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Design Research on Three-Phase PWM Rectifier Based on Double Closed Loop Control Technology

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Abstract: Based on the high frequency of three-phase voltage source PWM rectifier, this paper established a mathematical model of three phase current inner ring and outer ring voltage, and put forward the setting method of three phase double closed loop control. Finally, it was verified through simulation. The experimental results show that Three-phase output of DC voltage is stable with the operation of regulating systems, the current flowing into the grid tends to be sinusoidal and power factor is close to 1, which greatly reduce the interference of harmonics on the grid, thus improve grid operation. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: PWM, Double closed loop control, MATLAB, Rectifier.

1. Introduction

The so-called rectifier is the process of alternating current into direct current. That completing rectifier function circuit is called rectifier circuit. The rectifier is the device to realize rectification process [1, 2]. The power device in power electronic device is mostly in the switch state, which caused the grid harmonic pollution and energy loss. Such as in traditional diode rectifier operation process, the network side current have contains a lot of harmonic, and the power factor is low, and a large number of application caused by the electromagnetic compatibility problem may cause serious consequences. Compared with the traditional rectifier, PWM rectifier can realize network side high power factor and sinusoidal current control [3, 4], and even its energy can be two-way flowing, and dynamic response performance is faster, and its volume and weight are also greatly reduced, which has been widely used in the field of UPS uninterruptible power supply and power locomotive drive system. This paper introduces the three-phase voltage source PWM rectifier mathematical model and the work principle. And it analyses the design of current inner ring and outer ring voltage double closed loop control system. And it selects the circuit parameter. Finally, it is verified by simulation.

2. The Design of Three-Phase Bridge Type PWM Rectifier Main Circuit

Fig. 1 is the three-phase bridge type PWM rectifier circuit diagram of the main circuit.

It can be derived from Fig. 1 circuit analysis that the dc side voltage is given by equation (1).

$$v_{dc} = \frac{2\sqrt{2}U_A}{M\cos\delta} \quad (1)$$

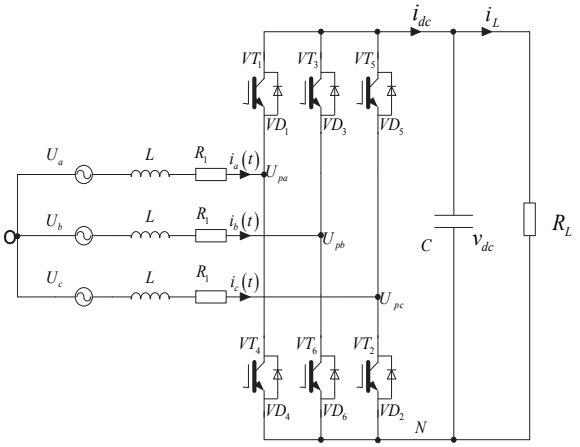

Fig. 1. Three-phase bridge type PWM rectifier main circuit.

When it is meeting the current transient tracking index, the range of three-phase rectifier inductance value is given by equation (2).

$$\frac{(2v_{dc}-3E_m)E_mT_s}{2v_{dc}\Delta i_{\max}} \le L \le \frac{2v_{dc}}{3I_m\omega} \quad (v_{dc}>1.5E_m) \tag{2}$$

When the system received step disturbance, if the rectifier is meeting the interference performance indicators, the capacitor of rectifier dc side should be large enough. And its limit value is given by equation (3).

$$C > \frac{1}{2\Delta V_m^* R_L} \tag{3}$$

By the analysis, it is shown that the capacitance value, which is calculated according to this type, is may not meet the index of dc voltage following performance. So the index of dc voltage following performance also should be used in the actual application [11].

3. The Design of Three-Phase Bridge Type PWM Rectifier Main Circuit

Three-phase voltage source PWM rectifier circuit topology is consisted of the main circuit and control circuit. Main circuit contain the ac voltage source, ac side of the inductance and resistance, direct current capacity and the whole switch devices and fly-wheel diode of three-phase full bridge circuit; Control circuit is mainly composed of the voltage outer ring regulator and the current inner ring regulator. Control switch device open circuit is playing a role for this [6-9].

