A NEW DC BIPOLAR CURRENT SOURCE FOR ORBIT CORRECTORS

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Abstract - **This paper presents the design of a new DC bipolar current source to supply the orbit correctors of the LNLS. Besides keeping the main characteristics of the present power supplies, such as high precision and stability, this new generation presents high input power factor, eliminates the need of forced ventilation, and faster response time. A 10A/10V prototype was assembled and tested.**

Keywords – **bipolar power supply, high power factor.**

I. INTRODUCTION

The Brazilian Synchrotron Light Laboratory – LNLS, located in Campinas – SP, has built and operates the only synchrotron light source in the southern hemisphere [1]. Since 1997, LNLS provides the necessary structure for many users of several countries to do their experiments in many technologic fields.

The storage ring electron beam must stay as near as possible to a defined orbit in order to obtain the needed stability for the beam lines to do the experiments. The magnets that do this function are called orbit correctors and they are dipole type magnets. They can be classified as vertical or horizontal correctors, depending on the position in which the poles are assembled.

Nowadays, there are approximately one hundred DC current sources that supply these magnets. Because the direction of the magnetic field produced by these magnets depends on many parameters, these power supplies must be bipolar, with smooth transition through zero. Moreover, the precision, long time and temperature stability, and ripple, must be better than 100ppm.

Some perturbations in the electron beam orbit are very fast, and the present corrector power supplies don't have enough velocity to compensate them. Therefore, a new current source was developed for the orbit corrector to attend this need. At the limit, the required correction frequency is 50Hz for small corrections.

Another disadvantage of the present orbit corrector source is its low efficiency, which implies the need for forced ventilation. We can estimate the expenses with this substitution (material and labor) of U$10.00 per unit per year, which gives about U$1000.00/year for this power supply model. Moreover, this change implies the power supply stay off for about one hour, what is a unsuitable situation. These aspects suggest that the new power supply must have no forced ventilation.

At last, input power correction was implemented so the input current THD can be minimized.

II. THE LNLS' POWER SUPPLIES FOR ORBIT CORRECTORS

A. Storage Ring Corrector Power Supplies

Nowadays, the current sources for orbit correctors used in the storage ring basically are made up of a three-phase rectifier with a capacitive filter, providing a symmetric DC voltage source for a series regulator with Bipolar Junction Transistor (BJT) [2]. The main disadvantage of this topology is its lower efficiency mainly at low output power, resulting in a increased size and weight with forced fan. The advantages are the independence of the inductance load value and the elimination of the electromagnetic interference. Figure 1 shows this current source simplified diagram.

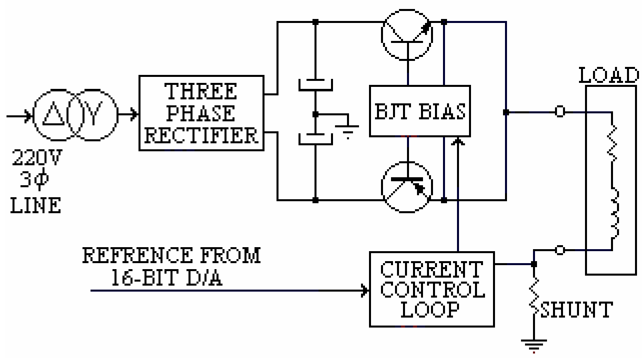

Fig. 1. Present Storage Ring Corrector Power Supply.

The NPN BJT provides positive load currents, and the PNP BJT provides negative currents. The control circuit has an error comparator and a proportional-integral (PI) amplifier.

The major disadvantage of this power supply is the BJT losses which implies a low efficiency and requires forced fan. A second disadvantage is the line frequency of the transformer, which increases its size and weight.

The maximum output current and voltage are respectively 10A/10V. The measured efficiency for this current source is 39.4% and the power factor is 0.73, for 10A output current. The ventilators are substituted every three years.

B. Booster Synchrotron Corrector Power Supplies

A second version of orbit corrector power supplies was developed when the 500MeV booster synchrotron machine was constructed [3]. Also series regulators with BJT stabilize the output current of these power supplies, allowing the required precision, with a control circuit similar the previous current source.

However, the DC voltage that feed these regulators are obtained with commercial personal computers (PC) power supplies, with their control network modified so the output voltage can be adjusted. Then the PC power supply output voltage is adjusted so the average collector-emitter voltage (VCE) of the regulator BJT is held at approximately 2V, which decreases its losses. In short time intervals this voltage changes to compensate output current fast variations, but the control circuit acts and compensates this change. Figure 2 shows the simplified diagram of these power supplies.

