BENDING MAGNET POWER SUPPLY WITH SWITCHING SERIES REGULATOR

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Abstract

We present a bending magnet power supply to be used for the LNLS VUV storage ring. The power converter uses a new topology, combining an SCR rectifier with a series modular transistor switching regulator. The performance of the converter under different tests is discussed.

1 Introduction

The LNLS is designing a 1.15 GeV storage ring for VUV and soft X rays synchrotron radiation (1). Injection into the ring is done at low energy from a 100 MeV LINAC (2). After low energy accumulation the field in the bending magnets is ramped up to a maximum of 1.4 T (3), at which value the beam is stored.

The power supply for the bending magnets must deliver a maximum of 270 A with a better than 10:1 dynamic range. Tracking accuracy, mean current stability and ripple must be better than 10^{-4}. Ramping time from low field up to maximum field is 20 s.

In this paper we discuss a power supply that has been developed at the LNLS and is currently undergoing extensive tests. The power supply design uses a new topology, which combines a SCR converter with a transistorized fast switching series regulator.

2 The power converter

The converter is a series association of 2 power supplies: a 6 pulse SCR rectifier with a LC filter which delivers up to 90% of load power with voltage ripple up to 5%, and a transistor chopper which trims the current to the required ripple and stability.

Fig.1 shows a diagram of the converter. The largest part of the power is supplied by a standard SCR bridge while the transistor regulator handles a small fraction of load power, switching full current at low voltage.

Furthermore, the design includes several features intended to minimize usual RFI problems due to large di/dt and dv/dt normaly produced in switching regulators, and allows for modular construction which can be expanded according to maximum current needs.

It uses modules built with MOSFET transistor, fast diode and small inductance. The modules are parallel conected. The transistors are sequentially switched on or off from a low voltage source. This permits to switch the current in steps. The small inductance is used to guarantee a balanced current distribution between the modules. As a result the value of di/dt is reduced by the number of modules used. Furthermore there is a corresponding reduction of dv/dt. If only one transistor is turned on, the switching regulator will apply into the load a fraction of its maximum voltage. When all the transistors are in conduction the total regulator voltage is available.

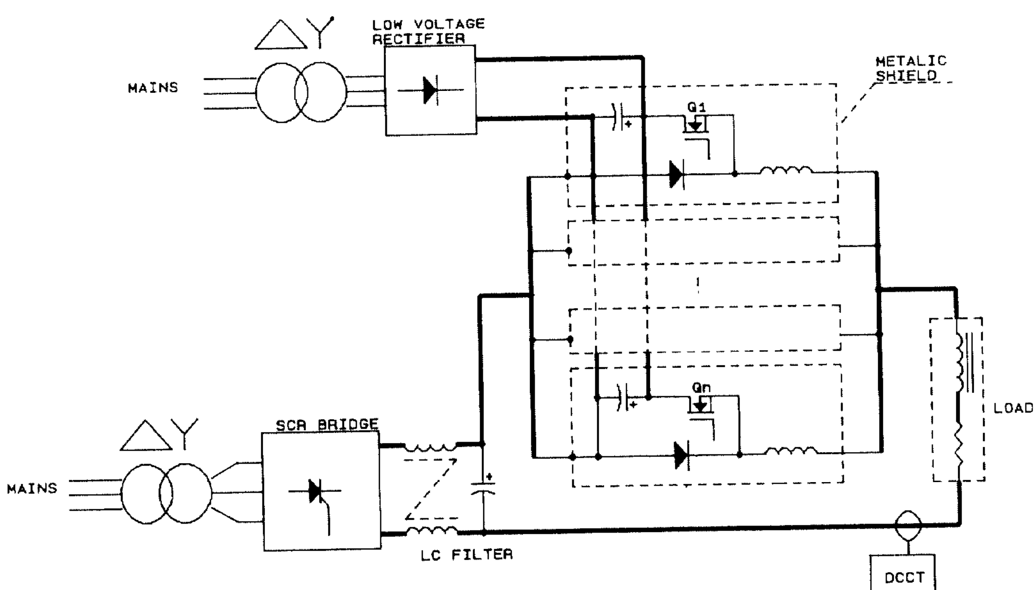

FIG. 1: SCHEMATIC DIAGRAM OF THE POWER SUPPLY

The current and voltage wave forms illustrating this effect are shown in Fig.2, where is possible to verify the transistors firing. Adjusting the delay time beetwen the firing it is possible to control the dv/dt.

