A PROTOTYPE OF PULSED POWER SUPPLY FOR CSNS/RCS INJECTION PAINTING BUMP MAGNETS*

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Abstract

The prototype of pulsed power supply for injection painting bump magnets of CSNS/RCS is being developed. It consists of IGBT H bridges in series and parallel. The pulse current of the prototype is 18000A, the equivalent frequency is 1.8432MHz and the tracking error is 1.5%. This paper will describe the power supply in detail.

INTRODUCTION

The China Spallation Neutron Source (CSNS) Rapid Cycling Synchrotron (RCS) injection system needs two pulsed power supplies (BHPS and BVPS) to drive eight beam painting bump magnets. These are connected as four horizontal painting bump magnets in series and four vertical painting bump magnets in series [1]. The prototype pulsed power supply has been developed successfully with the Xian Action Electronics Co. Ltd. in China. Table 1 shows the parameters of the prototype.

Table 1: The parameters of the prototype

Frequency(Hz)	25
Pulse rise time(μs)	1000
Pulse flat-top(μs)	50
Pulse fall time(μs)	450 programmed
Pulse current(A)	18000
Load inductance(μH)	12(including transmission lines)
Load voltage(V)	>3150
Current stability	<±0.5%
Tracking error	<2%

The injection system of the CSNS/RCS uses the bumping orbit scheme and phase space painting method to reduce the beam space charge effects [2]. So the power supply output pulse current falling edge has to be program controlled. To meet these requirements, the power supply uses an IGBT power amplifying method to generate the pulse current. The IGBT topology is H bridges in series and in parallel, and operating in the phase shifted method to divide the current and voltage and improve the equivalent frequency response. The reference setting waveform of the power supply is program controlled. The power supply output pulse current follows the setting waveform using a feedback control system to realize the controlled the falling edge of pulse current. The simulation of the power supply circuit with the multi-IGBT H bridges has been done using Matlab and PLECS software. The relationship between the tracking error and the equivalent frequency was determined from this simulation and is shown in table 2. The tracking error is one of the important specifications of the power supply. To obtain a tracking error < 2%, the equivalent frequency requested from the IGBT topology is > 400 KHz. The high power, high frequency, fast speed response and optimal feedback control strategy are the key to the good performance of this pulsed power supply. To overcome the low current non-linearity of an IGBT [3] [4], the IGBT H bridges work in 4 quadrant mode [5] [6]. The maximum fall rate of the pulse current is 260A/μs.

Table 2: The relation between the tracking error and the equivalent frequency

	BHPS	BVPS
200KHz	2.1%	2.1%
400KHz	1.95%	1.90%
500KHz	1.88%	1.80%
600KHz	1.74%	1.70%
800KHz	1.63%	1.65%

THE STRUCTURE OF POWER SUPPLY

The power supply has a modular structure. In Figure 1 are shown the 5 H bridges in series that compose one module. Ten of these modules in parallel make up the IGBT topology of 5 H bridges in series and 10 modules in parallel shown in Figure 2. One H bridge is one unit which includes rectifier circuit, voltage chopper and an IGBT H bridge (4 quadrant chopper). The IGBT type is FF450R12M3 which is a dual IGBT. Each IGBT works in switched mode at a switching frequency of 18.432KHz. The equivalent frequency of the IGBT topology is 1.8432MHz.

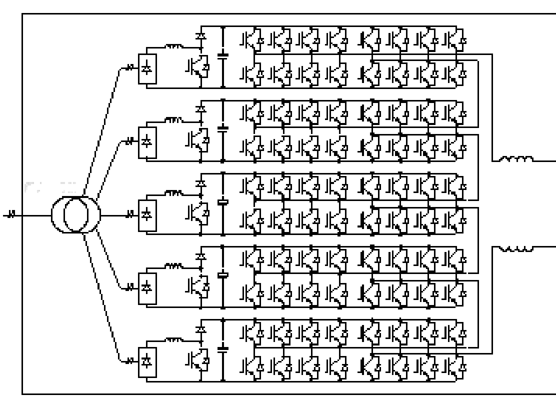


Figure 1: A module of 5H bridges in series.

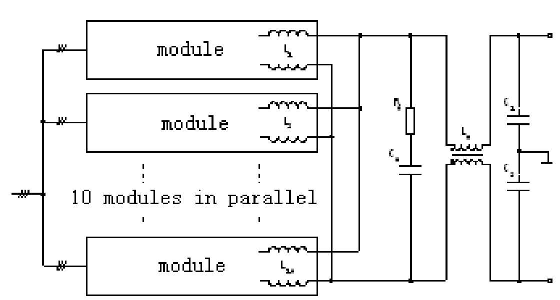


Figure 2: 10 modules in parallel.