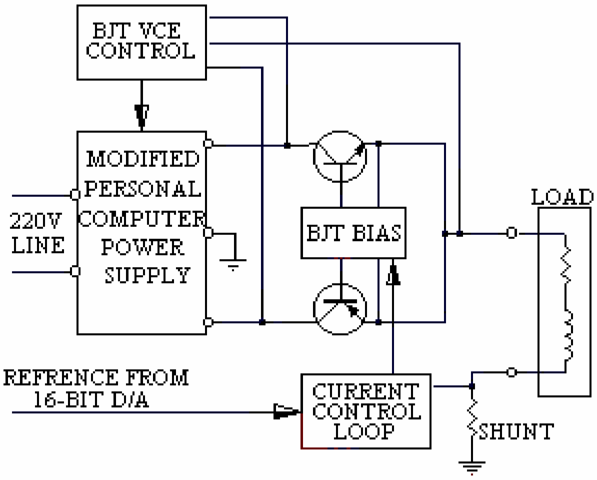

Fig. 2 – Simplified diagram for the orbit corrector power supplies of the Booster Machine.

This current source presents the advantages in relation the previous model: 1) higher efficiency, mainly in lower output power; 2) lower size and weight due to line frequency transformer absence and use of commercial PC power supplies. The main disadvantage is the use of ventilators, which are substituted every two years.

The maximum output current and voltage are respectively 10A/10V. The measured efficiency for this current source is 64.5% and the power factor is 0.535, for 10A output current.

III. THE NEW ORBIT CORRECTOR POWER SUPPLY

The new proposed topology for the orbit corrector current source is showed in figure 3. In comparison with figure 1, the PC power supply was substituted by a isolated half-bridge inverter, with a high frequency rectifier in its output. A power factor corrector (PFC) was added to the input circuit. Each one of the blocks will be briefly described next.

A. Power Factor Corrector (PFC)

The power factor implemented uses the Boost configuration in the continuous current mode, as shown in figure 4. Its function is to obtain an input current and voltage with the same waveform, providing a stabilized voltage for the inverter.

The PWM control is made by L4981A integrated circuit. A single module (SEMIKRON SK60GAL) contains the Insulated Gate Bipolar Transistor (IGBT) and diode used. The IGBT driving is made directly by the L4981A, without additional drive circuit. The switching frequency is 50kHz.

The output capacitance is divided in two capacitors, which gives a necessary symmetric voltage to the next stage.

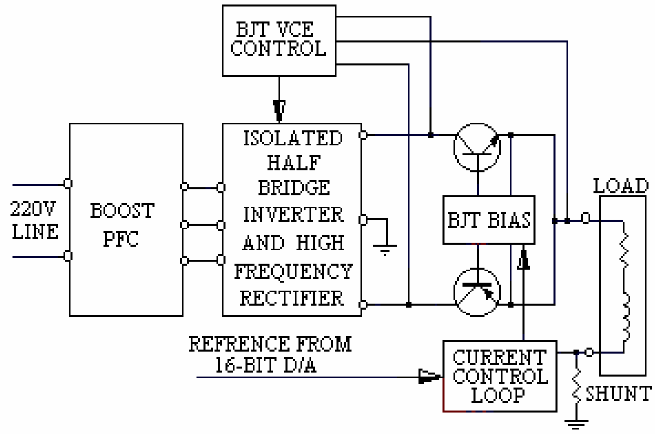

Fig. 3 – Proposed topology for the new orbit corrector current source.

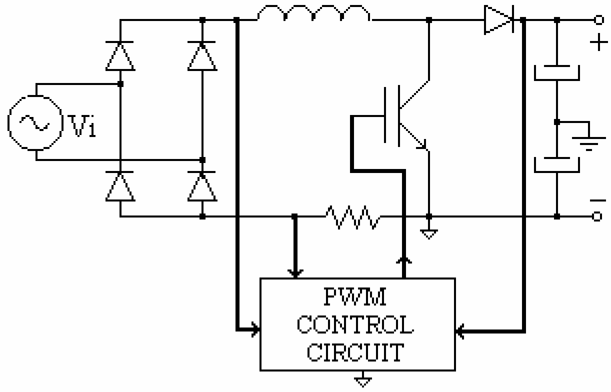

Fig. 4. PFC simplified diagram.

B. Isolated Half Bridge Inverter

The regulated PFC output voltage supplies the isolated inverter, as shown in figure 5. The main function of this stage is to provide the necessary voltage so the next stage BJT collector-emitter voltage is kept close to 2V. This voltage control is made by the pulse width modulation (PWM) of the isolated inverter. For transients of the reference voltage, the BJT will try to compensate the difference in the output current, changing its VCE. So the inverter IGBT pulse width is increased to a maximum giving the necessary load over-voltage (35V maximum) to obtain a faster response.

