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# Research on the Performance for Two Kinds of Topology of Constant Current Regulator of Navigational Lighting Aid

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**Abstract**

*In the modern airport system, safety for airport to take off and landing is an important matter. Navigational lighting aids are necessities for it. Accurate and constant current should be provided for lighting aid. This paper researched two kinds of topological structures and some control strategies. AC-AC converter and AC-DC-AC converter are proposed, both of them can provide accurate constant current for lighting aid. It can be distinguished from power supply. Three-phase source supplied for AC-DC-AC converter and Single-phase-source supplied for AC-AC converter. Topology of AC-DC-AC converter has lager power than AC-AC converter, then MATLAB/SIMULINK was used to simulate the two kinds of typologies with two kinds of control strategies named current single loop control strategy and voltage current double loop control strategy, the result showed that AC-DC-AC converter had faster response speed and more accurate output current than AC-AC converter. Voltage current double loop control strategy used in AC-DC-AC converter had more advantages than AC-AC converter.*

***Keywords**: Constant Current Regulator; AC-AC Converter; AC-DC-AC Converter; Current Single-Loop Control Strategy; Voltage Current Double Loop Control Strategy*

## 1. Introduction

When airplane taking off and landing in the evening. Navigational lighting aids in airport can provide illumination for airplane. It can provide a security for airplane. Now most airports used two type of regulator AC-AC converter and AC-DC-AC converter. It used IGBT instead of thyristors, because the traditional thyristor will produce a large number of harmonic, It cause enormous harm for power grid. High frequence switch can be used to solve the problem.

This paper used IGBT to realize High-frequence switch, and describe the principle of AC-AC converter and AC-DC-AC converter, used two kinds of control strategy to simulate these two topologies. Both of them can realize the constant current control, they were used in different topologies. Different performance was shown in the two topologies. The AC-DC-AC converter used voltage. current double loop control strategy showed the more advantages than AC-AC converter used current single-loop control strategy.

## 2. Analysis of Two Kinds of Topologies

First type of topological structure of constant regulator shows in Figure1. In this topology, two group of symmetrical IGBT-Diode are consisted in main circuit, lighting aids are regarded as loads in circuit. In this main circuit, IGBT $V_1$ and IGBT $V_2$ play conducing role and IGBT $V_3$, $V_4$ plays stream function in circuit. The direct current $i_N$ shows in Figure 1. The conducting order are from $V_1$ $D_2$ to load and the stream way is from load to $D_3$. When $i_N$ has a opposite direction, the other symmetrical IGBT-Diode is conducted, In this case, input voltage is suppose to equation (1).Switch $V_1$ and $V_2$ are

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regarded as S1,swith V3 and V4 is regraded as S2.Because of the PWM modulation in circuit, the two group switch should complementation in timing sequence, output voltage can be shown as equation (2). In this expression, 0 represent closing of switch S, 1 represent opening of switch S substituting equation (1) into (2), output voltage can be shown as equation (3).

Circuit switch function *G* is define as equation (4), switch function *G* unfold by Fourier series as equation (5).Substituting (5) into (2) the output voltage and current can be shown as equation (6) and (7). In (3),switch function *G* can be unfold by Fourier series[1],in Fourier series, DC component and a series of harmonics consisted the *G*. The harmonics caused output value which output voltage and output current contain harmonics, In order to get the high quality output result. A large number of harmonic can be filtrated by LC filter. If the cut-off frequency was designed suitable. The THD can be decreased a lot.

In (5), $D=\tau/Tc$, $\omega c=2\pi/Tc$, $\varphi a=a\pi DU_{nm}$ represent input voltage amplitude $Z_l$ represent impedance of fundamental frequency amplitude, represent fundamental wave impedance angle, represent amplitude of harmonic load impedance $Z_{aA}$ of angular frequency, $Z_{aB}$ represent amplitude of harmonic load impedance $Z_{aB}$ of angular frequency.