THE KEY TECHNOLOGY

The output current of the prototype is 18000A and the voltage is more than 3150V. The IGBT rating is 450A/1200V. We use 4 IGBTs in parallel and 10 modules also in parallel to divide the current and 5 H bridges in series to divide the voltage. Each IGBT conducts 450A at a voltage of 750V. The key to the IGBT's reliable operation is determined by the thermal effects. To absorb the heat coming from IGBTs due to power losses, the IGBTs are mounted on a stainless steel cooling water board. The average current of 10 modules uses the feedback loops with a proportion of 1 strategy. Each IGBT H bridge's 750V bus voltage (DC voltage) is controlled using the feedback control system.

The stability of the DC voltage is very important for the power supply since it affects the tracking error of pulse current. If the DC voltage is low, the speed of tracking will be lower and the tracking error will be large. Figure 3 shows the stability system of DC voltage diagram. The voltage feedback uses PI strategy to stabilize the DC voltage. The current feedback uses P to eliminate the fluctuation of DC voltage and the effect of output current for DC voltage.

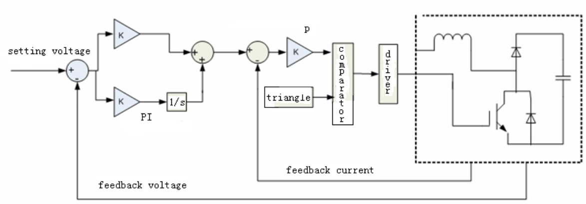


Figure 3: The stability system of DC voltage diagram.

The feedback control system of power supply uses the current feedback, current feed forward and 10 average current loops. Figure 4 shows the strategy of feedback control system. The current feedback uses P strategy to realize the fast tracking of pulsed current. The current feed forward is used to improve the tracking precision of pulsed current top. The output current of the power supply is subtracted from the reference setting waveform coming from an arbitrary function generator (WE7121). This goes through the P controller and feed forward and

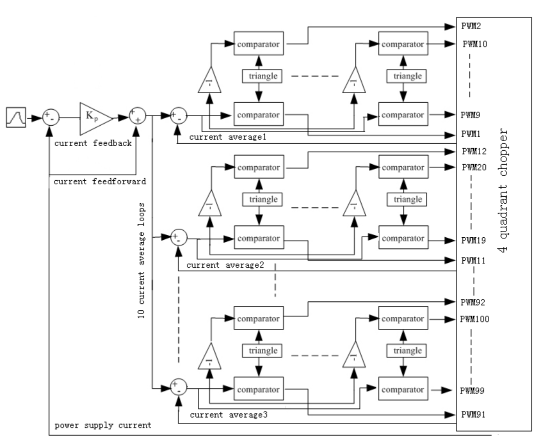


Figure 4: The feedback control system of power supply.

is sent to the average current loops where it is compared with the triangle waveforms to produce PWM signals to the IGBT's gates of 4 quadrant choppers.

To produce 100 PWM signals, we need 100 phase-shifted triangle waveforms. To ensure the phase precision of each PWM, we read the triangle waveform's data from an EPROM and these are produced as shown in Figure 5.

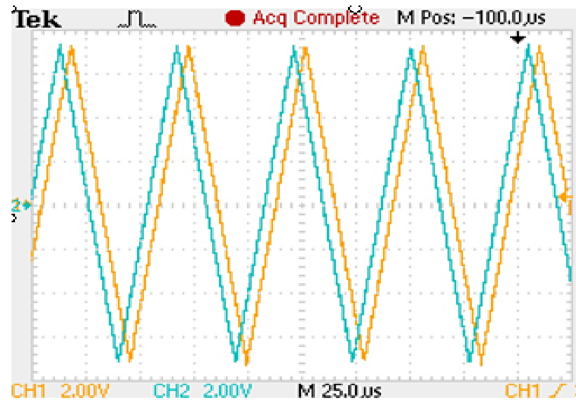


Figure 5: The EPROM triangle waveforms.

To reduce the harmonics on the input alternating current, we use a rectifier transformer shifted to improve the power factor and THD of power supply. The second windings of each rectifier transformer are shifted in phase by 12°and the power factor is 0.99, the THD is 7.4%. Figure 6 shows the input alternating current waveform.

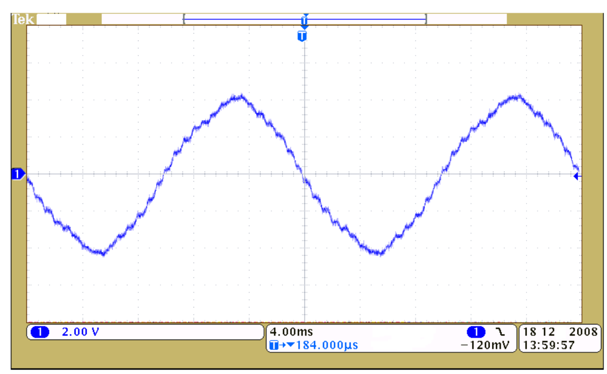


Figure 6: The input alternating current waveform.

