2Hz RAMPING MODE DIPOLE POWER SUPPLY FOR TESTING THE NSLSII BOOSTER DIPOLE MAGNETS

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Abstract

Budker Institute has designed and delivered Booster for NSLSII project including vacuum system, magnet system, diagnostics and power supplies. Dipole power supplies were directly delivered to BNL by sub-contractor (Danfysik, Denmark). To test dipole magnets on factory side, at BINP, it was decided to design and construct a high current ramping mode power supply. The designed power supply can operate with the reactive output power up to 150kVA and output current up to 900A at 2Hz ramping mode. The absolute accuracy achieved is better than 100ppm for the injection and extraction flats and better than 500ppm for the ramps.

PARAMETERS

Load Parameters

The main parameters of the Booster dipoles magnets are presented in Table 1 [1].

Table 1: Magnets' Parameters

Magnet, type	Current, A	Resistance, mOhms	Inductance, mH
BR-BF	862	3,68	1,18
BR-BD	742	18,9	9,56

The simplified current scenario for the Booster working cycle is shown on Figure 1 [2].

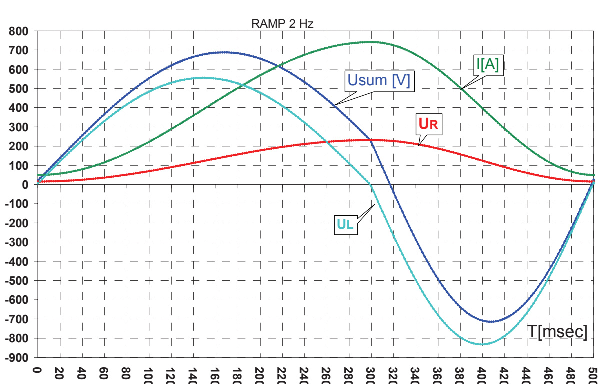

Figure 1: Dipoles Magnets Current Scenario.

PS Parameters

Since according to the contract dipoles power supplies were delivered directly from Danfysik (Denmark) to Brookhaven National Laboratory (BNL, New York, USA) it was decided to design and construct the independent power supply to test the dipoles magnets after manufacturing. To perform the full scale magnetic measurements with the shown above current scenario this power supply should deliver full current in the ramping mode (Table 2). To test few magnets in a chain PS should have sufficient peak voltage during the current ramp.

Table 2: PS Main Parameters

Parameter	Unit	Value
Maximal peak current	A	±900
Maximal peak voltage	V	±300
Switching frequency	kHz	10-20
Operational mode		1-2Hz cycles
Absolute accuracy: flat, not worse ramps (2Hz), not worse	 ppm ppm	 100 500
Cooling		Water

Test stand for the magnetic measurements is shown on Figure 2.

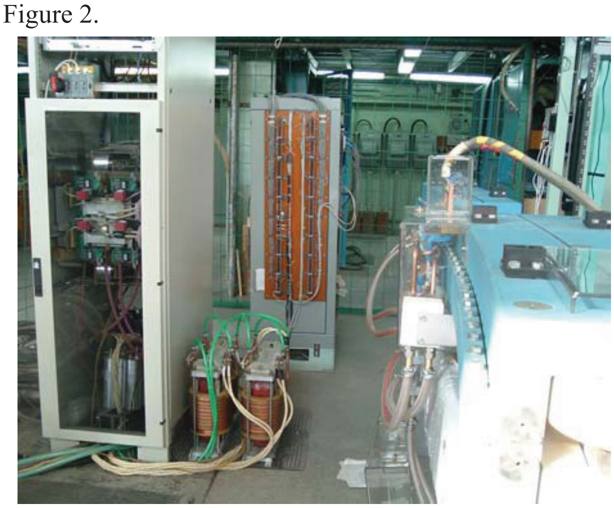

Figure 2: Test stand. Power supply (left) and dipoles (right).

PS TOPOLOGY

Principle of Operation

The reactive power oscillating into the magnets string and power losses at the resistive component of the strings impedance have the ratio about 10 both for the BR-BF and for BR-BD. To minimize the peak power consumption from the AC line it is proposed to use the buffer capacitors bank. With the capacitors bank and charging PS continuously charging the bank the output converter (Figure 3) provide the current scenario given on Figure 1. To prove the required accuracy and dynamics parameters the output converter is based on the H-bridge topology with the IGBT switches. The modules type FZ1200R12KE3 and drivers 1SD1548AI are chosen. PWM frequency is 10kHz, which is a compromise between the converter output ripples and heat losses over the switches. Taking into account the heat losses level (less than 5kW per two switches of one arm of the bridge) IGBT modules are installed on the water cooled heat sinks. Δt of the junction to case for the chosen IGBTs will not exceed 60°C. To compensate the mounting cross-inductance the additional high-frequency capacitors bank is used, the total capacitance is 100uF (C_{19}-C_{24}). The additional RCD snubbers with the capacitance of 2x0.47uF and resistance of 2.2 Ohms are installed over the IGBT power terminals.