$$U_N = U_{nm} Sin\omega t \tag{1}$$

$$U_0 = \begin{cases} U_n(S_1^0, S_2^1) \\ 0(S_1^1, S_2^0) \end{cases} \tag{2}$$

$$U_0 = GU_N = GU_{nm} Sin\omega T \tag{3}$$

$$G = \begin{cases} 1(S_1^0, S_2^1) \\ 0(S_1^1, S_2^0) \end{cases} \tag{4}$$

$$G = D + \frac{2}{\pi}\sum_{a=1}^{\infty}\frac{\sin\varphi_a}{a}\cos(a\omega_c t - \varphi_a) \tag{5}$$

$$\begin{aligned} U_0 &= U_{nm} Sin[D + \frac{2}{\pi}\sum_{a=1}^{\infty}\frac{\sin\varphi_a}{a}\cos(a\omega_c t - \varphi_a)] \\ &= DU_{nm} Sin[D + \frac{2}{\pi}\sum_{a=1}^{\infty}\frac{\sin\varphi_a}{a}\{\sin(a\omega_c + \omega)t - \varphi_a\} - \sin(a\omega_c - \omega)t - \varphi_a\} \end{aligned} \tag{6}$$

$$i_0 = \frac{DU_{nm}}{Z_1}\sin(\omega t - \phi_1) + \sum_{a=1}^{\infty}\frac{U_{nm} Sin\varphi_a}{a\pi}\times\{\frac{\sin[\{a\omega_c + \omega)t - \phi_{aA} - \varphi_a}{Z_{aA}} - \frac{\sin[(a\omega_c - \omega)t - \phi_{aB} - \phi_a]}{Z_{aB}}\} \tag{7}$$

In control aspect, control strategy of AC-AC converter uses non-complementary control strategy of current detection. Usually most lighting aids are resistance inductance loads, voltage pulls ahead current, when output voltage and current are same direction, loads absorbed energy from power, but when output voltage and current direction are opposite. Power will less than zero, loads retroaction energy to power. In this time, V1, D1 break over .However, V3 always sustain opposite voltage and can not break over. Circuit condition does not change, thus AC-AC circuit always used non-complementary control strategy of detection show as Figure2.

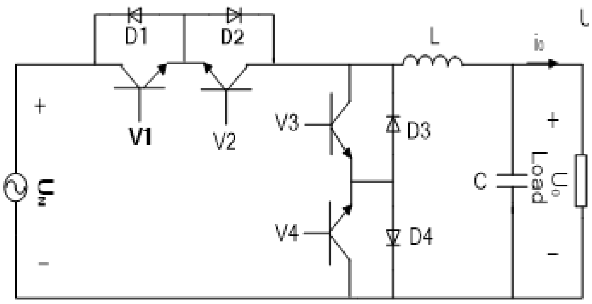


**Figure 1. Topology of AC-AC Converter**

 

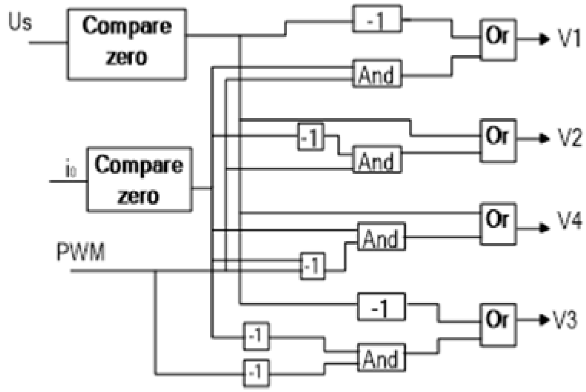


**Figure 2. Non-Complementary Control Strategy of Current Detection**

Second type of topology of constant current regulator is shown in Figure3.In this circuit, was consist of rectify circuit and bridge converter, it was supplied by three phase power. In the front-end of the circuit not controllable switching devices diode is used. Diode uncontrollable rectifier was widely used in superpower field and became simpleness and convenience in this filed. SPWM modulation is used to partial inverse transform. When circuit working normally. The input current was rectified by diode and was converted by IGBT. Due to the SPWM modulation was supplied in converter, the switch function S was defined:

$$S=\begin{cases}1 & nT_s<t<(n+D)T_s\\ 0 & (n+D)T_s<t<(n+1)T_s\end{cases} \quad (8)$$

*Ts* represent period of switch, represents duty cycle, $n=\pm 1,\pm 2$..................

