Research on Three Phase Rectifier Based on one Cycle Control Used in Aircraft

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***Abstract*—The three-phase rectifier that adopted one-cycle control technique used in the aircraft is introduced in this paper. The One Cycle Control (OCC) principle and the operation principle of the rectifier are presented. The double loop control is adopted in this paper. According to the mathematical model and the simulation model construct the hardware circuit. The experimental results show that the total harmonic distortion of the input current is about 4.5%, and the power factor of the rectifier has reach to 99.15%, and achieve the design requirement.**

Keywords- Rectifier, One-cycle control, High power factor, Hardware

I. INTRODUCTION

With the continuous development of modern science and technology, more and more advanced equipment used in the aircraft have been widely used in recent years, which increase the aircraft power supply system capacity. In the aircraft electrical and electronic equipment, some of them need the DC power, such as the control and protection devices, relays and contactors work coil, radio communications, radar, autopilot, DC motors and so on. In order to transform I the AC main power to the desired DC, the rectifier is essential for aircraft equipment, but the use of nonlinear loads increase the total harmonic distortion of the input current, which greatly affected the power quality. The study of new high power factor rectifier that used in the aircraft becomes research hotspot[1-2].

One-cycle control is a nonlinear control method, and not need the multiplier. It has the characters such as the simple structure, easy to realize and so on. In this paper, the one-cycle control was used to three-phase rectifiers in order to realize the high power factor. The load current in this rectifier can not arises the input current harmonic distortion, even if the load current with large of harmonic.

This paper will be structured as follows: In Section II, we will introduce the one-cycle control technique. The operation principle of three-phase three switch boost rectifier based on one-cycle control is presented in Section III; parts of the hardware circuit of the rectifier is given in section Ⅳ; some experiment results of the rectifier are given in Section Ⅴ.

II. ONE CYCLE CONTROL TECHNIQUE

In 1990s, the one-cycle control[2] was introduced by Keyue M. Smedley. One Cycle Control can realize the input current following the reference current, and not effected by the load current. The input current didn't appear the current distortion, even if the load has large of current harmonic. Comparing with the traditional methods, One Cycle Control strategy can obtain high power factor in continuous conduction mode. This control strategy is made up of the voltage loop and the current loop. This technique was used to the study of the three-phase high power factor rectifier for its good performances, such as fast dynamic response, constant switching frequency, etc. This method is a very suitable control method for the rectifier used in aircraft.

The circuit diagram of three-phase rectifier based on one cycle control is shown in Fig.1. In order to analyze easily, the three-phase voltage waveform of the rectifier in each cycle is divided into six intervals. We can see the circuit can consider as a dual-boost topology is shown in Fig2 according to the intervals. The two switches are not only driven by the same driver block, but also only one switch can operate at each half cycle. In Fig.2, Tp or Tn is the switch in different intervals, Vp or Vn is the equivalent voltage in different intervals, and Lp, Ln is the inductance in different intervals.

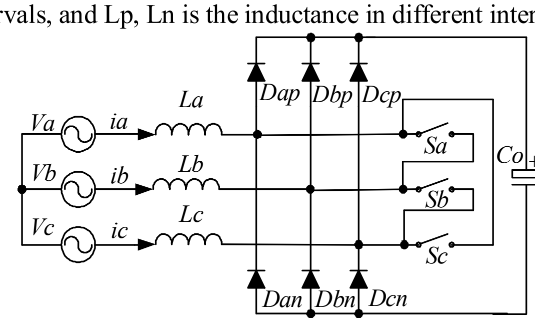

Figure 1. The circuit diagram of three-phase rectifier based on one cycle control

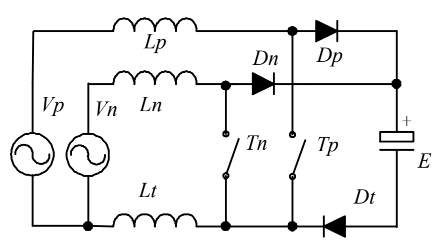

Figure 2. The chart of dual-boost topology circuit

In the interval (0~60), the voltage V_p is either $V_a - V_b$ or $V_c - V_b$, we easy to know that the voltage V_p in the other interval are similar. In each cycle, the switches state of the dual-boost topology circuit is different. Such as, the switch T_p is turn on and the switch T_n is turn off, the voltage of the three phase inductor can be analyzed, and the equation is as follows:

$$\begin{cases} V_p = L\cdot\dfrac{di_{Lp}}{dt} + L\cdot\dfrac{di_{Lt}}{dt} \\ V_n - E = L\cdot\dfrac{di_{Lt}}{dt} + L\cdot\dfrac{di_{Ln}}{dt} \\ i_{Lt} = i_{Lp} + i_{Ln} \end{cases} \tag{1}$$

Where, the value E is the DC side output voltage of the three phase high power rectifier. According to the equation (1), the equation (2) can be obtained.