The required accuracy is achieved with the high precision DAC, DCCT and corresponding feedback loop circuit. The DAC0 for the current reference drives the current channel. One DCCT is used for the feedback system and one for the current measurement. The output symmetrical LC filter has the total inductance 300uH and the capacitance 2.2mF which is enough to suppress the output ripples to the level not more than 0.5V.

Electrolytic capacitors (EPCOS, 450V, 12mF) are used for the capacitor bank with the total capacitance up to 0.66F (C_1-C_{18}). This decision allows to decrease the voltage variation over the capacitors to the specified level and to decrease the variation level of the power consumption from the AC line. The capacitors bank is protected by the controllable fuses (F_1-F_{18}) and by the active grounding circuit (Sw, R_6). The topology of the bank is chosen as shelves of 18 capacitors in such way that bank can consist from one to three shelves.

Power Supply Controller

Power supply is a computer controlled device with a wide number of DAC and ADC control channels and with digital IN/OUT registers to control the ON/OFF status interlocks.

All of these channels are connected to the computer control network via the Power Supply Interface Modules (PSI), developed by BNL computer control team for the NSLS-II [3].

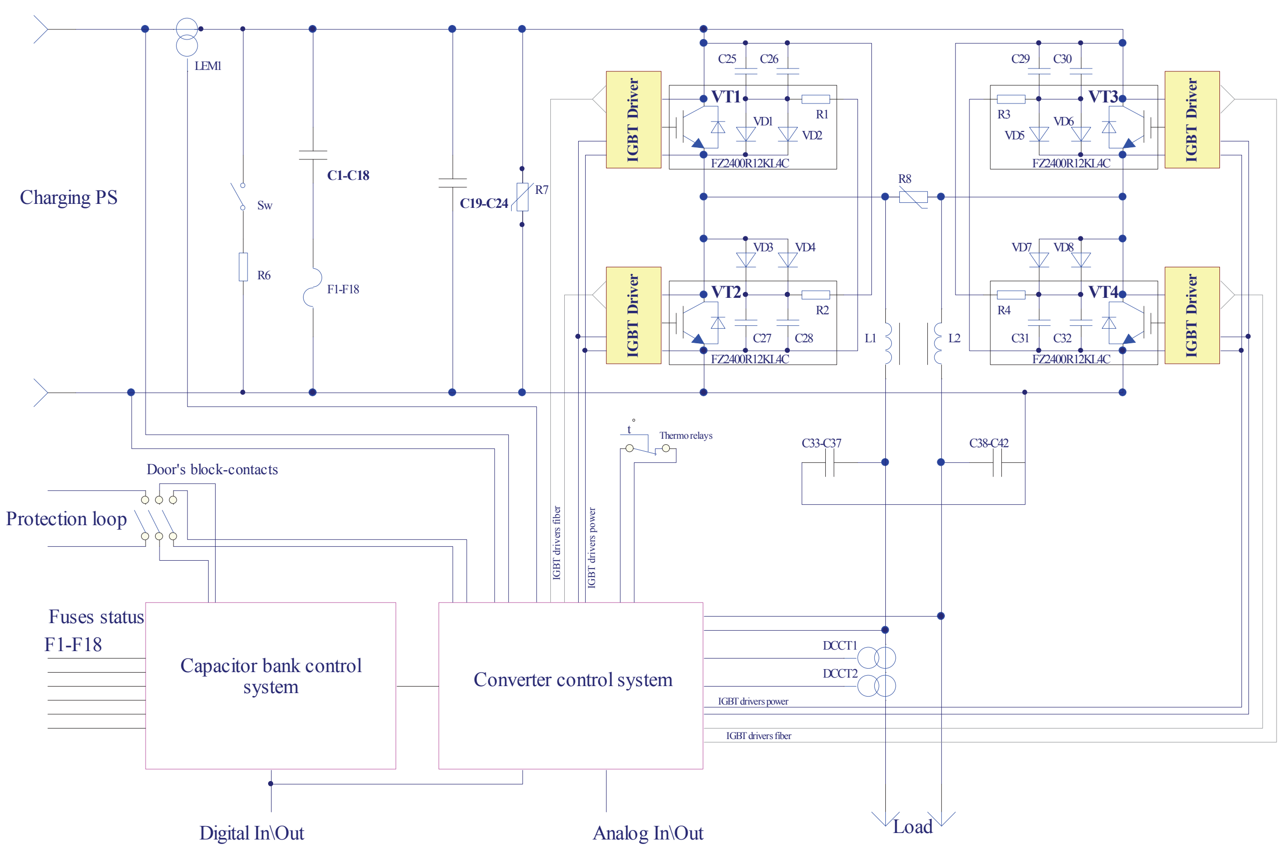

Figure 3: Power supply's block diagram.

