TELKOMNIKA, Vol.11, No.1, January 2013, pp. 376~382
ISSN: 2302-4046

A Novel Three-phase Rectifier Based on Improved PID Control Algorithm

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Abstract

The three-phase rectifier based on traditional PID control algorithm can improve its harmonic effect, and increase its power factor, but it can't overcome the problems of selection difficulty of the PID parameters and can realize the online self-turning function of the PID parameters. In order to deal with the questions, the three phase rectifier based on neural network PID control algorithm is designed in this paper. In this paper, the PID parameters of the novel rectifier can realize the function of the online self-turning, which increases the design efficiency and the control accuracy. The simulation results show that the three phase rectifier based on improved PID control algorithm can decrease the harmonic pollution and increase its power factor.

***Keywords**: three-phase rectifier; neural network; improved PID control algorithm*

1. Introduction

In recent decades, with the development of modern science and technology, the power electronic technology was widely used in power system. The traditional diode rectifier and the use of nonlinear loads can increase the total harmonic distortion of the input current, and highly pollute the power supply systems. So, the design of new high power factor rectifier becomes a research hotspot. Now days, the three-phase voltage rectifier were widely researched and used for the advantages of having a simple structure, lower loss, the fast dynamic response and control method simple, and so on. Compared with the traditional sinusoidal pulse width modulation (SPWM) control, the space vector PWM (SVPWM) control technology has the characters of the DC side voltage with high efficiency, fast dynamic response and easy to realize the digital control, and so on. In order to realize the digital control and the stable DC voltage output, the three-phase voltage PWM rectifier, adopted the SVPWM control method, was widely researched. The research of control strategy for the three-phase voltage source PWM rectifier has achieved certain results [1][2] in scholars home and abroad. The three-phase voltage PWM rectifier used in the aircraft, adopted SVPWM control technology, can achieve high power factor.

The three-phase voltage PWM rectifier mostly adopts double-loop control methods, that is to say, using the voltage outer ring and the inner current. In this rectifier, the loop PI regulators are integrant, which need spend a lot of time to choose of its parameters, and the traditional PID control parameters is fixed in the follow-up of the control process. This control method affects the accuracy of the output voltage because the PID control parameters is fixed, while the control method has the advantages of controlling simple, easy realization, and so on. The practical study found that these parameters require corresponding changes according to the requirement, thus the traditional PID controller can't reach the ideal effect [3].

The neural network algorithm has the ability of learning, self-adapting, and self-organizing, and so on. It was used to many control system and the fault diagnosis system, and acquire the satisfaction results. Neural network PID control algorithm combines neural network learning features and advantages of traditional PID control, can achieve proportional integral and differential parameters of PID controller through online learning. This new PID controller [2] mainly realizes the function that the proportional integral and differential parameters adjusted online, and acquire the PID control parameters. According to the research of the SVPWM control algorithm, the three-phase voltage PWM rectifier based on Neural Network PID control

Received Septembeer 3, 2012; Revised November 28, 2012; Accepted December 10, 2012

algorithm is researched in this paper, which can improve the AC current waveform distortion and acquire the high power factor.

2. The Traditional SVPWM Rectifier

The diagram of the three-phase voltage source PWM rectifier [5-7] is shown in Figure 1. The circuit of three phase rectifier is mainly made up of power side filter reactor, DC voltage side capacitor, the switch devices and diode. Where e_a, e_b and e_c are the three phase input voltage, i_a, i_b and i_c are AC input currents, L_s is the inductance of AC side filter reactor, R_s is AC side resistance, and R_L is the DC side load. In order to predigest circuit analysis, we assumed that the three phase voltage source is balanced, and the switch loss is ignored.