Moreover, Input voltage was defined as $U_i=U_m Sin2\pi fst$, , *Um* represent peak voltage, *fs* represent frequence. Suppose output voltage was defined as $U_0=S*U_i$, Fourier series was used to:

$$U_o=DUmSin2\pi f_s+\frac{Um}{\pi}\sum_{n=1}^{\infty}\frac{\sin n\pi D}{n}(a-b) \quad (9)$$

In equation (9) *a* and *b* represent:

$$a=\sin[2\pi(nf_c+f_s)t-n\pi D] \quad b=\sin[2\pi(nf_c-f_s)t-n\pi D] \quad (10)$$

$f_c$ represent carrier frequency n represent harmonic order.

(9) shows that output voltage not only has fundamental waves but also has other harmonics.LC filter can be designed to solve the problem..

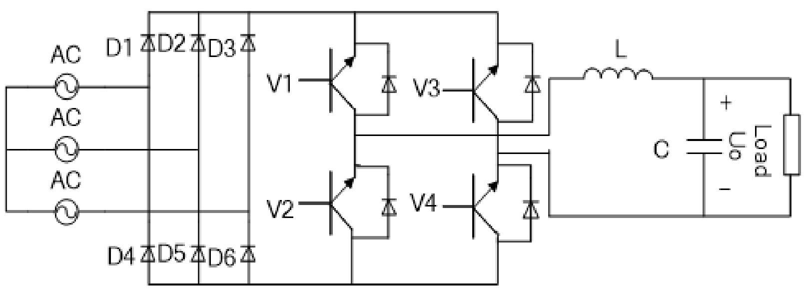


**Figure 3. Topology of AC-DC-AC Converter**

## 3. Research on Control Strategy

Output-end of circuit was analyzed at first, which was shown in Figure4. It follows from Kirchhoff current law that:

$$i_L = i_o + i_c \tag{11}$$

Mathematic model was established by Laplace transform[1] which shown as Figure5. The Kirchhoff current law equation in frequency domain was:

$$U_i(s) = sLi_L(s) + \frac{1}{sC} i_L(s), i_L(s) = i_c(s) + i_o(s), U_c(s) = Z(s)i_o(s) \tag{12}$$

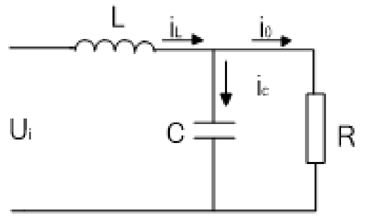


**Figure 4. Output-end of Circuit**

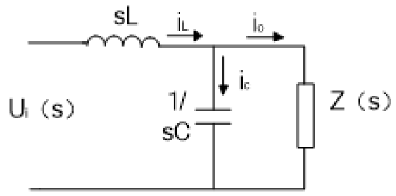


**Figure 5. Output-end of Circuit of Laplace Transform**

According to the automatic control theory, control blocks diagram show as Figure6 In order to have a high-quality for output value. Current single-loop control and current voltage double loop control strategy was used to circuit respectively. Two kinds of control strategies are shown in Figure6 and Figure7. Traditional single-loop controlled used the voltage single-loop controlled in converter the current single-loop controlled and voltage current double loop control were used in paper. Theory of the control strategy in them are very familiar. Output voltage was collected and compared with reference voltage. After PI controller to adjust the error signal as basic value of the current internal ring, and the load current instantaneous value compared with basic of the current internal ring, then the error single compared with triangular carrier wave and the SPWM controlled signal was produced.

This controlled strategy has function of output limiting. Though the output current was not very large the instantaneous control scheme in voltage current double-loop control strategy can adjust the wave of output voltage. The power supply quality can be advance largely. The current internal loop in voltage current double loop strategy can enlarge bandwidth of the inverter controlled system. The more quickly response speed and the less harmonic of output voltage and current can be got.

Typical 2nd-order system transfer function is

$$G(s) = \frac{\frac{1}{LC}}{s^2 + \frac{s}{RC} + \frac{1}{LC}} \tag{13}$$

Damping ratio ζ is a very important parameter in this system, response time and overshoot is decided by it. In 2nd-order system

$$\xi = \frac{\sqrt{LC}}{2RC} \qquad \omega_n = \sqrt{\frac{1}{LC}}$$

To improve the performance of the ζ, the voltage current double-loop control was used.

