

DESIGN OF MAIN RING DIPOLE POWER SUPPLY FOR HIRFL-CSR*

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Abstract

This paper introduces the main circuit topologic, control method and double reference setting system of a dipole power supply which is the pivotal device of the HIRFL-CSR (Heavy Ion Research Facility in Lanzhou-Cooling Storage Ring). The power supply works at the pulse mode, with the peak output power of 3.15MW (3000A, 1045V). To fulfil difficult requirements especially for the tracking error, which is needed less than 300ppm, a special topologic is adopted. The power supply has two parts: SCR rectifier provides the most energy and PWM converter provides correcting current and perfect reaction for tracking current setting. Now the dipole power supply is performing well during the CSR commissioning, with the perfect tracking error, well long-time stability and low ripple current.

INTRODUCTION OF THE POWER SUPPLY

The power supply is a pivotal device of HIRFL-CSR (Heavy Ion Research Facility in Lanzhou-Cooling Storage Ring), and it is a synchronized one. This synchronized power supply's output current must track the setting as Fig. 1.

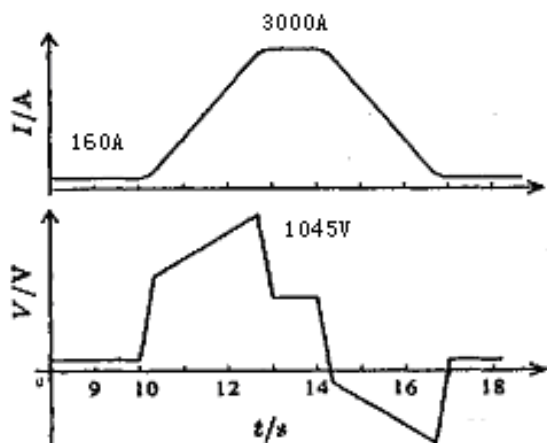


Figure 1: Plots of current and ideal voltage.

In Fig. 1, the output voltage only happens at the ideal state.

For heavy iron beam acceleration, the most important requirements on the power supply are listed below:

- Peak output power 3.15MW (3000A/1045V)

- Tracking error less than 200ppm
- Current stability better than 3×10^{-5}

This power supply works at two modes, one is the DC output mode and the other is Pulse output mode, in most cases the control system's parameters are different at the two modes.

DIPOLE POWER SUPPLY'S SCHEMATIC DIAGRAM

To fulfil these stringent requirements as mentioned above, our dipole power supply has two parts: SCR rectifier and switching mode DC converter. Fig. 2 shows the schematic diagram of the power supply.

In part one, we use 12 SCRs and connect them into two serial normal 3-phases SCR rectifiers. The transformer's input comes from 10KV power line, and the second side output voltage is 495V. This part provides the most output power (95%). IGBT is adopted in part two, which consists of 4 DC converters. Each DC converter uses a full-Bridge topologic and be connected in serial mode to supply the high-voltage output capability.

As we all know, the traditional SCR rectifier has advantages of high power output ability, high credibility and low-cost. But the SCR rectifier also has disadvantage of slow response in synchronized power supply. For the reason mentioned above, the switching mode converter is used to improve the fast-response ability. The very high switching frequency of IGBT makes it easy to control the power supply's output with a small tracking error. But the switching mode rectifier is of high-cost. In our power supply, we use the advantages of the two modes. It means that the SCR rectifier provides the most output power and the switching mode rectifier provides the fast-response ability for current tracking. There is a balance between the output powers of the two parts. In this power supply, the switching part can supply maximum current up to 200A, but in most cases this part's maximum output is less than 200A. The maximum output is controlled by a constant input, which is introduced in the following part of this paper.

CONTROL SYSTEM

In order to control these two parts work as we expect, P and PI method controller are used in the power supply's control system. The control loops are shown in Fig. 3.