ISBN 978-3-95450-122-9

Components Design

The design of the described components and their position relative to each other are very important in a successful proving of the power supply parameters. The front view converter is presented on Figure 4. It shows the compact relative position of IGBT modules, drivers, snubbers and energy storage capacitor bank components in combination with the flat shaped current conducting buses-sandwiches (behind the H-bridge). It allows us to minimize the switching interference and noise generation.

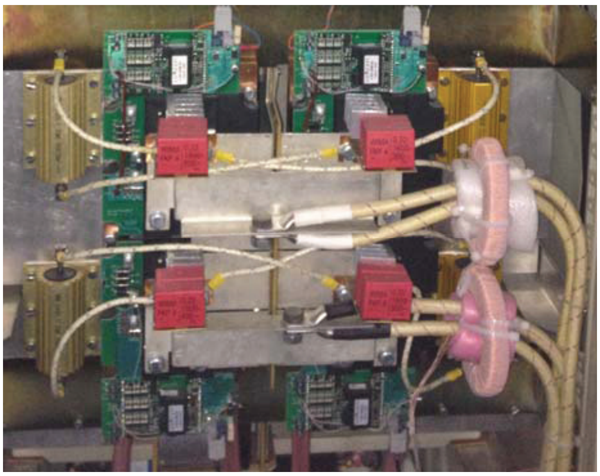

Figure 4: Converter's H-bridge.

Among the other mechanical parts produced in BINP the heatsinks for IGBT modules are very important and reliable component (Figure 5). To minimize Δt of the IGBT junctions the heatsinks are produced from the solid copper with the milled water channels. The last ones allow 50% covering of the surface by the water trough only 1.5 mm of the copper layer.

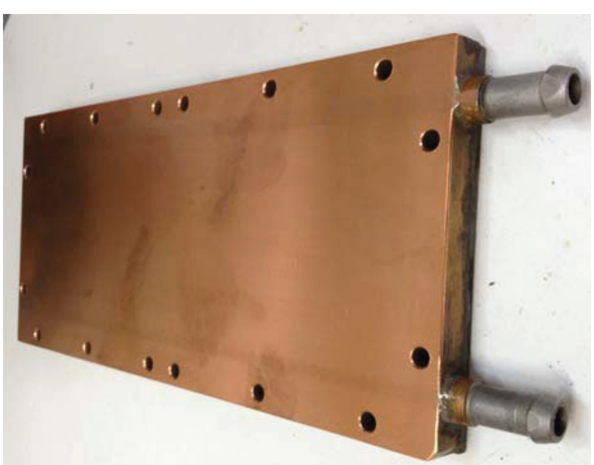

Figure 5: IGBT's heatsink.

TEST RESULTS

Power supply was successfully tested with the dipoles magnets. According to the magnetic measurements requirements tests were performed with 1Hz and 2Hz ramps. Figure 6 shows the power supply current and voltage during the typical 2Hz ramp. Injection flat is 50A, extraction 900A. The current regulation error is about ±90mA (100ppm) on flat part and about ±300mA (300ppm) during the ramp. Output voltage ripples with 10kHz are about 0.4V. Switching frequency can be increased up to 20kHz and the ripples value will be about 0.1V. But in this case peak current will be not more than 600-650A. For the future projects we designed and produced new power supply with the same topology but with the H-bridge based on FZ2400R12KL4C IGBT modules. This PS will operate with 20kHz switching frequency and with the peak current up to 1300A.

The test results of the dipole power supply have shown that all magnetic measurements of the dipoles magnets were done within the conditions which magnets will meet during the Booster operation [4].

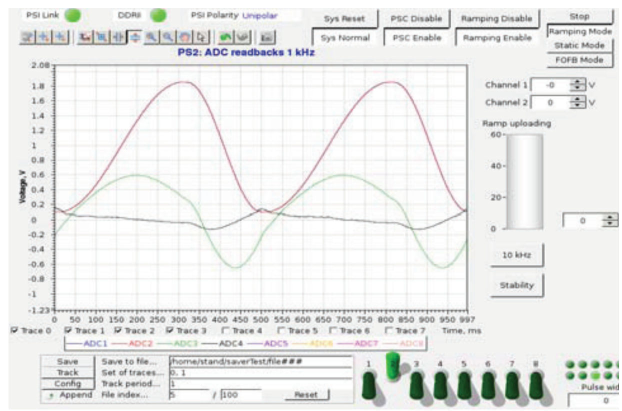

Figure 6: Power supply testing with engineering screen: load current (red), load voltage (green).

ACKNOWLEDGMENTS

We would like to thank E. Levichev, A. Medvedko, A. Steshov (BINP, Novosibirsk, Russia), T. Shaftan (BNL, NY, USA) on their help during the development and construction of the power supply. Also we would like to thank G. Ganetis and W. Louie (BNL, NY, USA) for their help with the supplying of PSI designed and produced in BNL. This work is supported by the Ministry of Education and Science of the Russian Federation.

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