The algorithm of PI was used to improve SPWM modulation just played a transmission gain in system. The current internal ring used P or PI regulator. So that the whole open-loop transfer function is

$$G(s)=\frac{K_{p1}K_{p2}K_{pwm}\frac{1}{LC}(Ts+1)}{Ts(s^2+\frac{s}{RC}+\frac{1}{LC})} \quad (14)$$

The transfer function can be written as

$$G(s)=\frac{K(s+a)}{s(s+b)(s+c)} \quad (15)$$

Substitute (14) into (15),transfer function can be written as equation(16). In this 2nd-order system adjust the zero-pole point and the transmission gain combine with PI adjuster. Increase the zero point, the output value of system changed from positive to negative. The pole point must greater than zero or the system became unstable. If the load is resistance-inductance transfer function can be written as equation(17). Because the imaginary root exist in the univariate cubic equation. the analysis in software with PI-PI or PI-P adjuster.

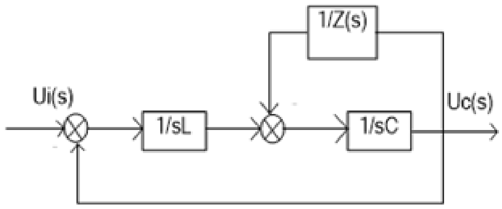


**Figure 6. 2-order System Diagram**

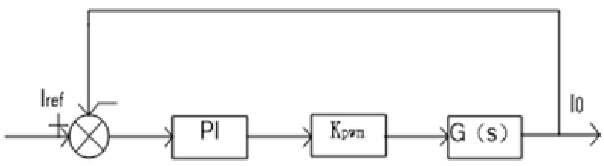


**Figure 7a. Current Single-loop Control Block Diagram**

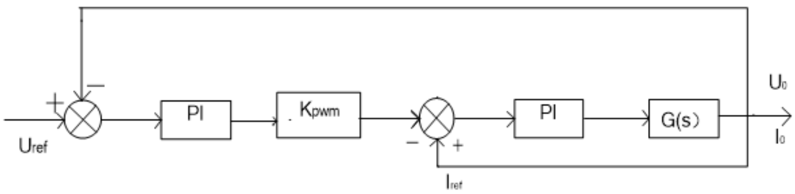


**Figure 7b. Voltage Current Double Loop Control Block Diagram**

$$G(s)=\frac{\frac{K_1K_2K_{PWM}}{T}(s+\frac{1}{T})}{s[s-(\frac{\sqrt{L^2-4R^2LC}-L}{2RLC})][s+\frac{L+\sqrt{L^2+4R^2LC}}{2RLC}]} \quad (16)$$

$$G(s)=\frac{R}{s^3L^2C+s^2RLC+2Ls+R} \quad (17)$$

## 4. Simulation Analysis

Simulation of the output voltage and current of the AC-AC converter used in the average current single-loop was shown in Figure 8.the parameters shows in Table1.The result shows that the slowly response speed and the larger ripple wave in this output result, In order to get the direct current in output. The large inductance L2 was use in system but the ripple wave large and the large inductance can consume much power from system. thus the adjusting of PWM was became more difficult and was limited a lot the other reason for large ripple wave was the average power control in single loop. The average current compared with reference value can't be accurate compared with instantaneous value .In this system, because of the single phase power supply, if bigger current wanted to be produced. The large inductance may cause big problems.

The result of the output voltage and current of AC-DC-AC topology was shown in Figure9. The parameters was shown in Table2.

The voltage current double loop control was use in this system, compare with the first one, the output-end instantaneous current was supplied and there was a other current loop in circuit. It can be obviously shown that the ripple wave was smaller than first one and response speed was also quickly than first one. The range of the out-put value adjusting was more widely, parameters of LC filter especially the inductance was smaller.

