THE CONTROL STRATEGY RESEARCH ON TWO KINDS OF TOPOLOGICAL PULSED POWER SUPPLY

Shi Chunfeng #, GUCAS, Beijing, 100049, China; IMP, Lanzhou, China
Gao Daqing , Huang Yuzhen， Zhou Zhongzu, Yan Huaihai
IMP, Lanzhou, 730000, China

Abstract

This paper introduces a kind of pulsed power supply at HIRFL-CSR， analyzes the ripple and current error of the quadrupole magnet power supply in the operation process, and gives a two-stage topology of pulsed power supply. The control method is simulinked and the results show that the new one can make up for the deficiencies of the existing pulse power supply and the main circuit structure and control method are feasible.

INTRODUCTION

HIRFL-CSR consisted of HIRFL（Heavy-Ion Research Facility in Lanzhou) and CSR(Cooling Storage Ring)is the highest energy heavy-ion research facility in our country at present. As the development of the modern accelerators, the quality and stabilization of beam are more important, so it would require that the response of power supply should be faster, tracking error better and current ripple smaller. The magnet power supply system contains: dipole power supply, quadrupole power supply, sextupole power supply, correction power supply and so on. Quadrupole power supply and sextupole power supply have the same topology and control mode. Along with longtime running and aging, the performance parameter such as current ripple and tracking error will affect the further improvement of the beam quality. Based on the above reasons, a two-stage power supply is studied. With the pre- voltage regulated in the front of the H-Bridge chopper [1], the new topology decreases the ripple wave and tracking error. As the Figure 1 shows: the inside of the dashed box is the pre- voltage regulated; the rest is H-Bridge chopper consisted of S1 and S2, filter consisted of R2,C3,C4 [2], and inductive load.

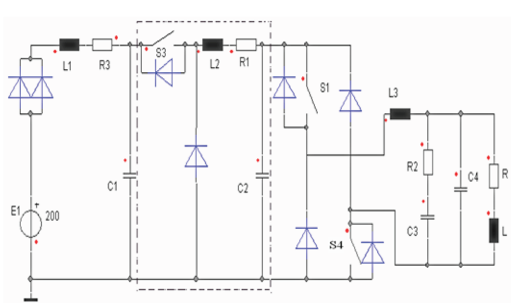

Figure 1: topology of the two-stage power.

H-BRIDGE CHOPPER OPERATIONAL PRINCIPLE

As the Figure 1 shows, removing the part inside of the dashed box, the rest is the topology structure of the running power supply on CSR. The circuit adopts PWM(Pulse Width Modulation) control method, and the modulated pulses are produced by comparison between a triangular wave and two error signals. Both of this two error signs come from current PI regulator, same amplitude but opposite sign. When the power supply works, switch S1 and S4 is running, and power supply outputs pulse or DC current. The relation between driving pulse of the two switch is shown in Figure 2. TR1 and TR4 are the PWM control signals of the switch S1 and S4 respectively. The duty ratio of single switch tube is 0~100% [3]. When the ratio is greater than 50%, switch S1 and S4 can have the common conduction time TR(as the Figure 2 shows). The effective duty ratio in one carrier wave period Ts is 2*TR, as the formula (1) shows.

$$2*TR=2(TR1-50\%)=2(TR2-50\%) \tag{1}$$

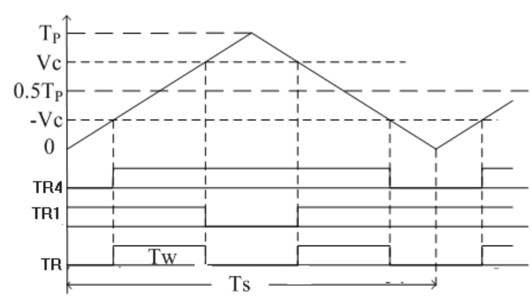

Figure 2: driving waves of the H-bridge chopper.