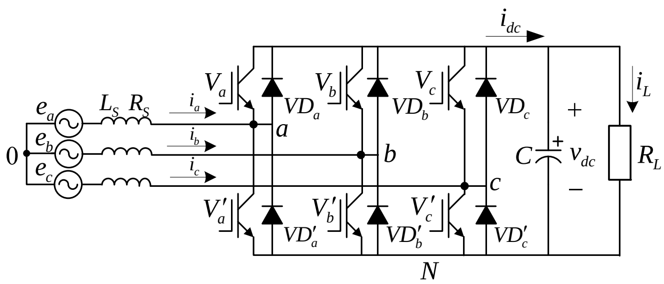


Figure 1. Diagram of the three-phase voltage source PWM rectifier

According to the circuit topology, the phase voltage equation can be described:

$$v_{j0}(t) = v_{jN}(t) + v_{N0}(t) \quad \left(j = a,b,c \right) \tag{1}$$

The equation (2) can be acquired by using the three phase inverter bridge voltage relationship,

$$v_{N0} = -\frac{v_{aN}\left(t\right) + v_{bN}\left(t\right) + v_{cN}\left(t\right)}{3} \tag{2}$$

The equation (3) is the bridge arm voltage vector,

$$v_{jN}\left(t\right) = s_j v_{dc} \quad \left(j = a,b,c \right) \tag{3}$$

Therefore, AC side voltage equation can be obtained,

$$V_{j0} = \left[s_j - \frac{1}{3}\left(s_a + s_b + s_c \right) \right] V_{dc} \quad \left(j = a,b,c \right) \tag{4}$$

The mathematical model of three-phase voltage source PWM rectifier is as following:

$$\begin{cases} L\dfrac{di_a}{dt} + Ri_a = e_a - (v_{dc}s_a + v_{N0}) \\ L\dfrac{di_b}{dt} + Ri_b = e_b - (v_{dc}s_b + v_{N0}) \\ L\dfrac{di_c}{dt} + Ri_c = e_c - (v_{dc}s_c + v_{N0}) \\ C\dfrac{dv_{dc}}{dt} = i_a s_a + i_a s_b + i_a s_c - \dfrac{v_{dc} - e_L}{R_L} \\ v_{N0} = -\dfrac{v_{dc}}{3}\sum\limits_{i=a,b,c} s_i \end{cases} \tag{5}$$

Where, $S_i\left(i=a,b,c\right)$ is the switching function. The control signals of the above and lower bridge of three-phase VSR are different at the same time. When $S_i=1$ ($i=a,b,c$), the above bridge arm is "ON", and the lower bridge arm is "OFF". So, the switching function S_i can define as:

$$S_i=\begin{cases}1 & The\ above\ bridge\ arm\ is\ "ON", \\ & the\ lower\ bridge\ arm\ is\ "OFF" \\ 0 & The\ above\ bridge\ arm\ is\ "OFF", \\ & the\ lower\ bridge\ arm\ is\ "ON"\end{cases}\left(i=a,b,c\right) \tag{6}$$

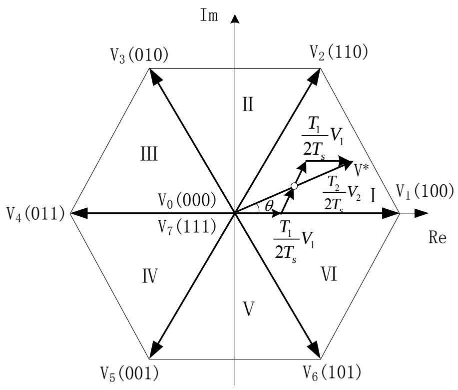


Figure 2. Diagram of space vectors

The diagram of space vectors is shown in Figure 2. The three-phase sinusoidal input voltage is divided into six intervals. Thus, only one phase current change its direction in one PWM cycle at any sectors. The sector of space vector V^* can be determined according to the relationship of three-phase voltages. This method is very beneficial to judge the sector position of voltage vector V^*. For a three-phase PWM rectifier with six switch devices, there are eight switch states for the three phase bridges. The switch modes include V0(000), V1(100), V2(110), V3(010), V4(011), 5(001), V6(101) and V7(111) vectors, among which V1 to V6 are nonzero vectors, V0 and V7 are two zero vectors.

At any sector, the voltage vector V^* can made up of the sector's nonzero vectors and zero vectors. The traditional SVPWM [4] algorithm includes three zero voltage vectors and four adjacent nonzero voltage vectors. The three zero vectors lie in the start, middle and the end position of the reference vector. Thus the power switch devices of three-phase PWM voltage rectifier must switch six times at any one PWM cycle in this rectifier.

3.The PID Controller Design

3.1. Traditional PID controller

Digital PID control algorithms are usually divided into positional and incremental PID control algorithm. The output of the controller adapted the incremental PID control algorithm has the relation with the previous sampling error, and can controlled by adding weight. Traditional incremental PID digital controller output is used to control the incremental value $\Delta u(k)$, thus this control method is easy to realize. Therefore, the incremental control algorithm was used in many control systems.

