POWER SUPPLY SYSTEM FOR THE LNLS MAGNETS

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Abstract

The light source of the Laboratório Nacional de Luz Síncrotron (LNLS) includes a linac, a transport line and a booster-storage ring. A total of 163 magnets are used. These magnets require 49 DC current power supplies for the storage ring, 26 for the transport line and 28 for the linac, adding to 103 power supplies. This results in a large variety of precise, highly stable average current, low ripple and large dynamic range of power supplies. Continuous operation current stability and ripple must, in general, be better than 10^{-3} and, for the 300 A / 300 kW dipole power supply, smaller than 7.10^{-5}. This paper describes the development, construction, testing, performance and operation of the LNLS dc power supply system.

1. INTRODUCTION

The light source of the Laboratório Nacional de Luz Síncrotron (LNLS) [1] , under commissioning in Campinas, S.P., includes an electron linear accelerator (linac), a transport line and a booster-storage ring. To achieve the characteristics of a high quality light source a total of 163 magnets are used. These magnets require 49 dc current power supplies for the storage ring, 26 for the transport line and 28 for the linac, adding to 103 power supplies, listed on table 1.

Table 1: Characteristics of the Power Supplies for the LNLS Magnets

Type of magnet	Load Current (A)	Load Voltage (V)	Current stability	Ripple ΔI/Imax	Number of power supplies
Storage ring					**49**
Dipole	300	950	10^{-4}	$7\ 10^{-5}$	1
2-quadrupole family	250	25	10^{-4}	10^{-4}	12
6-quadrupole family	250	45	10^{-4}	10^{-4}	2
Skew quadrupoles	10	10	10^{-4}	10^{-4}	1
Sextupoles	220	40	10^{-3}	10^{-3}	3
Steering magnets	±10	±10	10^{-3}	10^{-3}	30
Transport line					**26**
Vertical dipoles	15	65	10^{-4}	10^{-4}	1
Horizontal dipoles	15	40	10^{-4}	10^{-4}	1
Single quadrupoles	5	10	10^{-3}	10^{-3}	8
Quadrupoles families	10	10	10^{-3}	10^{-3}	2
Steering magnets	±10	±10	10^{-3}	10^{-3}	12
Thick Septum	15	12	10^{-4}	10^{-4}	1
Thin Septum	110	2	10^{-4}	10^{-4}	1
Linac					**28**
Klystron focusing coils	160	20	10^{-3}	10^{-3}	6
Lenses	10	10	10^{-3}	10^{-3}	3
Focusing solenoids	40	65	10^{-3}	10^{-3}	6
Steering coils	±10	±10	10^{-3}	10^{-3}	10
Single quadrupole	15	15	10^{-3}	10^{-3}	1
Quadrupole family	15	30	10^{-3}	10^{-3}	1
Spectrometer	30	30	10^{-3}	10^{-3}	1

The Power Electronic Group of the LNLS, was established in 1987 to develop, construct and operate the magnet power supplies. Specifications for the power supplies were worked out jointly by the Accelerator Physics, Magnet and Power Electronic Groups. This resulted in a large variety of very precise, highly stable average current, low ripple and large dynamic range set of power supplies. Other requirements derive from the intended use: computer controlled set point and status surveillance, high efficiency, reliable continuous operation, low maintenance, long lifetime. Power requirements of the supplies range from 200 W/10 A maximum current up to 300 kW/ 300A, operating with widely different loads: from almost purely resistive to time constants of several seconds.

For each group of loads the most convenient type of dc converter was chosen:

Transistor series regulator for steering magnets, linac lenses, transport line quadrupoles and klystron focusing coils.

Three phase SCR converters for linac solenoids.

Buck converter with IGBT switches for low voltage storage ring quadrupole families.

Combined SCR and switch mode power supply (SMPS) for the storage ring high voltage dipoles, quadrupole and sextupoles families and transport line dipoles.