NEW TOPOLOGY OPERATIONAL PRINCIPLE

The two-stage power supply is consisted of pre-voltage regulating part and H-bridge chopper. The operational principle of the H-bridge chopper is shown above. The control loop of the pre-voltage regulating is a P regulator with a proportional component only, so compared with the current PI regulator of H-bridge chopper, the regulating velocity of the P regulator is faster. Pre-voltage regulating part is controlled by the voltage U2 of the capacitance C2, and the preference voltage(Uref) is obtained by the differential of the given current Iref, as the formula (2) shows.

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$$Uref = 0.5(L*\frac{dIref}{dt} + R*Iref)/TR \qquad (2)$$

Making difference between Uref and U2, and then sending into the P regulator, comparison between the output of the P regulator and the triangular wave forms the driving pulse, which controls S3. The control strategy made the voltage wave of capacitance C2 and the load voltage nearly consistent, but faster than the change of load voltage. This kind of the voltage given method, made it possible to get the rated voltage in the energy stored capacitance C2 by the closed-loop regulating on the condition of the fluctuating AC network.

RELATION OF DUTY RATIO AND RIPPLE

Relation between duty ratio D of Buck circuit and ripple wave ΔV as formula (3) shows[4].

$$\Delta V = \frac{Uo(1-D)}{8LCf^2} \qquad (3)$$

Among which L,C are the follow-current inductance and filter capacitance of Buck circuit respectively, Uo is load voltage and f is the frequency of carrier triangular wave. Therefore, the ripple wave of the Buck circuit becomes smaller when the duty ratio increases. As the effective duty ratio TR of the H-bridge chopper shows, the chopping circuit of switch S1 and S4 are equivalent to series of the two Buck circuit. The relation between the effective duty ratio TR and the duty ratio TR1 ,TR2 of single switch are shown in formula (1).

Figure 3 shows the pulse wave of current and voltage of the dipole power supply in the HIRFL-CSRm[5].If this power supply uses the H chopper structure, where the preceding DC-voltage E is unadjustable, then at the arising and the flatting time of the current, theoretical effective duty ratio of the H-bridge chopper 2*TR are 1086/E(maximum) and 587/E respectively. If the maximum duty ratio amplitude limiting of chopper' single switch is 90%, then from formula (1), the chopper' maximum effective duty ratio 2*TR=80%(maximum effective duty ratio of the arising section of the pulse current), then the minimum value of DC voltage(E1) is 1357.5V, so the effective duty ratio of pulse' flat section is 2*TR=43%, substituting 80% and 43% in formula (3), namely D=2*TR, then the ripple wave of the flat section is 2.85 times of the arising section of the pulse current is obtained by comparison. But if we use the topology structure of the two-stage power supply, making the C2's voltage changes according to the load voltage by regulating of switch S3, then the pulsed current at the flat section can also keep larger effective duty ratio, thus reducing the ripple wave of the flat section. In accelerator physics, the flat section of the pulsed current is used for acceleration, injection and extraction, therefore, current in flattop is extremely important for the beam quality.

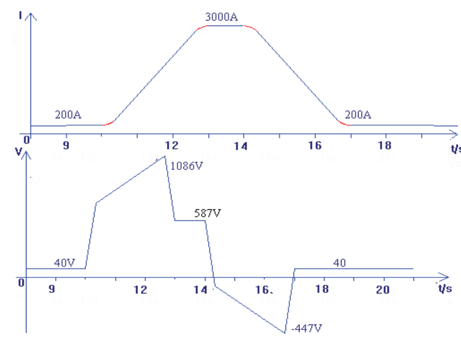

Figure 3: pulsed wave of dipole power supply in HIRFL-CSRm.

SIMULATION RESULTS OF THE TWO TOPOLOGIES

By use of the simulation software SIMPLORER, the ripple wave and following error of the two topological power supplies are simulated and compared. The parameters of the main circuit are same, DC power supply E=200V, energy storage capacitance C1=C2=20000uF, inductive load L=120mh, R=25mΩ, switch tube frequency f=10Hz, period of the output of pulsed current is 1.2s, the rate of rise and decline of current is 1500A/s, flattop current is 600A. In the case of identical parameters of the main circuit, optimum parameters are obtained by adjusting the regulator of the two control loop respectively.

