A DIPOLE POWER SUPPLY BASED ON MULTI-LEVER INVERTER TECHNIQUE

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Abstract

By applying multi-lever inverter technique to ion accelerator power supply, it can provide steady current in wide range, increase the power supply's equivalent output frequency, then further promote power supply's response capability and reduce the output ripple current. This article firstly by giving a detailed introduction of composite and basic working process of dipole power supply that also applied the technique mentioned above, interpret the working principle of multi-lever inverter, and illustrate its advantages. However, applying this technique will make controller more complicated, which need to be overcome by digital regulator technique. And meanwhile digital regulator technique can improve the power supply's performance. The second part of this article briefly introduces the overall scheme of digital regulator. And at last, this article illustrate the dipole power supply meet to design target and make some improvement by using the practical results to prove that applying multi-level inverter technique into accelerator power supply is practicable and beneficial.

INTRODUCTION

HIRFL(Heavy Ion Research Facility of Lanzhou) system need a dipole power supply , which is required to run with two modes of output pulse current or DC current. The most commonly used output current wave is shown in Figure 1 when pulse is working. The main technical parameters are shown in Table 1.

Table 1: The Parameters of the Dipole Power Supply

Resister	53.3mΩ
Inductive	106mH
Current	1050A
Voltage	185V
Tracking Error	$\leq\pm1\times10^{-4}$
Current Rising time(50A-1050A)	>=1s
Ripple Current	<0.025A

This power supply's load is a magnet that is an inductive load. The load parameters can be found in Table 1. The power supply's maximum rising rate of current is 1000A / s. Therefore, when pulse is working, 165v is required to be the maximum excitation voltage. While in DC current State, the power supply only requires a minimum output voltage of 2.8v(50A). Such large range of output is not conducive to the control of power supply ripple current. In addition, the tracking error is relatively difficult to complete. All these put forward the requirement that power supply must possess good dynamic response ability and low output capability of ripple current.

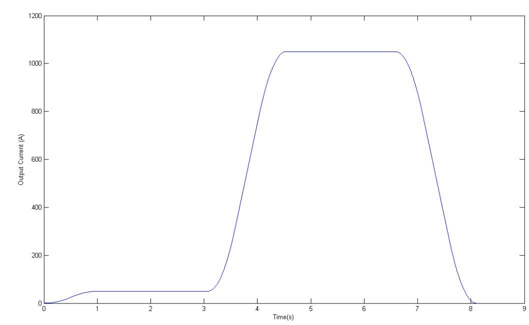

Figure 1: The normal form of output current.

DESCRIPTION AND ANALYSIS OF TOPOLOGY OF THE POWER SUPPLY

To meet with these requirements, this power supply uses the multi-level converter technology. The specific topology is shown in Figure 2.

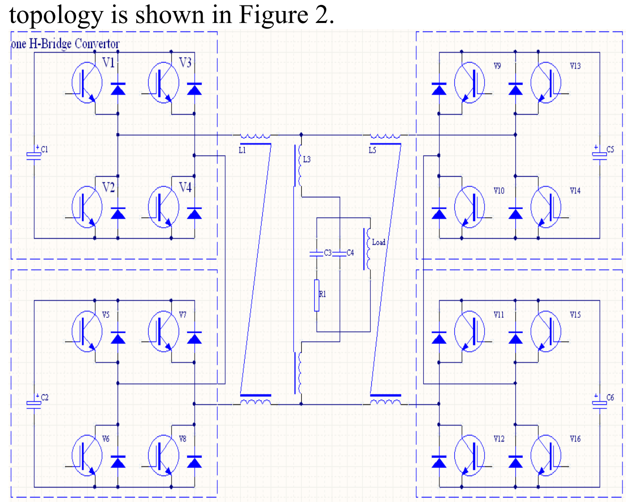

Figure 2: The topology of the dipole power supply.

Introduction of the Basic Unit of H-Bridge Converter

This multi-level converter consists of a number of H-bridge converters by series-parallel connection. For this H-bridge converter structure, it can work in the four-quadrant working states. But this power supply requires only forward current output, so it only works in the second quadrant, and only requires to drive a pair of IGBTs(Insulated Gate Bipolar Translator) (v1 and v4 see figure 2), as well as other two IGBTs (v2 and v3 see figure 2) do not drive, but they can work in the parasitic diode current flow. In order to achieve the effect of the frequency multiplication output, generally the control Signal of phase-shift is utilized to control the four power tubes. The control timing is shown in Figure 3 and Figure 4. The figures show the V1 and V4 driving signals.

