DIAMOND STORAGE RING POWER CONVERTERS

R.J. Rushton, C. A. Abraham, J. A. Dobbing (Diamond Light Source, Oxfordshire, UK), F. Cagnolati, G. Facchini, M. Pretelli, V. Rossi, L. Sita (OCEM SpA), C. Rossi (University of Bologna).

Abstract

The DC Magnet Power Converter requirements for the Storage Ring of the Diamond Project are described together with performance, commissioning and initial operating experience.

During the design phase, emphasis was placed on EMC, Reliability and Mean Time To Repair.

All converters are Switched Mode with full digital control and a common control interface.

DIPOLE POWER CONVERTER

Requirements

A single converter, with the following specification, powers a series connected string of 48 dipole magnets:

Table 1: Converter Specification

	Specification
Topology	1 quadrant
Output	50 - 1500A / 531V nominal
Short Term Stability	±10ppm / ±15mA
Long Term Stability	±50ppm / ±75mA
Resolution	3.81ppm (18bit)
Accuracy	±50ppm

The contract for design and manufacture of this supply was placed with OCEM, to a DLS Specification.

Power Circuit

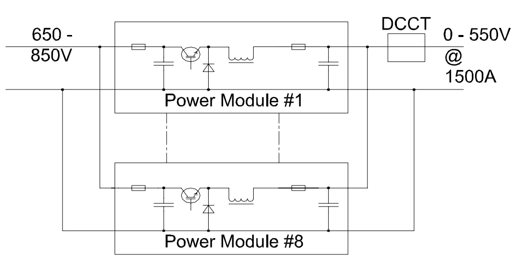

Figure 1: Dipole Converter Topology.

The power converter comprises of 8 paralleled modules. Each module is a non-isolated step down PWM switching regulator operating at a fixed frequency of 2 KHz. IGBT devices are used as the switching element. The 8 PWM drives are phase shifted by 360/8° to achieve a 16 KHz output ripple frequency.

Input power is 11KV 3 phase, which is transformed down and 12 pulse rectified to form a 750V nominal DC bus, which feeds the 8 power modules. Capacitance on this DC bus provides half cycle line dropout immunity.

Module current sharing circuits ensure that load current is shared to within ±5% between modules.

Mechanical Design

The 11KV transformer is located within the same cabinet as the converter, to minimise EMI from the interconnection. Total cabinet volume is 21.89m3. The cabinet is forced air cooled by internal fans and an external cooling unit with an air / water heat exchanger. The power modules and control modules are all of a ‘plug in’ construction, while auxiliary power supplies are DIN rail mounted

Q AND S POWER CONVERTERS

Requirements

One converter per magnet, with the following specification, is used for both Quadrupole (Q) and Sextupoles (S):

Table 2: Converter Specification

	Specification (Q / S)
Topology	1 quadrant
Output	200A / 100A @ 28 / 17.1V
Short Term Stability	±10ppm / ±2 / ±1mA
Long Term Stability	±50ppm / ±10mA / ±5mA
Resolution	3.81ppm (18bit)
Accuracy	±50ppm

240 Q and 168 S power converters are required in total

The contract for design and manufacture of this supply was placed with OCEM, to a DLS Specification.

Power Circuit

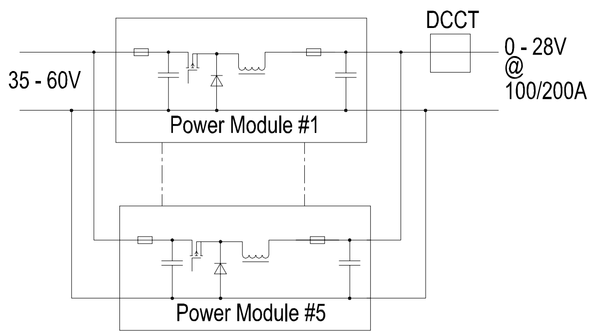

Figure 2: Converter Topology.

A power converter comprises of 5 paralleled modules. Each module is a non-isolated step down PWM switching regulator operating at a fixed frequency of 20 KHz. The 5 PWM drives are phase shifted by 360/5° to achieve a 100 KHz output ripple frequency.

Input power is 400V 3 phase, which is transformed down and 12 pulse rectified to form a common 42V DC bus, which feeds 17 power converters. Capacitance on this DC bus provides half cycle line dropout immunity.

Module current sharing circuits ensure that load current is shared to within ±5% between modules.

Mechanical Design

10 Q and 7 S Power Converters are housed, together with the common DC link rectifier, in a set of air cooled cabinets with a total volume of 5.44m^3. A temperature controlled, 16°C, inlet air supply is ducted under a false floor into the bottom and exhausted through the top of each of the cabinets. Additional fans within the cabinets are fitted to increase airflow where necessary.

STEERER POWER CONVERTERS

Requirements

Steering coils are wound onto each sextupole magnet. The steerer power converter has the following specification:

Table 3: Converter Specification

	Specification
Topology	4 quadrant
Output	±5A / ±20V
Short Term Stability	±15ppm / ±75uA
Resolution	3.81ppm (18bit)
Accuracy	±100ppm

432 Steering power converters are required in total, comprising of 7 vertical steerers, 7 Horizontal steerers and 4 skew quadrupoles per cell

The design of these converters was produced by DLS, with sub-contract manufacture.

Power Circuit

A 4 quadrant PWM full bridge topology is used. Input power is 24V nominal, from a common DC supply which powers all 18 steering power converters per cell and provides half cycle line dropout immunity.

Load current is measured by a 4 terminal precision ultra low temperature coefficient resistor.

