SLAC-PUB-11182
May 2005

PEP-II LARGE POWER SUPPLIES REBUILD PROGRAM AT SLAC*

P. Bellomo, J.J. Lipari, A.C. de Lira#, F.S. Rafael, SLAC, Menlo Park, CA 94025 USA.

Abstract

Seven large power supplies (LGPS) with output ratings from 72kW to 270kW power PEP-II quad magnets in the electron-positron collider region. These supplies have posed serious maintenance and reliability problems since they were installed in 1997, resulting in loss of accelerator availability. A redesign/rebuild program was undertaken by the SLAC Power Conversion Department. During the 2004 summer shutdown all the control circuits in these supplies were redesigned and replaced. A new PWM control board, programmable logic controller, and touch panel have been installed to improve LGPS reliability, and to make troubleshooting easier. In this paper we present the details of this rebuilding program and results.

INTRODUCTION

Seven large PEP-II [1], power supplies (LGPS) power quad magnets in the electron-positron collider region. Installed in 1997 [2], the LGPS ratings range from 72kW to 270kW. Table 1 summarizes the LGPS main characteristics.

Table 1: LGPS ratings

LGPS	V	I	P (kW)	Qty
BV1/2	80	900	72	1
QF2L/R	80	1250	100	2
QF5L/R	253	750	190	2
QD4L/R	200	1350	270	2

The LGPS are unipolar off-line switch mode supplies, with a 6 pulse bridge rectifying 480VAC, 3-phase input power to yield 650VDC unregulated. The unregulated 650VDC feeds one (or two) IGBT H-bridges, which convert the DC into PWM 16 kHz square wave AC. This high frequency AC drives the primary side of a step-down transformer followed by rectifiers and low pass filters. Figure 1 is a block diagram of the internal arrangement of such a LGPS.

Over the years, these LGPS have presented many problems primarily in their control circuits. They are difficult to troubleshoot and affect the overall accelerator availability. For this reason the Power Conversion Department (PCD) [3] at SLAC decided to redesign and rebuild the controls and interlocks for these power supplies.

During the 2004 accelerator summer shutdown all the control circuits in these supplies were redesigned and replaced. A new PWM control board, programmable logic controller (PLC), and touch panel were all installed to improve LGPS reliability, and to make troubleshooting easier.

*Work supported by the U.S. Department of Energy under contract DE-AC02-76SF00515
#delira@slac.stanford.edu

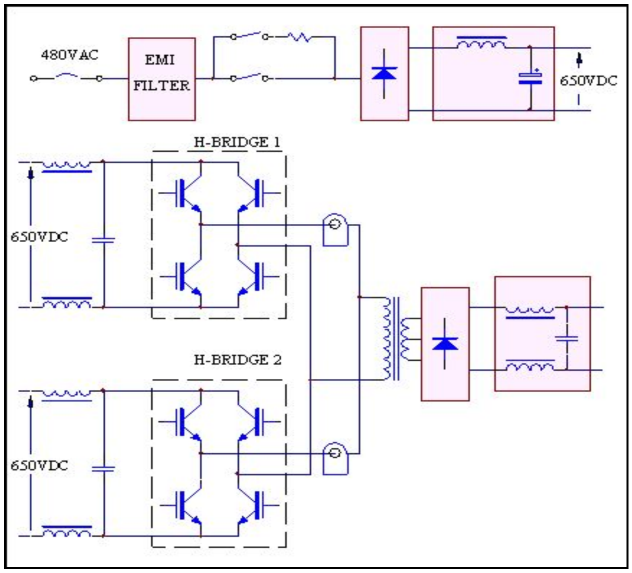

Figure 1: LGPS power block diagram.

History of Problems

Since installation, the LGPS reliability had steadily worsened, and they were increasingly difficult to troubleshoot and maintain. PCD was forced to make several modifications of the original configuration and control just to keep them running. LGPS trips suspend beam collisions experiments, and seriously affect accelerator availability.

PREPARATION

In the months preceding the 2004 summer accelerator shutdown a similar but off-line LGPS located elsewhere was dedicated to tests and experiments using the new control circuits and PLC. This unit was tested and the new control circuits developed using a resistive load. Prototype circuits were tested and modified, running the LGPS at low power until perfection of the final design. Once satisfied with the final prototype PWM board, IGBT driver boards and PLC controls, the PCD designed, fabricated and ordered the PC boards.