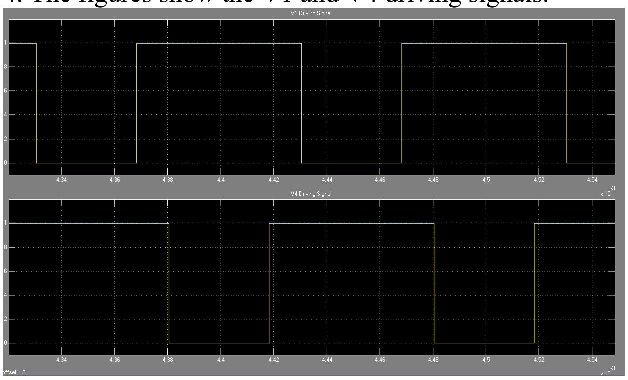

Figure 3: IGBT driving signals for positive output.

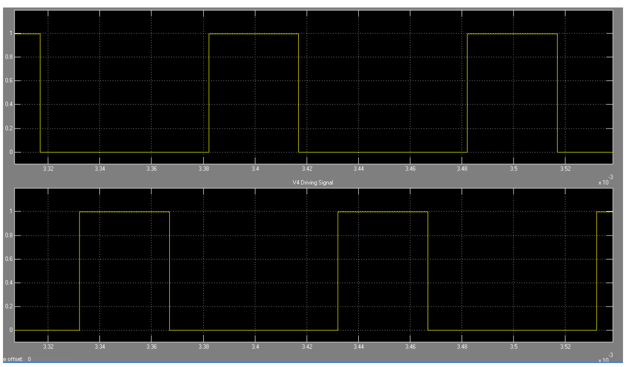

Figure 4: IGBT driving signals for negative output.

For inductive load, we can analyse the working status, which can be divided into four types, namely: 1. Positive voltage and positive current, V1 and V4 be turned on, converter provides energy to the load. 2. Continued flow state 1, V1 and V2's parasitic diode be turned on. 3. Continued flow state 2, V3 and V4' parasitic diode be turned on. 4. Positive current, negative voltage, V2 and V3'parasitic diode be turned on, the load transfers energy to the converter.

Through such a control mode, the converter can achieve the energy transmission with the load. At this point, because of the role of controlling signal, in each cycle the twice energy transmission processes will appear. Thus, frequency multiplication output effect is achieved. For inhibiting ripple current, improving the system's response has positive significance. [1]

Series Connection of Many H-Bridge Converters.

The series connection method connects two sets of H-bridge, and then stagger fixed phase between the control pulse in each H-bridge set, so that another frequency multiplication effect can be formed in the output side. Figure 5 and Figure 6 illustrate correlation wave of the two serial H-bridges, each of which has a input voltage of 30V, output voltage of each individual H-bridge in the figure are "H Bridge1" and "H Bridge2", and the total output voltage is "Series Output" after the series connection. Figure 8 illustrates the results when single H-bridge output duty cycle is less than 0.5. Figure 9 illustrates the results that single H-bridge output duty cycle is larger than 0.5.

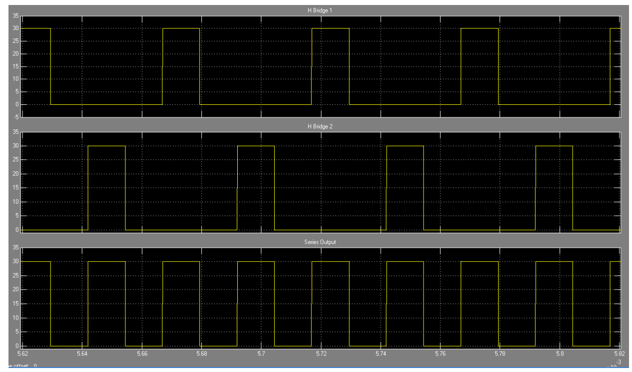

Figure 5: H bridges & series output voltage when duty less than 0.5.

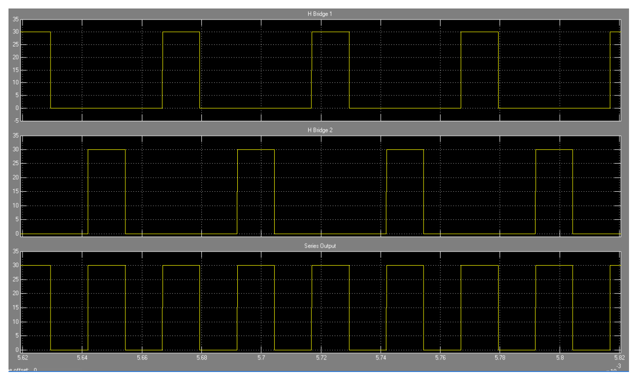

Figure 6: H bridges & series output voltage when duty more than 0.5.

It can be seen from the figure that, for a two-serial circuit, when the duty cycle of single H-bridge is less than 0.5, the duty cycle of the serial output side is amplified to be double, but its output peak-voltage still maintain the input voltage of each H-bridge. When the duty cycle is larger than 0.5, the duty of output pulse is the same with the value that duty cycle of single H-bridge minus 0.5, but the output pulse has been turned into a pulse riding on 30V (input voltage of single H-bridge). Such series connection brings benefits that: when the output voltage is low, the peak-voltage of output pulse is still the input voltage of single H-bridge, the duty cycle doubles, which is conductive to control the ripple current. And the series connection can provide a higher output voltage.