According to the relevant references traditional PID controller,

$$u(k) = K_P e(k) + K_I \sum_{j=1}^{k} e(j) + K_D [e(k) - e(k-1)] \quad (7)$$

Where, K_p ,K_I ,K_D is the proportional, integral, differential coefficient. $e(j)$ is the input deviation of the sampling time j, $u(k)$ is the the output value of the sampling time k. The corresponding incremental PID control algorithm is

$$\Delta u(k) = K_P [e(k) - e(k-1)] + K_I e(k) + K_D [e(k) - 2e(k-1) + e(k-2)] \quad (8)$$

In the control circuit, the output value of PID regulator is limited in a certain range. When output a large deviation with a short period of time, the output value of the control regulator becomes very large. This will cause the system oscillation, and let the adjustment longer. In order to effectively avoid the variable of PID controller output saturation and overflow, the output value will be limited in a certain range in the traditional PID control algorithm. The traditional PID control algorithm implementation process is shown in Figure 3.

3.2. Improved PID controller

The selection of the PID parameters of the three phase voltage source PWM rectifier adopted traditional incremental PID control algorithm are very difficult in the design, and can't realize the online self-turning function of the PID parameters. The neural network [3][6] has the advantages of self-learning, high adaptive ability, and easy to calculate, and so on. So, the improved PID algorithm combine neural network algorithm with traditional incremental PID control algorithm, which can acquire better control purpose, and realize the online self-turning function of the PID parameters.

Suppose neuron input is

$$\begin{cases} x_1(k) = e(k) - e(k-1) = \Delta e(k) \\ x_2(k) = e(k) \\ x_3(k) = e(k) - 2e(k-1) + e(k-2) \end{cases} \quad (9)$$

The output function of the equation (10) is

$$u(k) = u(k-1) + \omega_1 x_1(k) + \omega_2 x_2(k) + \omega_3 x_3(k) \quad (10)$$

Where, ω_1 , ω_2 , ω_3 are the corresponding weight value of $x_i(k)$ （$i = 1,2,3$）. The three parameters adopt supervised learning rule [1], the learning algorithm is defined as follows:

$$\omega_i(k) = \omega_i(k-1) + \eta_j e(k-1) u(k-1) x_i(k-1) \quad (11)$$

Where, $i = 1,2,3$, $j = P, I, D$.

In this algorithm, the $x_1(k)$, $x_2(k)$ and $x_3(k)$ are the neural network input signals, and the three output signals as the improved PID output. The flow chart of improved Incremental PID control algorithm is shown in Figure 4.

4.The Novel Three-phase Rectifier Design

The three-phase rectifier based on the Improved PID control algorithm is shown in Figure 5. At the control circuit design of three-phase rectifier, the voltage and current adopt double closed-loop control methods in order to acquire the stability of output and unity power factor of the input current. In the rectifier, the output signals of the control circuit are the 6 roads PWM signals, which can be used to driver the six switch devices, thus the input current is identical with its input voltage in the rectifier.