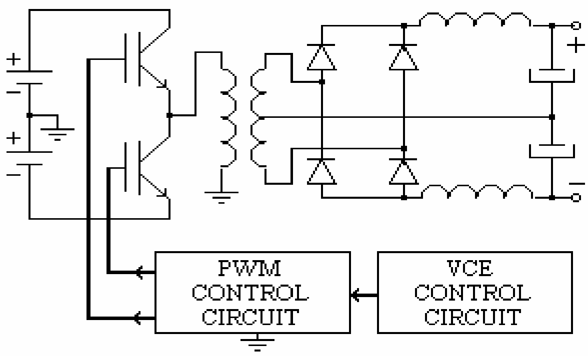

Fig. 5. Isolated Half-Bridge Inverter simplified diagram.

The VCE control circuit generates an error voltage proportional to difference between the active BJT collector-emitter voltage and the pre-defined desired value. This error is sent to PWM integrated circuit (SG3525A) by a PI amplifier. The IGBT isolated gate signals is obtained by a commercial drive circuit. The switching frequency is 43kHz. The chosen IGBTs are SEMIKRON SK45GB models.

C. BJT Series Regulator

The BJT series regulator used is similar to that others orbit corrector power supplies. This stage is still necessary to obtain the zero soft transition and the high stability required.

The main change in the Series Regulator is the BJT heat sink layout. It was placed outside the power supply, so the heat exchange efficiency was increased, which allow the elimination of the forced fan. This heat sink is also used to the output inverter fast diodes.

IV. EXPERIMENTAL RESULTS

One prototype of the proposed power supply was assembled and tested. All results shown here were obtained with an orbit corrector magnet as load (1Ω/10mH, approximately).

Figure 6 shows the PFC input waveforms (voltage, current and power), for 218V input rms voltage and 10A output current. In this situation, the measured output voltage was 9.85V. The measured input current was 0.89A which gives 194VA voltampere input. The input power was 188W, which gives 0.97 power factor. The efficiency measured was 52.4%.

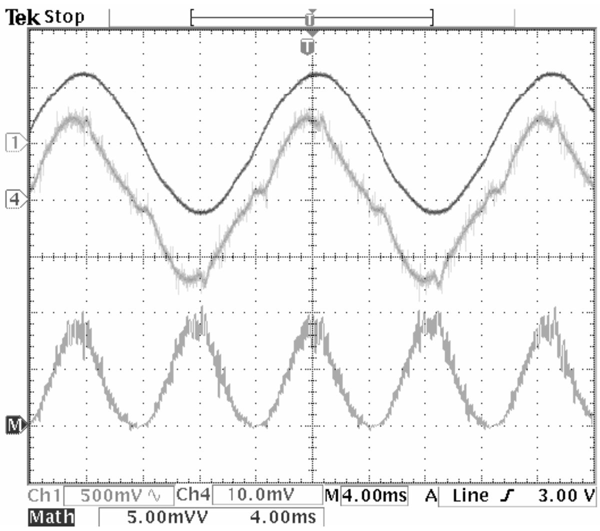

Fig. 6. Power factor input waveforms: a) Ch1: Voltage (upper trace: 250V/div); b) Ch4: Current (middle trace: 1A/div); c) Math: Power (lower trace: 250W/div).

Figure 7 shows the output current and voltage ripple. The rms current ripple measured was 330µA, better than specified values.

Figure 8 shows the PFC output voltage and high frequency transformer primary voltage. Snubber circuits minimized the spikes.

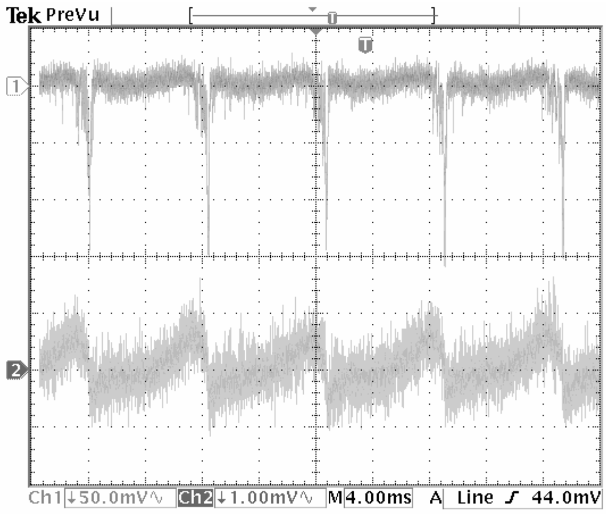

Fig. 7. Output Voltage (upper trace: 50mV/div) and Current (lower trace: 1mA/div) ripple.