Still to get a lower RFI and eddy current effect a "coaxial" box mounting of the switching components is used. The capacitive filter, chopping transistor and free wheeling diode are mounted inside a metalic tunnel, with current flowing out of it through a busbar and returning via the tunnel walls.

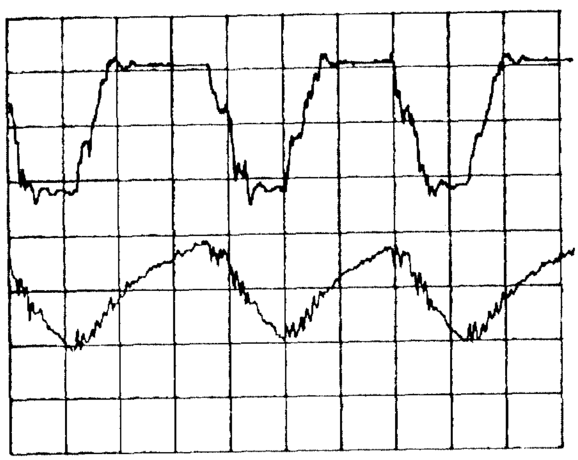

Figure 2: (a) Switching regulator output voltage (5V/div) and (b) load current ripple (20mA/div), for 100 A load current. Horz.: 20us/div

3 The control system

The power supply regulation has a control hierarchy with the switching regulator operating as master and the SCR bridge subordinated to it. The switching regulator control is based on the current Limit Regulation (CLR) principle. Load current, measured by a DCCT, is compared with upper and lower reference limits. This current window defines the ripple. The semiconductor switches are turned on and off so as to mantain the load current within the stablished ripple limits.

Given the load resistance, R, and inductance, L, the switching frequency depends on the SCR rectifier voltage, Vo, and the transistorized switching series regulator voltage, V, according to the expression:

$$f = \frac{RIo - Vo}{L\Delta I}\left[1 - \frac{RIo - Vo}{V}\right]$$

where Io is the load mean current and I the allowed current variation, determined by the control circuit. This expression consider the voltage apllied into the load as a square wave.

The SCR bridge conduction angle is determined such that the transistors duty cycle, on the switching regulator, is 50%. Slow mains variations are corrected by changes on the SCR firing angle, while fast mains disturbances and SCR bridge ripple are compensated adjusting the transistors duty cycle.

A block diagram of the control system can be seen in Fig. 3.

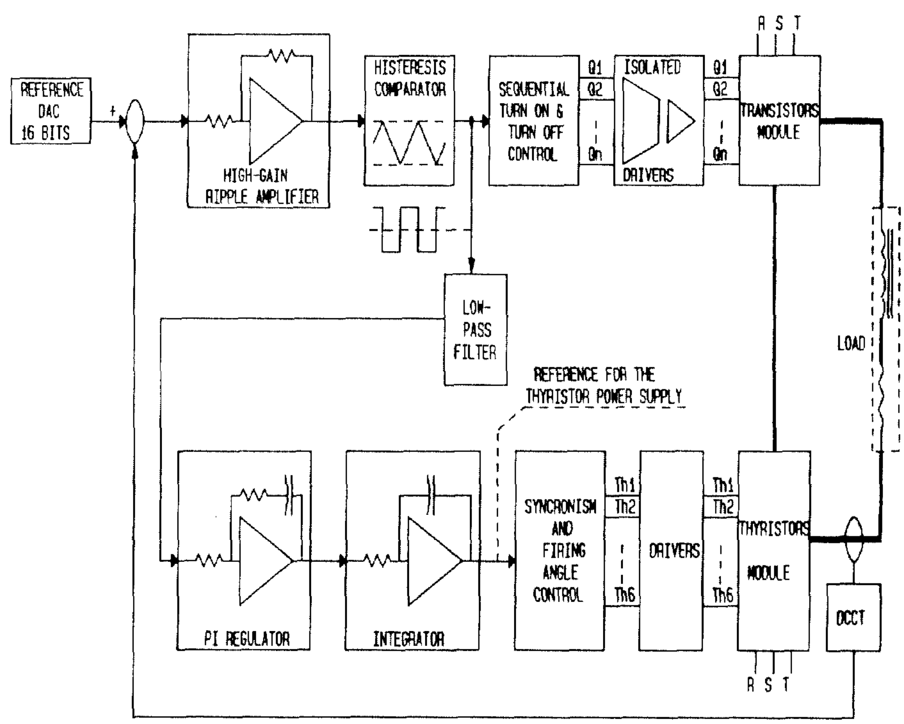

FIG. 3: BLOCK DIAGRAM OF THE CONTROL SYSTEM

4 Performance

Several tests had been made with a 15kW, 270 A power supply prototype to be used for magnetic measurements of each individual bending magnet. The load used in the tests had a relatively small time constant of 0.18 s.

