The Australian Synchrotron Storage Ring Dipole Power Supply

Neil Meadowcroft (Australian Synchrotron Project), Richard Farnsworth (Australian Synchrotron Project), Paul Bellomo (SLAC), Ron Rumrill (Alpha Scientific Electronics), Stan Cohen (Los Alamos)

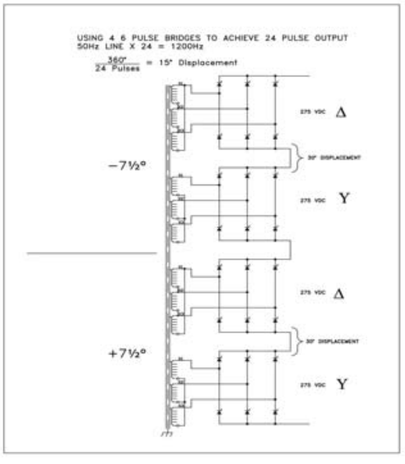
Introduction

The Australian Synchrotron storage ring consists of 28 dipoles, 56 focusing quadrupoles, 28 defocusing quadrupoles, 98 sextupoles, 42 horizontal correctors, 56 vertical correctors and 28 skew quad correctors. The 28 dipole magnets are series connected and powered by a single 24 pulse power supply that was designed, constructed and tested by Alpha Scientific Electronics in collaboration with the Electrical and Control Engineering Teams at the Australian Synchrotron, Paul Bellomo at SLAC and Stan Cohen at Los Alamos.

Design

The dipole power supply specification required to a maximum of 1100V to be delivered to the string of 28 dipole magnets from a 415V 3 phase 50Hz supply while a separate 240V single phase feed is used for the power supply control system. A motor operated air circuit breaker, operated remotely from the local control interface energises the power supply, while three additional AC contactors provide inrush current limiting and SIL3 safety rated interfaces to the facility personnel safety system. The 1100V output is derived using two water cooled rectifier transformers, with the primaries extended delta connected to yield a +7.5°or -7.5° phase shift and two secondary windings. These secondaries are connected to independent 6 pulse rectifier bridges configured in pairs to provide a centre grounded 24 pulse rectifier and filter configuration delivering a 550V – 0V – 550V dc output.

Parameters	Value
Input voltage (three phase)	415V ±10%
Rectification	24 pulse
Input current balance tolerance (phase to phase)	1%
Output voltage (required)	550-0-550V
Output current (required)	775A
Isolation to ground (as a multiple of the maximum output voltage)	> 2V
Output current stability (Short Term – less than 8 hours)	50ppm
Output current stability (Long Term – 8 hours to 6 months)	50ppm
Output current ripple (peak to peak) up to 50kHz	< 50ppm
Reproducibility	50ppm
Resolution	16bit
Efficiency	> 95%
Power factor; for 80 to 100% of full output with the three phase input voltage variation specified above	>0.95
Output voltage operating range	0 to 100%
Output current operating range	0 to 100%
Output current regulation range, as a percentage of full output	20 to 100%
Inrush current limitation (as a multiple of the maximum input current, I_{max})	< 5 I_{max} A



Rectifier Bridge

Each rectifier bridge consists of six water cooled SCRs connected in full wave six-pulse bridge configuration. The dipole magnet power supply uses four of these bridges connected in series, with each bridge contributing ¼ of the load voltage at the rated load current. Since the rectifier transformer secondary voltages are displaced by 30° due to their delta/wye configuration, each transformer produces a twelve-pulse DC output. To further increase the number of DC pulses, the primary windings are skewed ±7.5° by virtue of their extended delta winding configuration. This combination of four displaced bridge outputs produces a twenty-four pulse output which is easily filtered and controlled. The final DC ripple component is twenty-four times the mains frequency, or 1200Hz.

Gate drive board

The firing sequence of the SCRs on the rectifier bridges is controlled by two 12 pulse gate driver boards. These boards allow the SCRs to be fired at any point of the incoming sine wave with the phase reference for these two gate driver boards derived from two separate reference transformers on the rectifier transformer primaries.

LC Filter

The output of the rectifier bridges is filtered using two water-cooled inductors, and two capacitor networks connected in parallel. The filter will reduce the ripple voltage to less than 12 volts, (typically). In addition to the filter stage consisting of eight capacitors, there is a damping stage consisting of twenty-one capacitors. Each stage is monitored, and the ripple current is displayed. The damping stage of the LC filter circuit is designed to minimize resonant peaks in the frequency response of the LC circuit. However, if there is any trouble in the damping stage (21 capacitors) the entire stage may be disabled by disconnecting the wire at the 1.6Ω 1000-watt resistor. The waveform at the filter input can be measured from a diagnostic BNC and should show all 24 pulses or predominately 1200Hz ripple frequency. However, since the LC filter is more effective in attenuating high frequencies, the filter output waveform will show the effects of line imbalance, and other imbalances, and regulator circuit effects, resulting in predominate frequencies lower than 1200Hz.

Ground Fault Monitor

The power supply common dc output connection is connected to ground through a 100Ω, 225W resistor. The voltage across this resistor (proportional to ground current) is monitored and displayed on the smart relay display screen. By noting the polarity of the ground current it can be determined which side of the load is leaking current to ground, halving the number of dipole magnets that fault finding needs to be carried out on.

Stored Energy Discharge

When operational the power supply filter stores 1200 joules. To avoid the need for additional external safety measures to discharge this stored energy the power supply was fitted with a normally closed contactor which discharges the capacitors through a 100 ohm when the power supply is turned off.

EMC shielding

The dipole power supply is physically located next to other storage ring systems, including ion pump controllers, beam position monitors and rack mounted input output controllers. To ensure that the dipole power supply did not affect the performance of this other equipment ac multi-stage EMC filters were fitted to the three phase and single phase feeds and a dc multi-stage filter was fitted to the power supply output, with the positive, common and negative all being filtered. In addition, to guard against radiate interference the power supply cubicle panels and were fitted with EMI gaskets and the fans were fitted with proprietary EMI shields.

Controls Interfaces

The Australian Synchrotron has selected EPICS running under Linux as its major control system, and a reliable method of communicating to the dipole power supply controller was required. As the controller was custom developed for this job, a protocol was devised. This protocol was based on earlier similar devices, but contained a number of enhancements for this particular power supply. The built in controller uses a small Programmable logic controller, some custom electronics boards and a Windows CE based touch screen for its local control. Because a commercial operating system was selected for the controller, it was possible to use common hand held devices (a Pocket PC or PDA) to run the same communications software as the controller and simulate its operation. In this way, the EPICS interface was able to be build tested and deployed a significant time ahead of the delivery of the actual power supply. It meant that all software and communications assumptions were tested ahead of time and that a number of refinements and clarifications could be made long before the actual physical delivery of the hardware. In addition, a test support item was produced, consisting of a set of EPICS software (drivers, database and user interface) to assist with the acceptance testing of the actual unit whilst in the factory.

All of this meant that the instrumentation and controls team at the Australian Synchrotron were able to communicate with and control the dipole power supply safely and reliably on the day of installation. It has run nearly continuously ever since.

ALPHA SCIENTIFIC ELECTRONICS

State Government Victoria AUSTRALIA