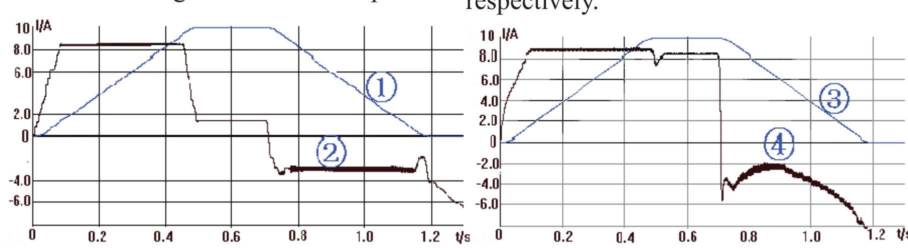

Figure 4: output-current and regulator waveforms of the two power supply.

As Figure 4 shows, the curves ①② are output-current of the existing pulsed power supply(60 times smaller than reality) and output-signal of the regulator LIM1 respectively, and curves ③④ are output-current of the new power supply(60 times smaller than reality) and output-signal of the regulator LIM2 respectively.

Relation between output-signal of the regulator and duty ratio of the switch tube TR1, TR4 is as follows:

$$TRx(x=1,4) = \frac{(10+LIM)}{20} \qquad (4)$$

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The arising section of the pulsed current changes a lot from the flattop section in LIM1, while LIM2 changes a little in these sections. The declining section of the current is energy leakage section of the load, which is uncontrollable, so regulator's signals of LIM change nearly the same. At the flattop of the current LIM1=1.5, LIM2=8.5, the duty ratio of the switch at the flattop can be obtained by substituting LIM1 and LIM2 into the formula (4), associating with formula (1)(3), the existing ripple wave at the flattop is 5.7 times of the new power supply.

Figure 5 is the curve for the following error of the current, which is obtained by scaling down 100 times of the real value. Curve ⑤ is the following error of the running power supply, and curve ⑥ is for the new power supply. According to the contrast，the tracking error of the new power supply is better than the existing one at the whole pulsed period, where the numerical value reduced by one times or more and the two spikes appeared at the turning point of the flattop turn out to be one.

CONCLUSION

This paper make comparisons and analysis between the two types of the topology structure power supply by using performance parameter ripple wave and tracking error from theory and simulation respectively. The result is that the two-stage power supply can cover the shortage of the existing power supply, therefore, knowing well the control method of the new topology structure is necessary. Although the new topology structure and the control method is more complicated than the existing power supply, but it is supported on the bases of the existing power supply technology, at the same time it supports the theory and technology for the updating of the power supply in the HIRFL-CSR and power supply of the heavy ion therapeutic system.

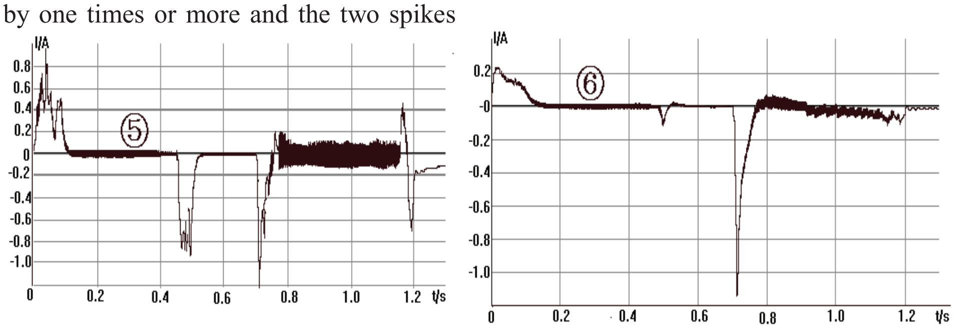

Figure 5: curve for following error of the current.

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