REBUILD PROGRAM

The LGPS rebuild program began in July 2004 and ended in October 2004. It involved essentially the following activities:

- Removing existing control circuits and wiring.
- LGPS general cleanup.
- Installation of new IGBT gate driver boards
- Installation of additional cooling fans
- Installation of new control board, a PLC and a touch panel
- Rewiring controls

THE NEW CONTROLS

The primary goal of redesigning the power supply controls was to make them simpler and use more up-to-date components. As mentioned before, over the years of operation, the internal power supply controls suffered a lot of undocumented changes. These changes were not necessarily common to all the units. This resulted in documentation confusion and further complicated power supply repair and maintenance.

Keeping the same control philosophy as the original controls design and taking into account the experience accumulated over the years of operation and maintenance, PCD designed a new control board that centralizes the main voltage and current regulation functions of the LGPS. The new board contains an output voltage feedback control loop, some of the PWM and over-current interlocks, and an interface with an external Bitbus controller [2]. The new control board also provides the PWM signals to the IGBT gate driver boards.

On the new control board, a switch allows us to break the output voltage control loop and provide a reference directly to the PWM circuits. This makes it simpler to troubleshoot the equipment and provides a way to monitor the open loop transfer function and establish the voltage loop control gain.

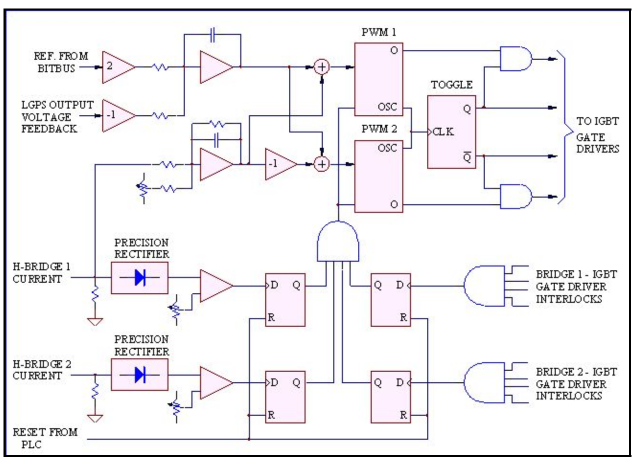

Figure 2: LGPS - new control board block diagram

A local adjustable potentiometer located on the front panel of the LGPS provides a reference to an over-current protection loop that overrides the reference coming from the Bitbus controller.

The addition of a PLC takes care of the internal power supply interlocks, monitors the LGPS operating parameters and turns the LGPS on and off. A touch panel connected to the PLC provides a user-friendly local interface for both an operator and maintenance technician to monitor the LGPS internal states of operation.

In case an interlock trips an LGPS, this information is stored in the PLC and is accessible to maintenance technicians on the touch panel.

Primary Current Control

One major problem with H-bridge primary control is that the primary side of the power transformer can easily saturate when there is even a slight DC current in the primary winding due to imbalance in the PWM control pulses. Keeping the original design of the LGPS, a current transformer monitors the power transformer primary current (the H-bridge output current) and sends this information to the control board. A fast compensator circuit averages 5 full wave cycles and provides an offset to the PWM circuits that control the pulse width applied to the H-bridge(s) IGBTs to keep the DC current in the primary winding close to zero.

In LGPS with two H-bridges connected in parallel, only one primary current transformer is used to feedback information to the control board. Independent current monitoring from both bridges however does go to comparators to interlock the LGPS in case the primary current in one of the H-bridges becomes excessive.

Interlocks

The configuration of the interlocks remained almost unchanged from the original design. However, PCD added new interlocks in conjunction with the new IGBT gate drivers.

The PLC monitors all interlock signals, and turns the LGPS off in an event of a fault.

Some of the interlocks present in the new control board: primary over-current at either of the H-bridges, output over-current, and IGBT gate driver interlocks. With the exception of a load over-current, all interlocks disable the PWM circuits in the control board and this information is also relayed to the PLC to turn off the main contactor and log the interlock information.

Output Voltage Control

The design of the output voltage control loop compensates for fast AC line mains transients or variations, and has a typical stability requirement of 0.1%.

The closed loop mode has a 3dB frequency bandwidth of 1.6 kHz from an integrator compensator adjusted to this cutoff frequency. In order to achieve fast correction, the output voltage feedback signal is taken at the output of the high frequency rectifiers (upstream the output LC filter). This avoids having to compensate also for the frequency response of the LPGS' output filter.

Figure 3 shows the typical closed loop frequency response of the output voltage control loop obtained from one of the LGPS.