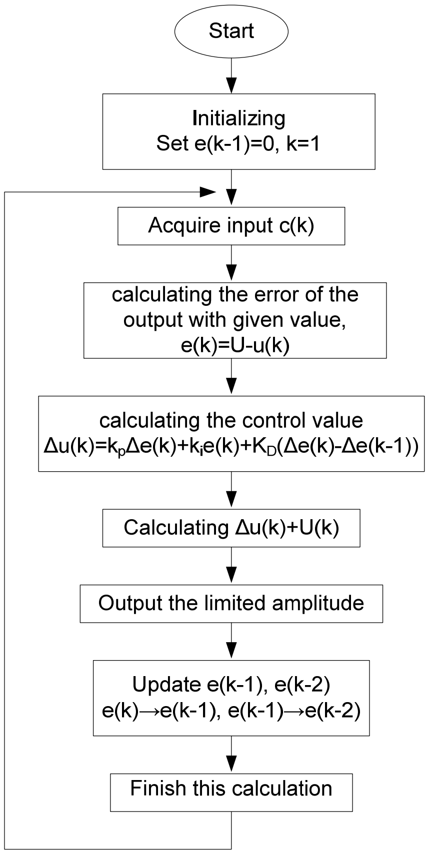


Figure 3. Flow chart of traditional PID control algorithm

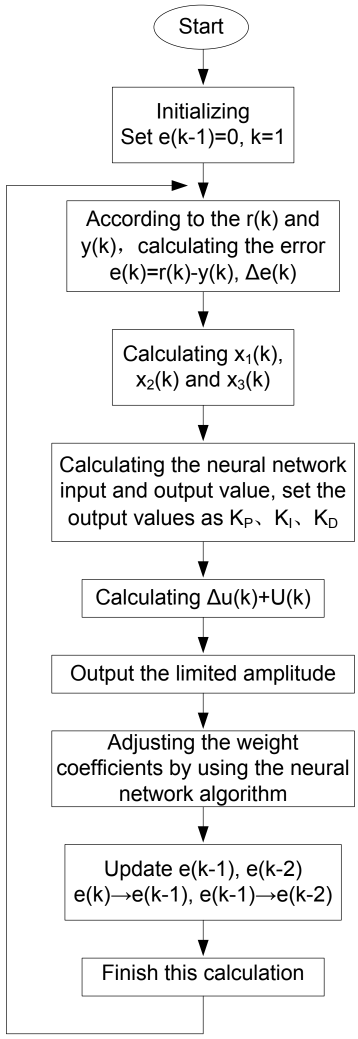


Figure 4. Flow chart of improved incremental PID control algorithm

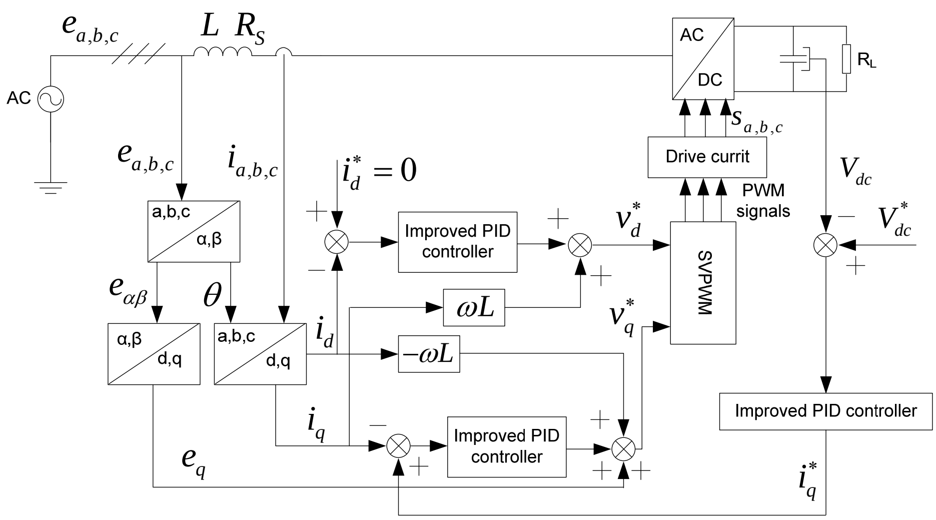
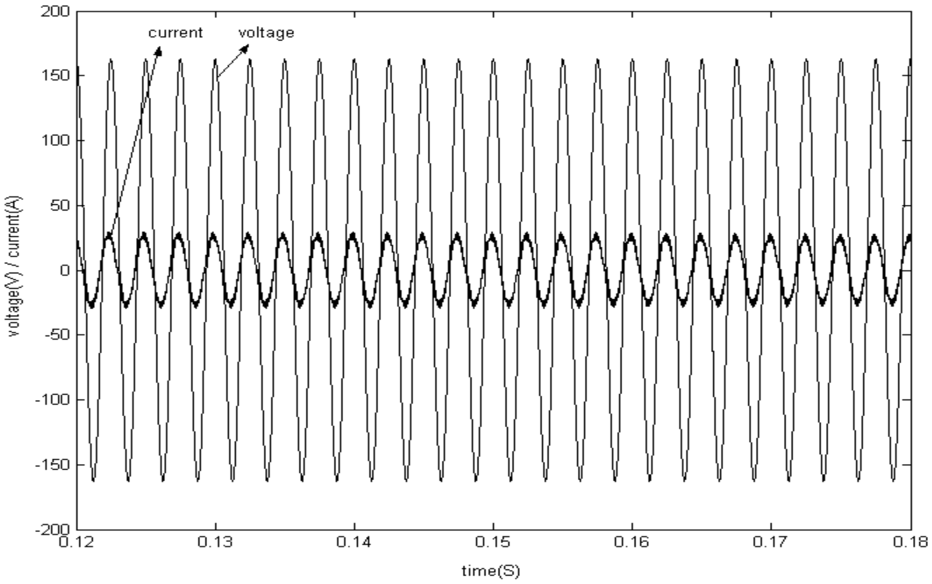