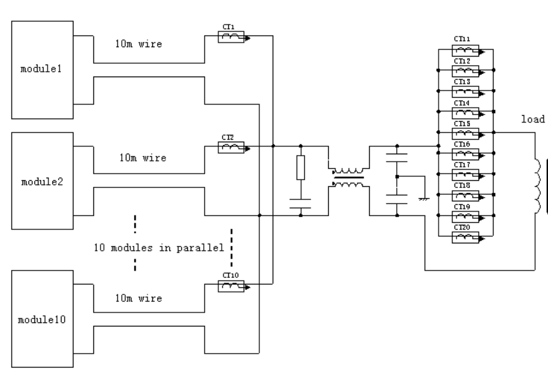
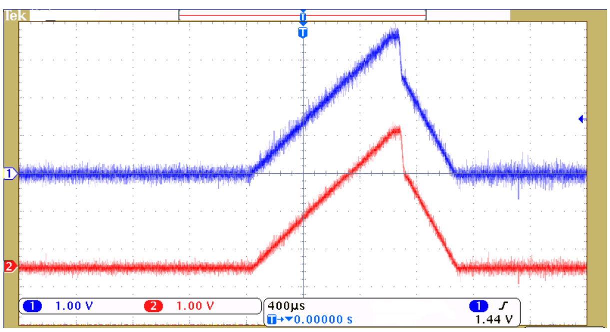


Figure 7: The position of CTs in the power supply.

The current measurement is made using LEM LF2005-s type CT that have a conversion ratio of 1:5000. Figure 7 shows the position of the CTs in the power supply where 10 CTs in parallel are used to measure the output current of power supply. The other 10 are used to measure the current of each module for the feedback control system to the average current loops. The average current of CTs in parallel depends on the resistance of the transmission lines between the power supply and the load.

TEST RESULTS

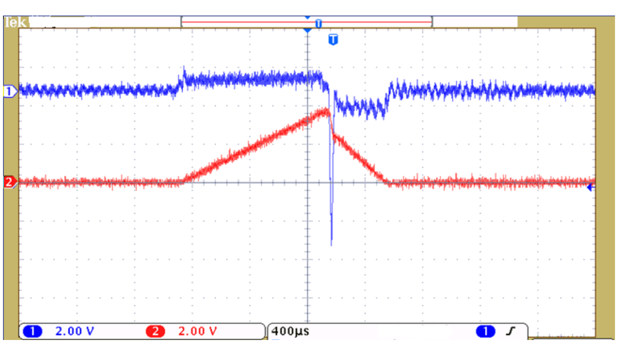
The power supply's load includes a painting bump magnet, a dummy load and transmission lines. The total inductance is 12μH. Figure 8 shows the output pulse current waveform of power supply, where the current is 18000A. The tracking error of the pulse current is 1.5%. Figure 9 shows the output voltage waveform of the power supply, operating at a value of 3319V.



Channel 1: The setting waveform

Channel 2: The output pulse current

Figure 8: The output pulse current (18000A 5000A/div).



Channel 1: The output voltage

Channel 2: The output pulse current

Figure 9: The output voltage (3319V 404.72V/div).

DIGITAL STUDY

The digitally controlled power supply has more advantages compared with an analogue power supply. Because of the digital control of the power supply's feedback control system, it enables the PWM signals to have a very high precision.

We use an FPGA to realize the control strategy and to produce the PWM signals. We have embedded within the core of the FPGA to the internet communications with a PC using TCP/IP. Figure 10 shows the digital feedback control system diagram which is being tested at the present time.

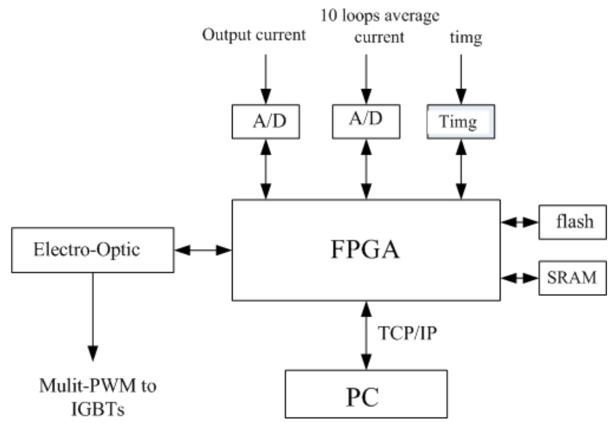


Figure 10: The digital feedback control system diagram.

SUMMARY

This paper has described the features and results of the prototype of pulsed power supply. The test results meet the required specifications. The output pulse current is 18000A, the output voltage is 3319V and the tracking error is 1.5%. The CSNS/RCS injection system requires two of these beam painting pulsed power supplies.

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