2 THE CONTROL METHOD

Although several different type of converters are employed, the same basic control system, current limit modulation (CLM), is used for all power supplies, to achieve the required precision. CLM control forces the load current to swing between definite limits set by a hysteresis comparator driven by the error signal between the set-point and measured current value. This guarantees that the current ripple be constant at any current. The ripple frequency is determined by the load time constant and the hysteresis gap. There is a minimum gap determined by the current sensor sensitivity which defines the maximum load current variation around the average value. A small gap results in a small amplitude high frequency current ripple, typically 10 kHz. At these frequencies, the magnetic material of the magnets core and the stainless steal of the vacuum chamber provide an additional attenuation, reducing the relative field ripple. Thus, since the important parameter is the field ripple, CLM is a particularly adequate control technique. To guarantee 10^{-3} stability a shunt transducer suffices, while for the more stable supplies a DCCT is needed. The way CLM is applied depends on specific converter. For series-regulated transistor supplies the hysteresis comparator modulates the voltage of the preamplifier. For the switching supplies, the CLM control defines the on/off states of the switch. Even in the SCR converters CLM can be used by modulating the conduction angle. In this particular case the modulating frequency is determined by the rectifier ripple. SCR converters are used for the ironless linac solenoids.

3 SPECIAL TOPOLOGIES

The power supply for the storage ring 12 bending dipoles required the development of a special supply [2]. It is the largest power and higher performance supply. Initially, a reduced power prototype, for a single dipole, was developed. The prototype is a series association of two converters: a 6-pulse SCR rectifier with a LC filter, which delivers up to 90% of the load power, and a set of 6 SMPS, parallel connected, fed from a common transformer, which trims the current to the required ripple and stability, handling a small fraction of the load power. The prototype power supply was used to demonstrate the adequacy of the new principle. All the measure results are better than the required performance. The equipment has performed with complete reliability and has been in used for magnets characterization in the Magnet. Laboratory during the last 5 years. Based on the experience obtained with the above development a full size power supply for the 12 bending magnets was designed and built. It is also made out of a 12-pulse SCR converter with 910 V maximum output, in series with 10-IGBT switching supplies, parallel connected, with 90 V 300 A maximum output. The IGBT's are sequentially switched on or off. This permits switching the total current in steps with reduced di/dt and dv/dt. At first, the supply had been tested with a reduced load of 6 dipoles due to limitations in the cooling systems available in the test area. This load was equivalent to an RL of 1.32 Ω, 3.6 H. Now, this power supply has a full load operation. The current dynamic range is better than 100 and current can be ramped, with zero tracking error in 12 s. Current ripple is ±7.5 mA @300 A which corresponds to ±25 ppm, but the corresponding magnetic field ripple is ± 4 ppm. Current stability is ±14 ppm @ 300 A at constant room temperature and current drift is 8 ppm/°C. Mains disturbances are compensated by the fast switching together with the SCR triggering system based on $\cos^{-1}$ control. To check the repeatability of current setting, a series of 40.000 current cycles, form 0 to 300 A was performed during 2 weeks of continuous operation without failures. Measures of the final current resulted in a 10^{-4} dispersion around the expected value.

More recently, a new topology [3] was developed for the 2 families of 6 quadrupoles. Again, the power supply uses a combination of an SCR rectifier and an SMPS. In the new topology, the SMPS handles not only a fraction of the load power, as in the power supply for the dipole magnets, but also a small part of the load current. The ramping power supply operates with a maximum of 45 V

@ 200 A. The SMPS uses a single IGBT which conducts, on the average, only 6 A in steady state, less than 30 times the load current. Ramping time with zero tracking error is 5 s. Operating at 15 kHz the load current ripple is 0.01% and the magnetic field variation is 5 ppm.

To develop the power supplies and attain the required specifications is only part of the task. As important as that is to establish adequate production procedures, guarantee components quality, develop tests criteria and create the corresponding complete documentation. Aging tests for some component subjected to more critical working conditions had been performed to attain a minimum equivalent life time of 5 years under expected operational conditions of the LNLS accelerators. Other tests include burn in, simultaneous computer monitored tests under variable operating conditions of power supplies during several months, to observe possible component failure or cross talking interference. Finally, during the last 6 years, a 50 MeV linac has been in regular operation at the LNLS. This facility has served as a realistic set up for long duration tests of various power supplies resulting in design and component improvements. Final installation has been accomplished this year and figure 1 shows the power supply room.

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5 REFERENCES

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Figure 1: power supply room of the LNLS.