Mechanical Design

A modular design is used, based upon a custom 4U 19” sub rack. A fully populated sub rack contains 3 power converter channels, with each channel consisting of 4 x 3U modules, i.e. Digital Controller, ADC module, Current Transducer and Inverter.

Sub racks are populated into a 600mm x 800mm x 2m cabinet which contains AC power distribution, control interface crate and separate 24V DC power supplies for both control circuits and inverters.

Airflow within the cabinet is optimised such that all modules have inlet air at a controlled stable temperature, while ensuring that exhausted air is not recycled. Multiple cooling fans are fitted into a sub rack.

CONTROL

A digital control scheme, originally developed for SLS [1], is used for control of all three converter types. A standard PI control scheme is used.

The Q and S converters use a controller with modified DSP firmware for control of the common DC link rectifier and a single Digital Controller per power converter. Modified FPGA firmware generates a phase shifted PWM output for each of the 5 power modules. A status signal from each module is monitored by the Digital Controller for fault protection and alarm reporting.

Control of the Dipole converter is similar to the Q and S converters except that 8 phase shifted PWM outputs are required. Only 1 digital controller is used for both input rectifier and load current control.

REDUNDANCY AND MAINTAINABILITY

Dipole, Q and S power converters use an N+1 redundant power module configuration.

If a power module fails, PWM drive to it is inhibited. A catastrophic failure, e.g. an IGBT, MOSFET or freewheel diode short circuit, will blow either a module input or output fuse, isolating the module. Operation can continue with the remaining modules as the FPGA automatically re-synchronises for minimum ripple current.

A failed module can be quickly replaced by a new one, at a convenient time, and repaired in the workshop rather than on site. Corrector, Quadrupole and Sextupole modules may be hot swapped but this is not practical for the Dipole power converter.

Auxiliary and Corrector input power supplies are configured as N+1 redundant and AC power is from both UPS and non-UPS sources.

Failure of a cooling fan is detected by solid state airflow sensors or by speed monitoring and fan trays are of a plug in type, to minimise repair time. Operation can continue with a failed fan.

RELIABILITY

The Quadrupole and Sextupole power converters use a large number (2040) of identical power modules. MTBF calculations were made, using MIL HDBK 217F (GB), during the design phase and Highly Accelerated Stress Screening (HASS) testing was performed on a prototype batch of power modules to test the ruggedness of the design prior to a production run.

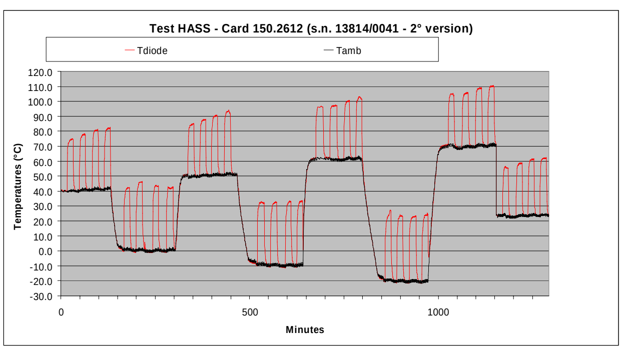

Figure 3: HASS component temperature stress profile

Adequate component de-rating and predicted lifetime of certain components, e.g. fans and electrolytic capacitors, was assessed during the design phase.

Corrector power modules were extensively tested prior to production to verify reliability, component thermal and electrical stress and manufacturability.

EMC

In order to minimise interference from the switched mode power converters, the procurement specifications included conformance to European EMC directives.
EMC measures within the designs include:

- Input filtering of cabinet AC supplies
- PFC correction and filtering to EN55022B of the 24V cabinet power
- Input rectification scheme to minimise line harmonics
- Corrector Power converter output filtering
- The use of 'emc' subracks and enclosure of Corrector inverter modules within a screened housing

Due to the large installed quantity of corrector power converters, radiated and conducted EMC testing was done on a typical configuration of corrector cabinet to verify performance prior to installation in the synchrotron.

COMMISSIONING AND OPERATION

Testing, initial commissioning and calibration of the Quadrupole, Sextupole and Corrector power converters was done prior to installation in the synchrotron building.

Once installed, final commissioning was minimal. Commissioning of all power converters was achieved within 4 months, by a team of 3 people.

The dipole converter could not be factory tested at full load or with 11KV input power. Instead, 400V input power was used and each module was individually tested at full power with final commissioning on site.

All power converters use the same control interface and similar EPICS panels, making it easy to familiarise staff with power converter operating procedures.

Power converter stability appears to be good and no modifications have been made to any of the power converters.

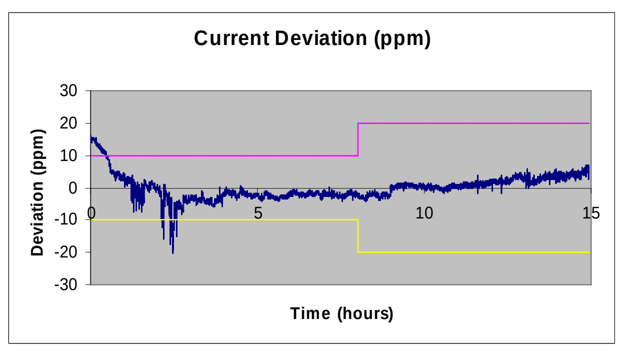

Figure 4: Q Converter Stability

ACKNOWLEDGEMENTS

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REFERENCES

[1] F. Jenni, L. Tanner, "Digital Control for Highest Precision Accelerator Power Supplies", PAC'01, Chicago, June 2001, p3681.