data analysis. Through running the harmonic analysis module and the power factor analysis module of the system, and analyzed the data collected, we achieved the total harmonic content of C phase current is 5.23 % and the fundamental frequency is 400.01 Hz and power factor rectifier 0.991, as is shown in Fig. 7. When we using the traditional PID control on the same experimental prototype, we achieved the total harmonic content of C phase current is 7.84 % and the power factor is 0.963. By contrast, it easy to visible that the improvement of rectifier control algorithm can effectively reduce the harmonic content, and can achieve high power factor rectifier.

8. Conclusion

The technique is presented in this paper using neural network to improve PID control parameters tuning, can overcome the PID parameters online tuning difficult problem. Through the experiment, we know that the used neural network PID control three-phase voltage source rectifier voltage wave and current wave are basic same phase and can achieve unity power factor.

![Fig. 7. Current harmonic spectrum.](image)

At the same time, when compared the traditional PID control with the improved neural network for PID control, the neural network control is realized the on-line tuning of PID parameters, reduce the proportion, integral and differential parameter adjusting time, improve the efficiency of design.

References


2014 Copyright ©, International Frequency Sensor Association (IFSA) Publishing, S. L. All rights reserved. (http://www.sensorsportal.com)