**Table 1. AC-AC Circuit Parameter**

| | |
|---|---|
| L1 | 0.29H |
| L2 | 9H |
| C | 0.0000728F |
| Load | 5Ohm 0.05H |
| Input voltage | 220V |

**Table 2. AC-DC-AC Circuit Parameter**

| | |
|---|---|
| L | 0.007334H |
| C | 0.000303F |
| Load | 1Ohm 0.001H |
| Input voltage (phase) | 220V |

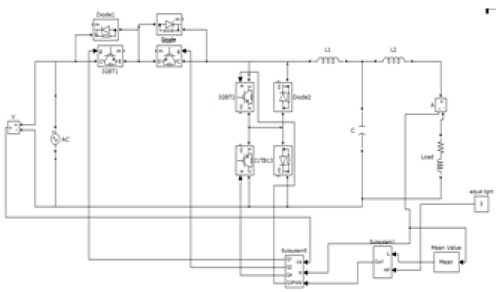

**Figure 8. AC-AC Converter Simulation Mode**

 

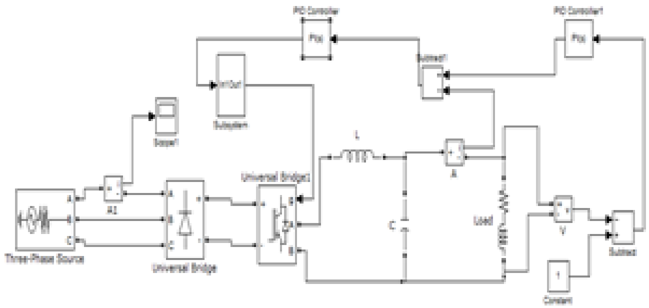


**Figure 9. AC-DC-AC Converter Simulation Model**

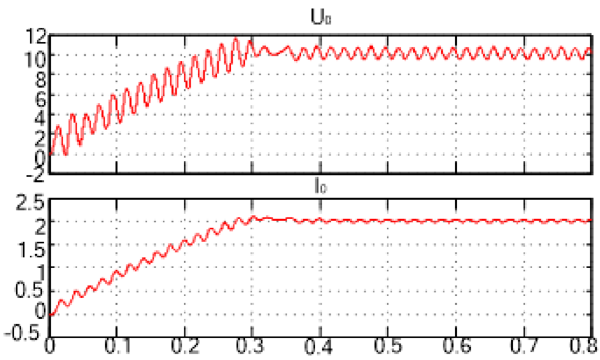


**Figure 10. AC-AC Current Single-loop Control Strategy Output Voltage and Current**

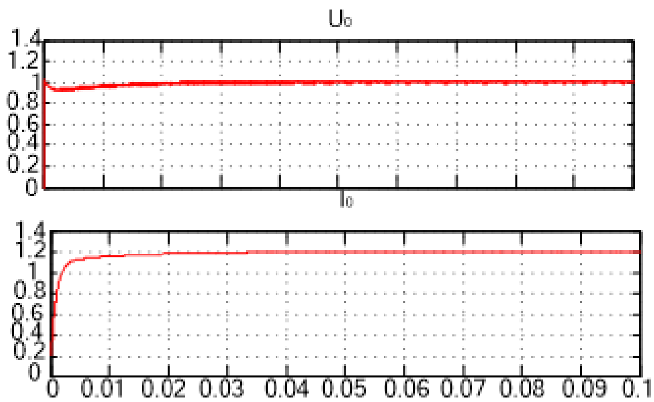


**Figure 11. AC-DC-AC Double Loop Control Strategy Output Voltage and Current (Whole)**

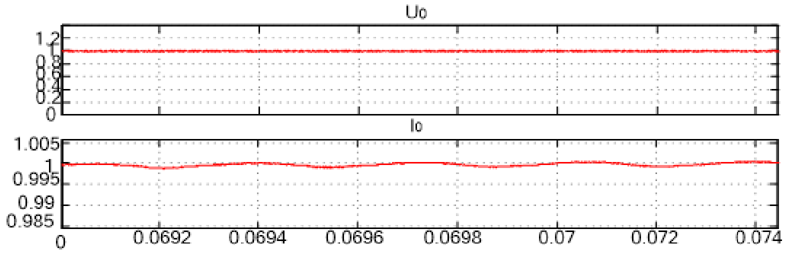


**Figure 12. AC-DC-AC Double Loop Control Strategy Output Voltage and Current (Part)**

## 5. Conclusion

In this two kinds of topology. The result are not same though the direct current be get the performance from each other's is different. In the first one due to the large inductance and the ripple wave, the simulation is not desirable, the power factor are very low and the high elev current value is achieved difficultly and the response speed is also slow than the second one. The large inductance limited the PWM adjusting the second topology has more advantages than first one, due to double loop control strategy ,the response speed and the accuracy of the output is more superior than first one .

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