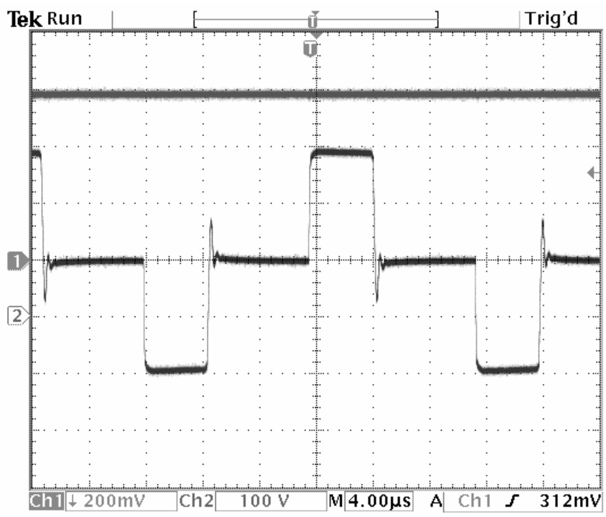

Fig. 8. PFC Output Voltage (Ch2, upper trace: 100V/div) and high frequency primary transformer voltage (Ch1, lower trace: 100V/div).

Figure 9 shows the power supply dynamic response, for a sinusoidal reference of 10A peak-to-peak and 30Hz frequency. This figure also shows the BJT collector voltage. For 50Hz frequency the peak-to-peak voltage reference that the output follows close must be reduced to 7A.

Figure 10 shows the output current step response. The used reference voltage was a +/-5V 20Hz square wave. The time to output current to reach the steady-state value is 10ms.

V. CONCLUSION

The tests realized with the assembled prototype have shown satisfactory results.

The power factor measured is close to the expected value, and will contribute to improve the LNLS electric line quality.

Although the measured efficiency was not high, the mechanical lay-out changes were sufficient to allow the power supply to operate without forced ventilation.

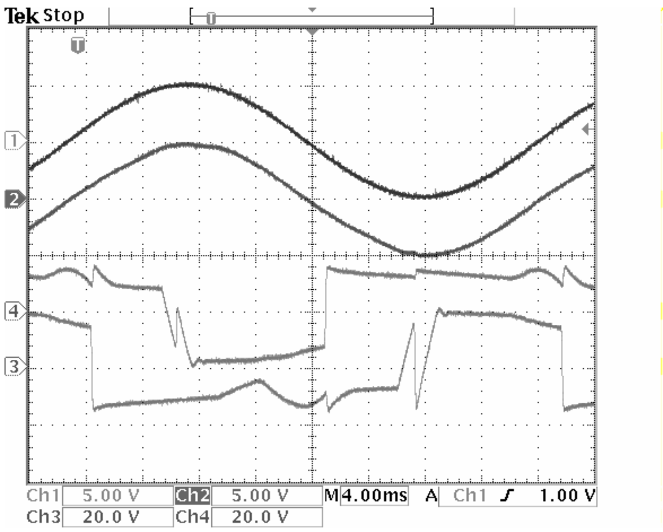

Fig. 9. Output Dynamic Response: Ch1: Reference voltage (upper trace: 5V/div); Ch2: Output Current (middle one trace: 5A/div); Ch3: Positive BJT collector voltage (middle two: 20V/div); Ch4: Negative BJT collector voltage (lower trace: 20V/div).

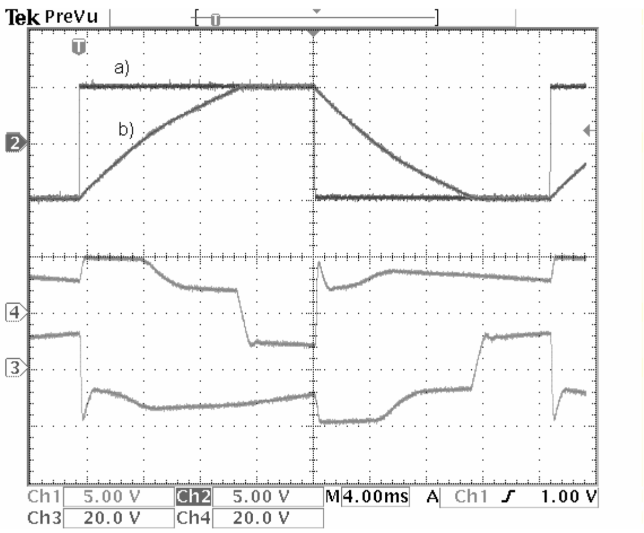

Fig. 10. Output Current Step Response: Ch1 (a): Reference voltage (upper trace: 5V/div); Ch2 (b): Output Current (upper trace: 5A/div); Ch3: Positive BJT collector voltage (middle trace: 20V/div); Ch4: Negative BJT collector voltage (lower trace: 20V/div).

The rms output current ripple found (33ppm of nominal current) is about 1/3 better than the specified.

The output current is capable of following a 7A peak-to-peak 50Hz sinusoidal reference. This value must be enough to make fast orbit corrections in the storage ring, so these corrections are small.

Now the power supply will be tested in the storage ring. If the results are satisfactory, gradually this new model will substitute the present orbit corrector current source.

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