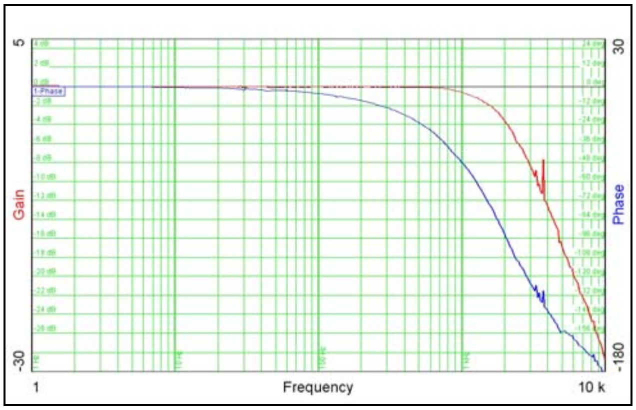

Figure 3: LGPS output voltage closed loop control transfer function

PLC and Touch Panel

The PLC uses 3 Input Modules (16-channel 5V TTL source, 16-channel 24V sink, 4-channel analog), and 2 output modules (8-channel isolated relay, 16-channel 5V TTL sink).

The color touch panel displays the power supply ON/OFF status, the output DC voltage and current, and the state of all the internal interlocks. The touch panel is not used for any power supply control functions but only for local (LGPS front panel) display. On the touch panel it is also possible to monitor the interlocks that might have tripped the LGPS.

RESULTS

The existing output current control loop was not modified during the upgrade program. Reference [2] describes the typical current control system employed in the LGPS.

Figure 4 shows a load current stability measurement over a period of 7+ hours in one of the LGPS, where the total room temperature deviation was 5º C.

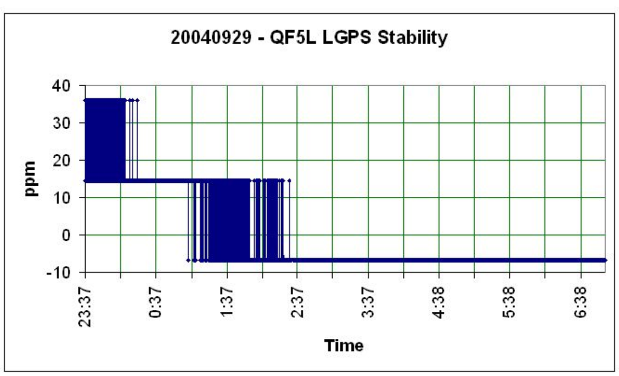

Figure 4: LGPS output current stability at 467A. 1 measurement/sec.

A large frequency bandwidth in the design of the LGPS output voltage control loop is a guarantee to the rejection of line disturbances. Figure 5 shows the output current spectrum in one of the LGPS.

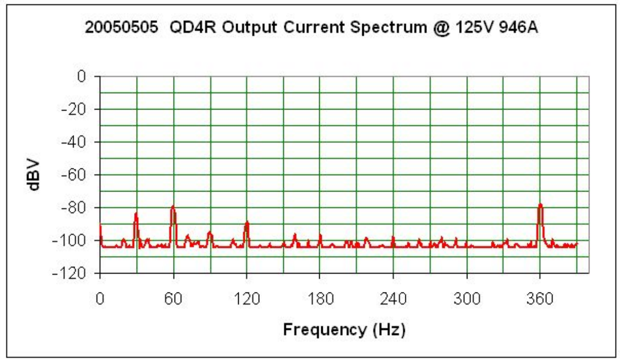

Figure 5: LGPS typical current spectrum. Scale: 0 dBV = 200A.

CONCLUSIONS

The Power Conversion Department at SLAC implemented and successfully completed an aggressive program to retrofit the LGPS around the interaction region in PEP-II during the 2004 summer shutdown. The LGPS now have a consistent, uniform and very well documented control system. Similar modifications to two other supplies located elsewhere are under consideration.

ACKNOLEDGEMENTS

The authors wish to express their acknowledgements to Mr. M. Larrus for the PLC programming and to the technical personnel from the PCD and the ED&M group from the Stanford Synchrotron Radiation Laboratory (SSRL) for their invaluable support during this project.

REFERENCES

[1] http://www.slac.stanford.edu/accel/pepii/home.html.

[2] L.T. Jackson et al, "PEP-II Magnet Power Conversion Systems", PAC'95, Dallas, May 1995.

[3] http://134.79.112.52:8080/pcd/