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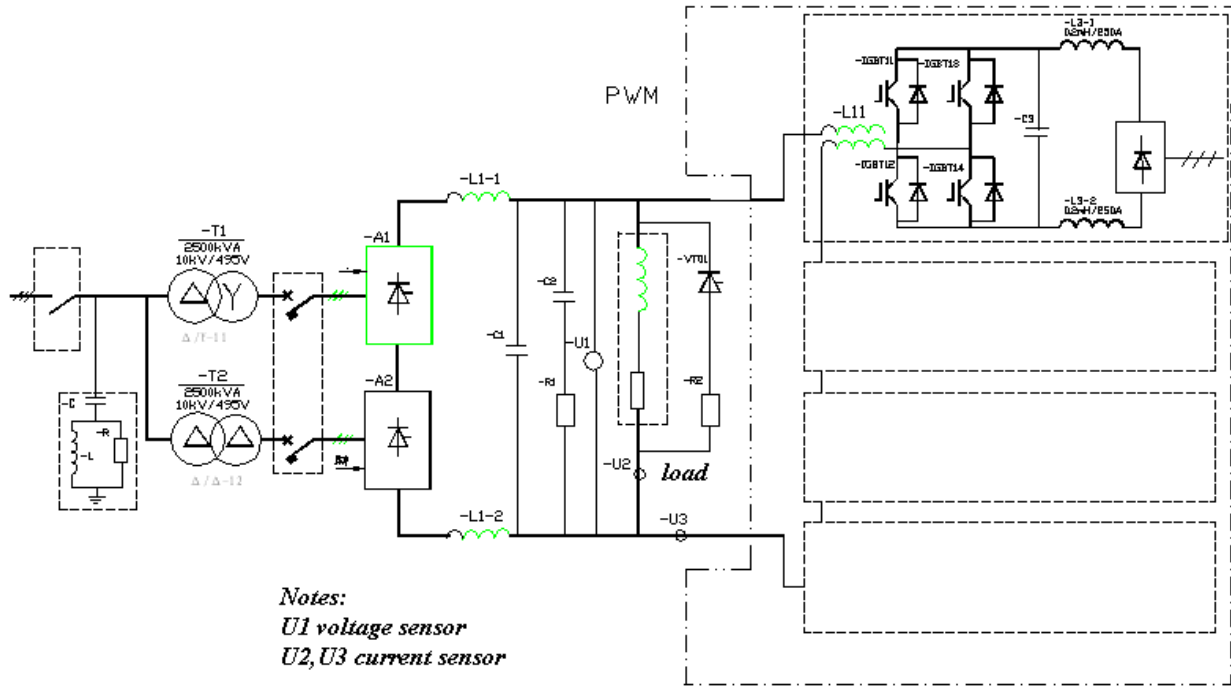