It is assumed that the network voltage three-phase symmetric is stable. According to the KVL, we can list the differential equation of system as following:

$$L\frac{di_a}{dt}+Ri_a=e_a-u_{ao} \tag{4}$$

$$L\frac{di_b}{dt}+Ri_b=e_b-u_{bo} \tag{5}$$

$$L\frac{di_c}{dt}+Ri_c=e_c+u_{ao} \tag{6}$$

Laplace transform is used for this type, and the three-phase transfer function a, b, c are gained:

$$\frac{i_a(s)}{e_a(s)-u_{ao}(s)}=\frac{1}{Ls+R} \tag{7}$$

$$\frac{i_b(s)}{e_a(s)-u_{ao}(s)}=\frac{1}{Ls+R} \tag{8}$$

$$\frac{i_c(s)}{e_c(s)-u_{co}(s)}=\frac{1}{Ls+R} \tag{9}$$

4. The Setting of Double Closed Loopcontrol System PI Parameter

4.1. The Setting of Current Inner Ring Regulator PI Parameter

In the double closed loop rectifier system, current is the inner ring, which is forcing the input current tracking input voltage and improving the dynamic response of the system performance. In the double closed loop control design, the current control dynamic performance is directly affected the control performance of VSR voltage outer ring [10]. The Fig. 2 represents the simplified structure of the current inner ring structure.

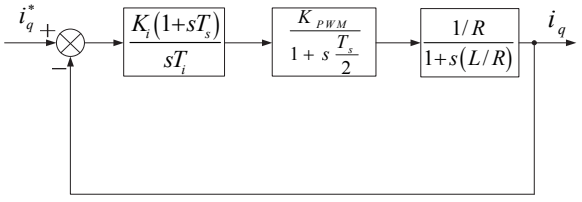

Fig. 2. The inner circuit simplified structure with no eq. disturbance.

T_s is the inner ring current sampling period of current (That is PWM switch cycle). K_{pwm} is the equivalent gain of the bridge road PWM [3]. Current controller adopted PI to control. And the transfer function is given by equation (10).

$$G_{pn}(s)=K_{ip}+\frac{K_{iI}}{s} \tag{10}$$

Current inner ring transfer function is given by equation (11).

$$G_{oi}(s)=\frac{K_p}{L}\frac{s+K_1/K_p}{s^2+(R+K_p)s/L+K_I/L} \tag{11}$$

In the equation: $K_p = K_{ip} K_{pwm}$; $K_I = K_{iI} K_{pwm}$.

From the equation (11), we can gain the current inner ring damping ratio and the natural oscillation frequency on followings:

$$\xi = \frac{(R + K_p)}{2\sqrt{K_I L}} \tag{12}$$

$$\omega_n = \sqrt{K_I / L} \tag{13}$$

Solution:

$$K_{ip} = \frac{2\xi w_n L - R}{K_{pwm}} \tag{14}$$

$$K_{iI} = \frac{L\omega_n^2}{K_{pwm}} \tag{15}$$

In the equations, we take current inner ring natural oscillation frequency, and damping ratio equals 0.707. Substituting equations (12), (13) into equations (14), (15), we can gain the current inner ring PI control parameters.

4.2. The Setting of Voltage Outer Ring Regulator PI Parameter

Voltage regulator is the outer ring regulations, which can stable output dc voltage, and make the output dc voltage higher than the input voltage on peak. Usually current inner ring control broadband is bigger than voltage outer ring control broadband. In voltage outer ring control, we can think that three phase the actual current ia, ib, ic is completely tracking with three-phase reference current ia*, ib*, ic* [5]. So in voltage outer ring control, transfer function Goi of current inner ring can be simplified to equation (8). Fig. 3 shows the voltage outer ring control structure.