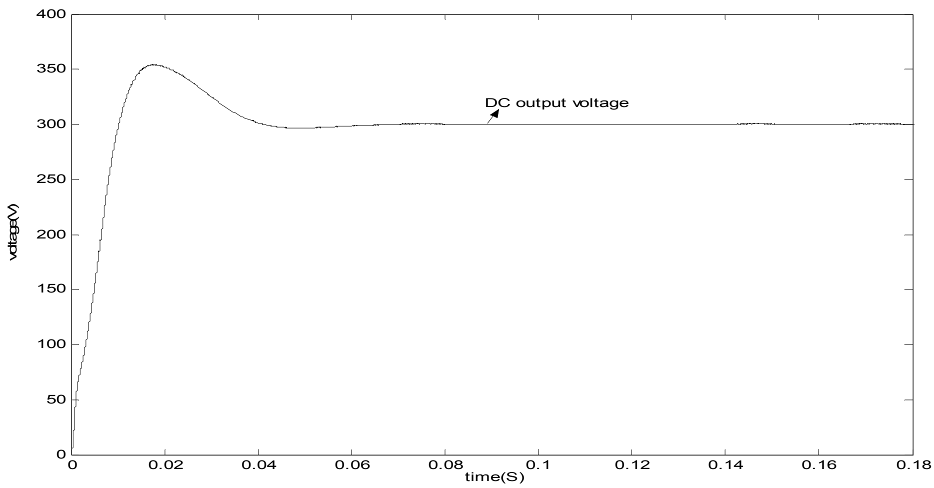
Figure 5. Schematic diagram of three-phase rectifier based on improved SVPWM control

The control circuit of the three-phase rectifier adopts double-loop control structure, which are the voltage loop and the current loop. The voltage loop mainly used to control the DC output signal of the rectifier, and the current loop used to control the current signals according to the output signal of the voltage loop. In this control system, the improved PID controllers were replaced traditional PID controllers. Compared with the traditional SVPWM control, the controllers adopted neural network PID control algorithm can help to realize the PID parameter self-learning process, and increase the stabilization of the output voltage.

In the system, the three-phase voltage and current signals are transformed to the components i_d and i_q, and then the voltage error signals are changed into the active current command value i_q^* by using the neural network PID controller. At the same time, suppose the reactive current command value as zero, and acquire the control signals by calculating the SVPWM algorithm.



(a) B phase voltage and current waveform



(b) DC output voltage waveform

Figure 6. B phase voltage and current waveform

5. Experiment Results

In order to validate the accuracy and feasibility of the novel PID control algorithm, the rectifier simulation circuits using MATLAB software was established according to its mathematical models. The mainly simulation parameters are set as following: three-phase Input voltage is 115V/400Hz three-phase AC voltage source, the network side three-phase filter inductance are 0.4mH, the DC side capacitor is $2200\mu F$, the DC output voltage is set to 300V, and the switching frequency is 10K.

The system simulation results of three-phase rectifier are shown in Figure 6. The waveforms of B phase input voltage and current is shown in Figure 6 (a). The waveform of DC output voltage is shown in Figure 6 (b). As can be seen from the graph, the phase voltage and current can basically reach the same phase, that is to say, the current can track its phase voltage, and the rectifier can achieve high power factor. The DC output voltage can reach at 300V in a very short period of time.

6. Conclusion

The simulation results show that the phase of B phase input current is identical with its phase voltage, and the DC output voltage can quickly reach to 300V. Compared with traditional PID control, the improved rectifier realizes on-line tuning of PID parameters, and reduces the adjusting time of the proportion, integral and differential parameters, and improves the efficiency of design. The three-phase rectifier based on neural network PID control algorithm can achieve the high power factor in the rectifier and reaches to the requirement of design.

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