Parallel Connection of Many H-Bridge Converters

Finally, the power connects the two sets of H-bridge in the parallel way, such combination can be more conducive to the output of ripple current, especially with some special duty cycles, the ripple current can be zero theoretically [2]. In addition, the parallel connections can double the current output ability with a lower cost for the whole power supply.

THE INTRODUCTION OF THE CONTROLLER

From the above control sequence, in order to achieve the control over topological structure of two serial ones and two parallel ones, the controller requires the drive signals of eight IGBTs. The eight signals have each two in a group, require the phase shift of 180 degrees, the duty cycle are exactly the same and are continuously adjustable.

The four signal groups require phase shift of 45 degrees between each two groups. In order to avoid problems resulted from differences of duty cycles, duty cycles of each IGBT drive signal should be as consistent as possible. It will be too difficult if the drive pulse generator use analog circuit. And because the worse consistence of the analog circuits, it will be more difficult. However, it will be easy to achieve these functions with digital circuit, and maintain the output consistency. Therefore, the power supply utilizes a digital controller to control power. Figure 7 show the structure diagram of digital controller.

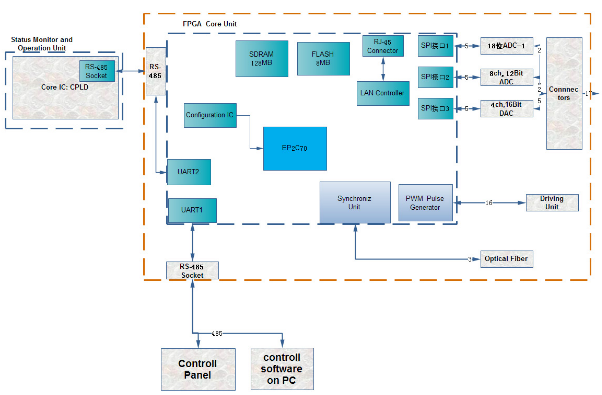

Figure 7: The structure diagram of digital controller.

This controller contains a high-precision ADC unit, which can high-speed sample the output current (current sensor is DCCT), and regulate the output current tracking the reference current through real-time calculation and regulation. Moreover, to achieve the pulse-output of current, the controller also possesses the functions of reference waveform download (via Ethernet interface) and synchronization running (via optical fiber interface). In addition, this digital controller also has the functions of monitoring status of power supply and real-time protection.

EXPERIMENTAL RESULTS AND CONCLUSIONS.

After adjusting the power supply, satisfactory results are obtained. Figure 8 shows the results of tracking errors.

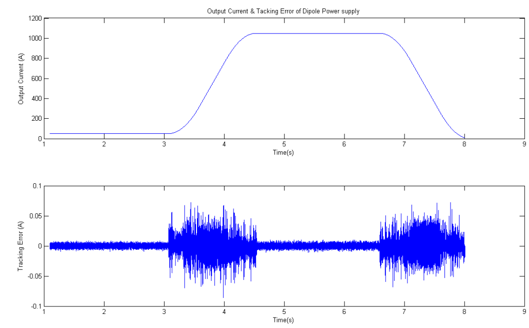

Figure 8: Output current & tracking error.

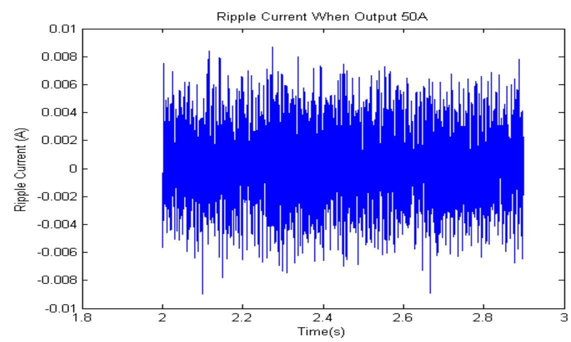

Figure 9: Ripple current on low output.

It can be seen from Figure 8 that, the tracking errors of power supply are less than $\pm 0.05\ A$, the relative errors are less than $\pm 2.5\times10^{-5}$. It can be seen from Figure 9 that, when the output current is 50A, the ripple current less than $\pm 0.004\ A$, and the relative value is $\pm 1\times 10^{-4}$. All these reach the design goals.

From the above experimental results, the multi-level converter with two serial ones and two parallel ones can effectively control the low output ripple, and improve the response speed of the power, providing a good choice for accelerator power with a wide range of output. However, this approach also has its flaws, namely, the complex topological structure, complex controller and higher cost, all these flaws require further improvement in the next step.

REFERENCES

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[2] Xunwei Zhou and Peng Xu, "A Novel Current-Sharing control technique for Low-voltage High-Current Voltage regulator Module Application", 2000, 15[6], IEEE Transaction on Power electronic, p.1153-1162 (2000).