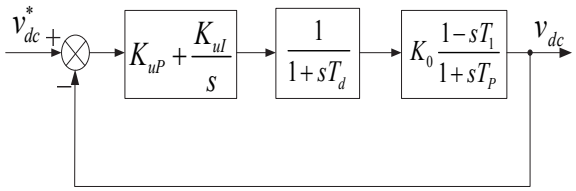

Fig. 3. Three-phase voltage outer ring control chart.

Regulator adopted PI to control, and the transfer function is given by equation (16).

$$G_{PI2}(s) = \frac{K_v(1+T_v s)}{T_v s} \tag{16}$$

Voltage outer ring open loop transfer function is given by equation (17).

$$W_{OV} = \frac{0.75K_V(1+T_V s)}{T_V C_s^2(\tau_V s+1)} \tag{17}$$

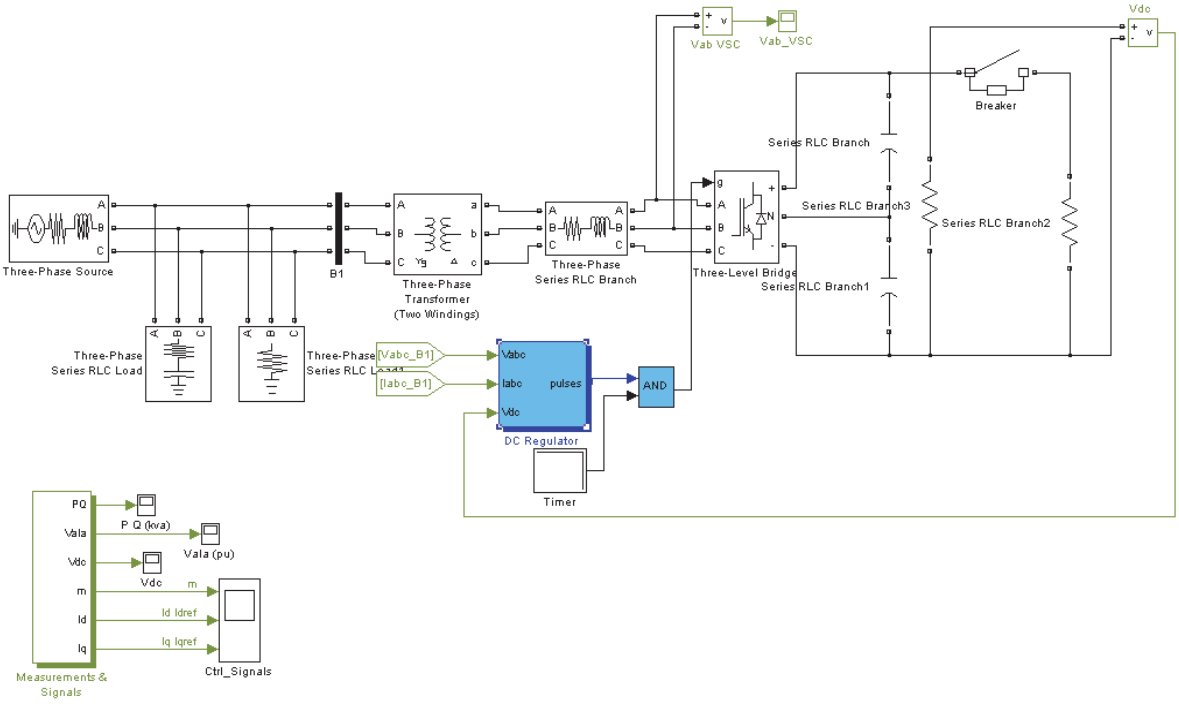

Fig. 4. Three-phase voltage outer ring control system simulation structure diagram.

5. The Simulation

The three-phase voltage outer ring control system simulation structure chart is showed in Fig.4. Edify the above three-phase PWM rectifier double closed loop control system setting method is feasible.