Figure 2: Schematic diagram of the dipole power supply

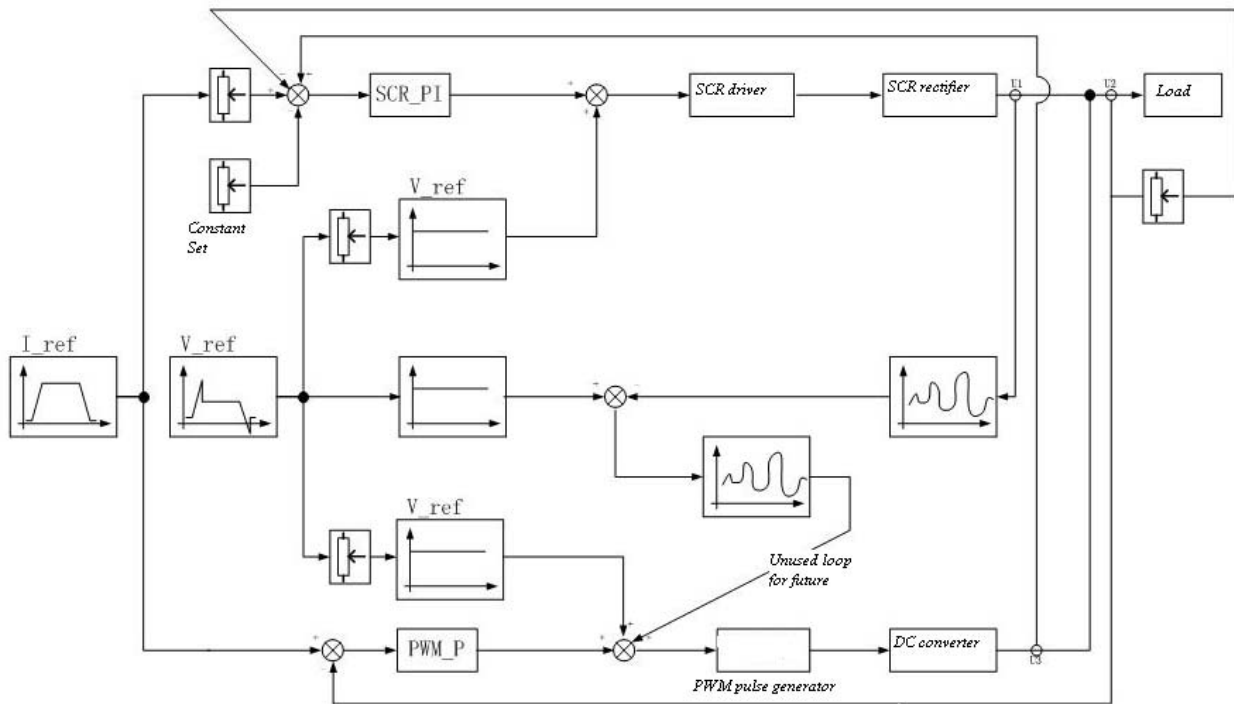


Figure 3: Block diagram of the control system.

There are two control loops in control system. We call loop 1 the main loop, which uses P mode method to control the switching part. The input error signal is the deviation of the current setting from the output current feedback. Using the P mode controller loop 1 achieves the ability of fast response to meet the crucial requirement of the tracking error. Loop 2 uses PI method to control the

SCR rectifier part, and the input error signal is decided by the following equation:

$$Error = I_{Set} - I_{all} - Const + I_{switching_part} \quad (1)$$

The “Const” in equation is a constant setting voltage, which defines the switching part’s maximum output current.

There is a feed forward loop, which we call forward-voltage reference system. There are two reasons why we need two-reference setting. The first is that the load’s inductive reactance changes with the current and the change is large. The second is that the P method controller always has a bias between the setting and feedback signals, so we use the forward-voltage reference setting to correct those.

The load’s inductive reactance can be measured easily, so that the mathematic mode of load also can be made. For voltage-forward signal, we just need calculate it according to the following equations:

$$U_o = L(\text{current}) * di/dt + I \times R \quad (2)$$

The results of the experiment and simulation tell us that the precision of forward-voltage signal only needs to be less than 1%. Fig. 4 shows the actual inductive reactance of our dipole magnet.

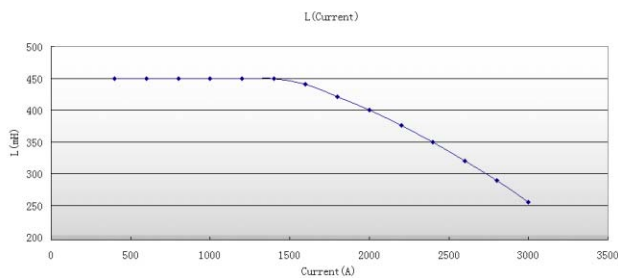


Figure 4: the inductive reactance of load.

Fig. 5 shows a voltage-forward, output current and tracking error signals we use at present. Ch1 shows actual output current come from the DCCT current sensor. Ch2 shows the voltage-forward signal. Ch4 is the tracking error, which has been amplified 150 times.

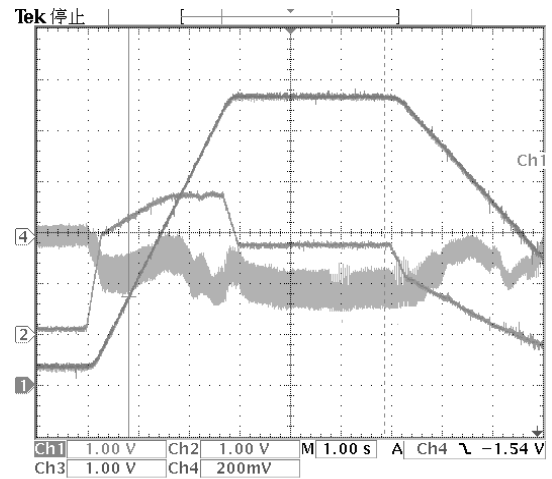


Figure 5: signals of voltage-forward, output current and tracking error.

CONCLUSION

It is a simple and low-cost way to use SCR rectifier and IGBT switching converter synthetically for high power output synchronized power supply.

The controller which consists of double feedback loops and a feed forward loop can be regulated easily, and it is robust.

The feed forward loop which we use as forward-voltage system is very important for tracking error.

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