$$\begin{cases} V_p = 2L\cdot\dfrac{di_{Lp}}{dt} + L\cdot\dfrac{di_{Ln}}{dt} \\ V_n - E = L\cdot\dfrac{di_{Lp}}{dt} + 2L\cdot\dfrac{di_{Ln}}{dt} \end{cases} \tag{2}$$

According to the equation (2), the equation (3) can be received:

$$\begin{cases} \dfrac{2V_p - V_n + E}{3} = L\cdot\dfrac{di_{Lp}}{dt} = V_{Lp} \\ \dfrac{2(V_n - E) - V_p}{3} = L\cdot\dfrac{di_{Ln}}{dt} = V_{Ln} \\ \dfrac{V_p + V_n - E}{3} = L\cdot\dfrac{di_{Lt}}{dt} = V_{Lt} \end{cases} \tag{3}$$

Similarly, the other switch status can be analyzed by using the similar methods. At last, we can obtain,

$$\begin{bmatrix} V_p^* \\ V_n^* \\ V_t^* \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & -\frac{1}{3} \\ -\frac{1}{3} & \frac{2}{3} \\ \frac{1}{3} & \frac{1}{3} \end{bmatrix} \cdot \begin{bmatrix} V_p \\ V_n \end{bmatrix} \tag{4}$$

Suppose, the switching frequency of the rectifier used in the aircraft is much higher than the frequency of the power system, then the average value can be looked as zero. For a balanced three-phase power system, the equation (5) can be given:

$$\begin{cases} V_p^*\cdot d_n + (V_p^* + \frac{1}{3}\cdot E)\cdot(d_p - d_n) + (V_p^* - \frac{1}{3}\cdot E)\cdot(1 - d_p) = 0 \\ V_n^*\cdot d_n + (V_n^* - \frac{2}{3}\cdot E)\cdot(d_p - d_n) + (V_n^* - \frac{1}{3}\cdot E)\cdot(1 - d_p) = 0 \\ V_t^*\cdot d_n + (V_t^* - \frac{1}{3}\cdot E)\cdot(d_p - d_n) + (V_t^* - \frac{2}{3}\cdot E)\cdot(1 - d_p) = 0 \end{cases} \tag{5}$$

Because the power system is balanced system, so the equation (6) can be obtained：

$$V_p^* + V_n^* - V_t^* = 0 \tag{6}$$

According to the equation (5) and equation (6), the equation (7) can be given

$$\begin{bmatrix} 1 - d_p \\ 1 - d_n \end{bmatrix} = \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \cdot \begin{bmatrix} V_p^*/E \\ V_n^*/E \end{bmatrix} \tag{7}$$

The equation (7) can be used in the other intervals.

III. THREE-PHASE RECTIFIER BASED ON OCC[3]

The circuit diagram of the three-phase three switch boost rectifier based on one-cycle control is shown in Fig.1. In order to analyze, the three-phase voltage waveform in each cycle is divided into six intervals; the three-phase rectifier can obtain unit power factor by controlling two switches within each 60° interval. The operation principle of the rectifier based one-cycle control can be given in Fig.1. The value that the dc output voltage compares with the reference value will be sent to the multiplier circuit, and then the results will be sent to the one-cycle control circuit. The three phase voltage will be sent to the interval circuit, and the three-phase current will be sent to the input multiplexer circuit. The values obtained from the two circuits will be sent to the one-cycle control circuit. After that, we can receive two triggering signals. At last, the drive signals can be obtained through the output logic circuit, this signals can be used to control the switch devices.

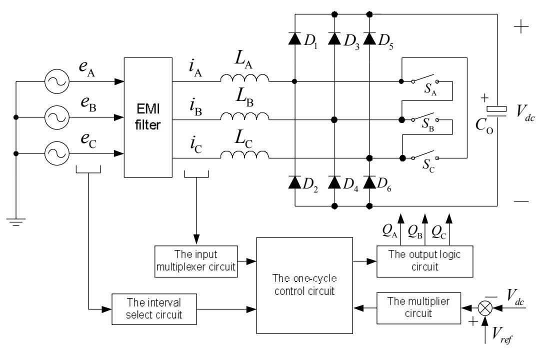

Figure 3. Three-phase boost rectifier based on circuit diagram

IV. HARDWARE CIRCUIT DESIGN

A. Absolute value circuit

In the control circuit, the absolute value circuit mainly used to calculate the absolute values of the three-phase current signals through the precision rectifier circuit. It is a general circuit that can be realized in Fig.2.

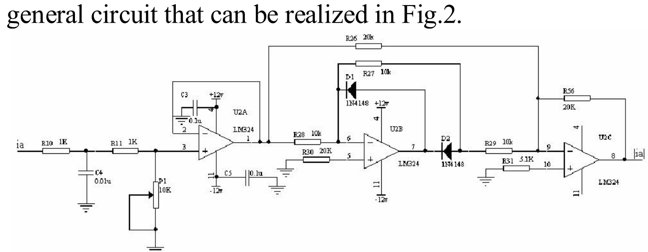

Figure 4. Absolute value circuit

B. Voltage feedback circuit

Voltage feedback circuit is used to realize the voltage feedback in order to control the dc output voltage. After comparing with the reference value, the obtained value can be changed into the signal comp by using a PI regulator and integrator with reset switch. The signal comp can be given,

$$comp = V_m \cdot (1 - \frac{t}{\tau})$$

Where, $comp$ is the error amplifier output signal, τ is the integrator time constant and equal to $10\mu s$, and the switching frequency is 100K in this design.