After some hundred hours tests with large number of operating cycles and ambient temperature ranging from 18 to 35°C, the power supply has performed reliably and without failures

The power efficiency of the total power supply at maximum current is 85% and the dynamic range is better than 100, from 2 A to 270 A.

In fig. 2 can be seen the current ripple.

It is constant about 20 mA. The current amplitude variation is independent of the mean current as a result of the Current Limit Regulation. Ripple frequency is about 20 kHz. This frequency is limited by the DCCT and control circuit dynamic response.

This results in a still smaller ripple on the magnetic field because of magnet and vacuum chamber atenuation at high frequencies. Fig. 4 shows the magnetic field ripple in the gap, without vacuum chamber, for two different field values. The ripple is independent of B and about 0.1 gauss, or 8. 10^{-5} at injection energy (1.2 kgauss) and 7. 10^{-6} at full energy (14 kgauss). The vaccum chamber will reduce still more the field ripple.

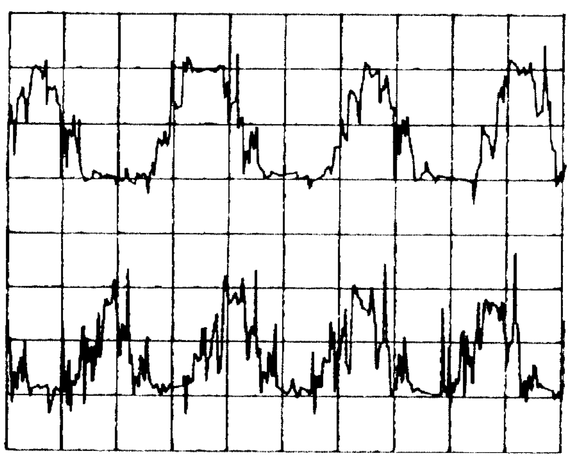

Figure 4: Field ripple at 1.2kG (a) and 11.4kG (b) Horz.: 20us/div Vert.: 0.1G/div

The DC current in the load has been measured for periods of several hours, equivalent to the storage beam life time to determine the power supply stability at full current. Using as reference a 16 bits DAC (± 7 ppm) the average current remains stable within ± 8 ppm (240 A).

Tests of the power supply tracking precision during ramping had been performed for 20 s ramping time from low current, corresponding to injection energy magnetic field, up to maximum current.

Fig. 5 shows the measure values at intermediate points along the ramp, indicating a tracking precision similar to the reference precision.

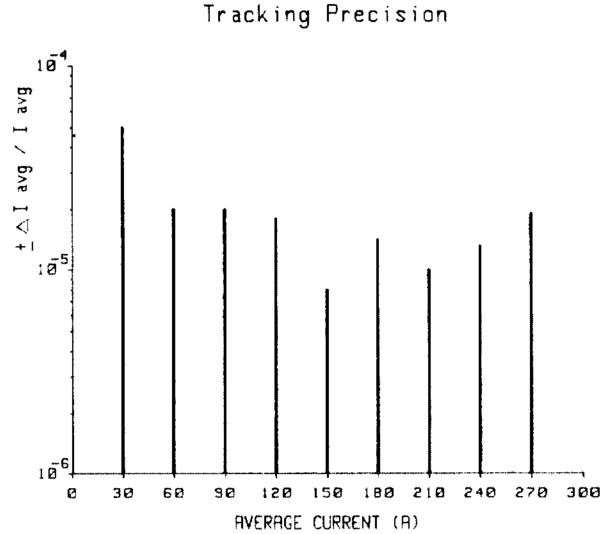

Figure 5: Tracking precision during ramping

5 Conclusion

We have discussed a new design of a power supply to feed the LNLS VUV ring bending magnets.

Several testes had been made to study its performance and reliability. The system has a good efficiency, is precise both during the tracking and DC operation. The RFI is reduced using differents strategies.

Acknowledgement

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