Simulation Parameters is: network voltage is 600 V. By the three-phase transformer access to rectifier, and transformer adopts Y/Δ to connect, and secondary side voltage is 240 V, and output is 500 KW; Three-phase ac side inductance L equals 0.008 H, and resistance R equals 0.001, and dc side capacitor C equals 0.0075 F, and given dc voltage is 600 V.

When the current sampling time Ts is 0.001 s, and voltage outer ring sampling time is 0.002 s. According to the above formula by deduced, we can gain that current inner ring PI parameters is: KIP equals 32, equals 133.3; Voltage outer ring PI parameters is: Kv equals 6, TV equals 0.025.

When the system operate to 0.5 seconds, step disturbance add to the system. When the system reaches to steady state, the system dynamic response curve is shown as Fig. 5.

When the system process adds sudden disturbance, three-phase output dc voltage can quickly make voltage stable in the control system under the action.

The system has good resistance to disturbance resistance.

Intercepting 0.5 s to 0.6 s ac voltage and current waveform, we can see from Fig. 6, the current that flows into the power grid is closed to the sine wave with a little fluctuation, and it have the same phase with ac voltage.

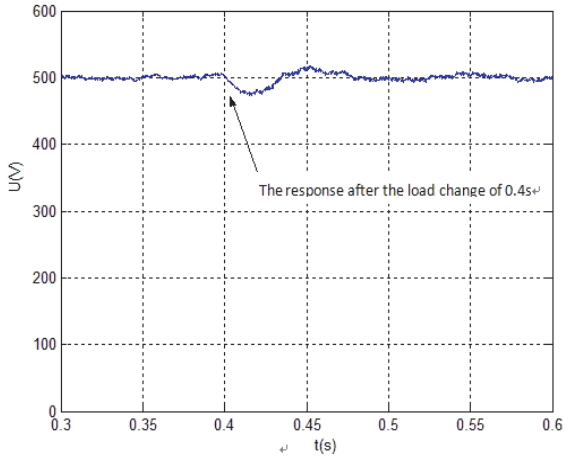

Fig. 5. Load disturbance in dc side voltage waveform y.

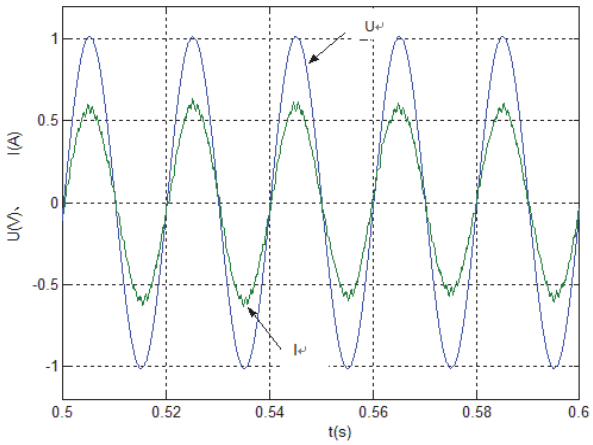

Fig. 6. Rectifier ac voltage and current curve.

Fig. 7 is the power calculation link. When the circuit diagram is 0.5 s, we can gain that active power is 34.48, and reactive power is 0.1423 (multiplied by the ratio of value). We calculate the power factor is 0.9999.

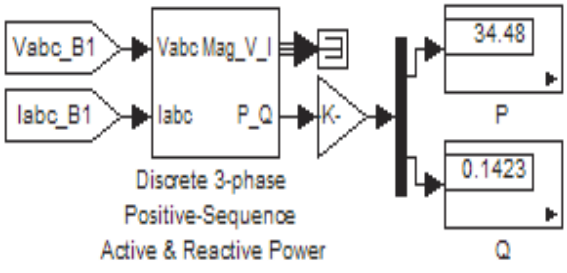

Fig. 7. Rectifier ac voltage and current curve.

5. Conclusions

By the simulation test, we can conclude that when current inner ring and outer ring voltage adopt the mentioned setting method in paper, three-phase PWM rectifier double closed loop control system has good current tracking performance and anti-jamming performance, which have the better system response curve.

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