V. EXPERIMENT RESULTS

In order to verify the correctness of the theory and the analysis of the three-phase rectifier based on one-cycle control technique, the experimental circuit of the rectifier has been constructed according to the mathematical and simulation models. In the laboratory, the experiment about this rectifier has been finished with different load. When the load is 18.5Ω, the measured results of B-phase voltage and current waveforms are shown in Fig.3; After modifying the circuit parameters, When increasing the load to 35Ω, the results of B-phase voltage and current waveforms are shown in Fig.4, and the dc output voltage is 350V; when the load reaching to 217 Ω, the B-phase voltage and current waveforms are shown in Fig.5.

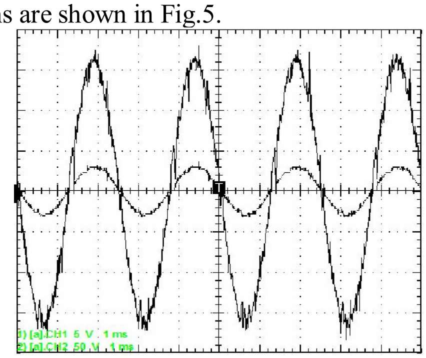

Figure 5. voltage and current waveforms（18.5Ω）

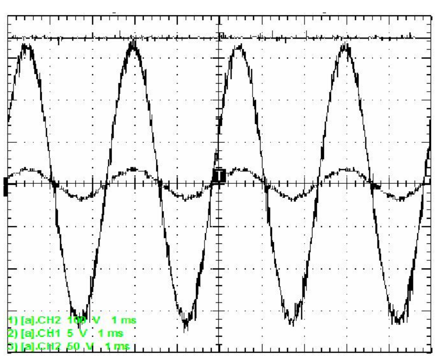

Figure 6. voltage and current waveforms（35Ω）

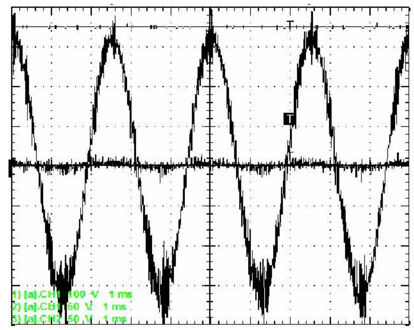

Figure 7. voltage and current waveforms（217Ω）

At the same time, the voltage transient for the rectifier at turning on has been realized by using the portable test equipment in the laboratory. The results of C phase voltage, current and dc voltage waveforms are shown in Fig6. When the load is add at transient, and is turn off after a while, the waveforms of the current and the dc side output voltage is shown in Fig.9.

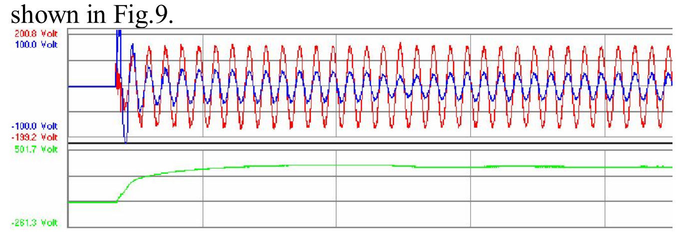

Figure 8. transient voltage and current waveform

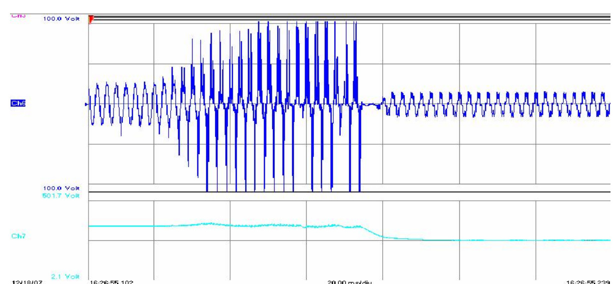

Figure 9. the expermiental waveforms when adding the load and turn off

The acquired data has been analyzed by using the data analysis and processing program based on LabVIEW. The total harmonic distortions of the three-phase current are 4.83%, 5.43% and 5.19%, and the power factor of B phase current is 99.15%. As can be seen from the above figures, the phase voltage and corresponding current remains the same phase, and realizes high power factor rectifier, and the dc output voltage at 350V.

VI. CONCLUSION

The results are shown that the rectifier based on-cycle control can achieve high power factor. The dc output voltage can fleetly reach to 350V, basically reach the design requirements.

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