A new concept of High Current Power Supply for the Main Cyclotron Magnet at TRIUMF

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Introduction and summary

- **A new concept of power supply was studied and designed by OCEM Power Electronics to supply a high current to the main magnet of the TRIUMF cyclotron**
- **The power supply will be operated with a current up to 20000 A in DC mode**
- **It has been designed using a modular approach, with two 12-pulse input rectifiers driving two DC links, which feeds sixteen DC/DC chopper modules in connected in parallel**
- **The power supply integrates a sophisticated control system and a precise current measurement chain developed at CERN for the Large Hadron Collider (LHC)**
- **The new power supply must fit within the same floor space as the existing supply, and deliver the same high-level of performance, while assuring high reliability and maintainability for at least the next twenty years**

Main PS Components

The main PS components are:

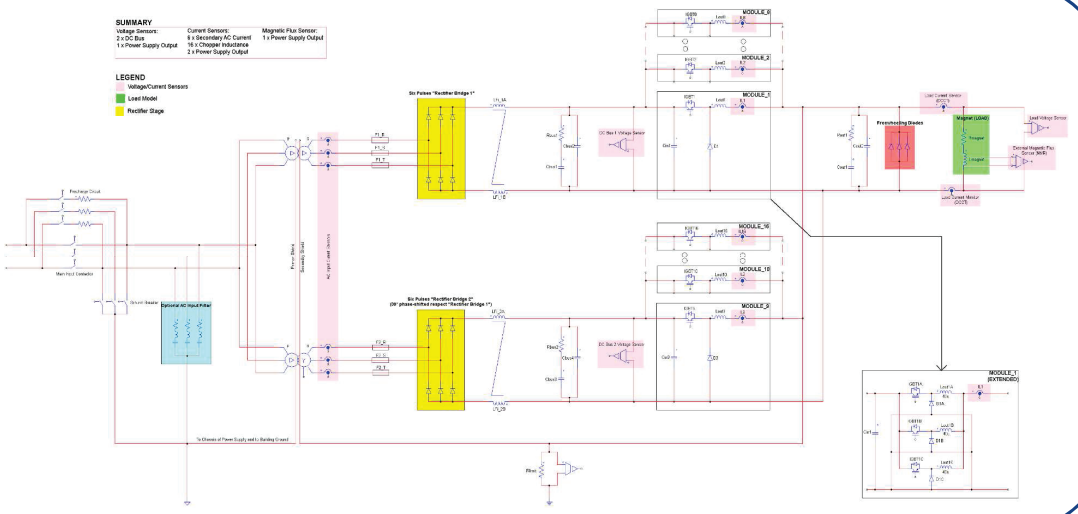
- Input Circuit Breakers and Pre-charge Circuit.
- Two Rectifier Transformers.
- Two Main Rectifier stages (with fuses).
- Two passive RLC Filters downstream from each Main Rectifier stage.
- Output stage composed of 16 IGBT chopper modules operating in parallel.
- Freewheeling diodes across the output bars.

The input stage realizes a 12-pulse topology through two three-phase transformers, phase-shifted by 30 degrees.

All the switching modules have an output filter inductor, and converge on a damped capacitive filter, placed at the output of the power supply.

A free-wheeling diode is located across the output bus bars to safely discharge the energy stored in the magnet when the power supply turns off.

Power Supply Schematic



Technical Specifications

PARAMETER	VALUE
Output Current/Voltage	20000 A / 80 V
Output Power	1600 kW
Mode of operation	DC
Regulation Mode	Constant Current
Topology	IGBT based buck converter
Equivalent Output Switching Frequency	16 x 10 kHz = 160 kHz (10 kHz for each module and 8 PWM carriers phase-shifted)
Absolute Accuracy	±1 part in 10^4
Current Ripple	±2 ppm of 20 kA for the range 17 kA to 20 kA
Short Term Stability (5 min) @ max I_{OUT}	≤ 2 ppm of 20 kA
Long Term Stability (8 hour) @ max I_{OUT}	≤ 5 ppm of 20 kA
Power Factor	≥ 0.96
THDin	Typical of a 12-pulse rectifier stage
AC Input	3ϕ, 3-wire, 800 VAC
Cooling	Air and Water cooling
Footprint	20.7 x 8.4 feet

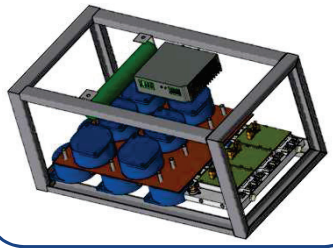
Chopper Modules

The output stage is a chopper converter that consists of 16 modules in parallel.

Each module has three IGBTs in parallel with the same PWM and every IGBT has its own inductor.

The switching frequency is 10 kHz and the power of each module is up to 100 kW.

The 16 modules are controlled with a phase-shift to increase the effective switching frequency to 160 kHz and thus reduce the ripple in the output current.



Control Electronics

The power supply will use the CERN Type-10 RegFGC3 crate. This control system is an evolution of the controls originally created for the power supplies used in the Large Hadron Collider (LHC).

It is based on a CERN-designed embedded control computer called a Function Generator/Controller (FGC).

The FGC3 has a USB interface and an Ethernet interface. The new power supply will be controlled initially through the USB interface, which is fast enough for short commands and responses.

It is also possible to monitor the performance of the regulation through the USB interface as it has two channels:

- one for commands and responses
- one used to stream six signals at 1 ksps.

The six signals transmitted can be selected from a long list of signals in the FGC3.

The TRIUMF application requires short term stability for the current in the order of two part per million (ppm) of nominal (20 kA), after the first five minutes following a current change. Repeatability must be of the same order and current ripple must be within ±2 ppm of 20 kA for the range from 17 kA to 20 kA.

The performance of the current regulation, in particular stability and repeatability, greatly depends on the current measurement system. The current measurement chain for the new power supply is composed of a DCCT head, DCCT electronics and an Analog-to-Digital Converter (ADC). Two independent measurement chains are used for redundancy purposes.

Layout

The power supply is composed of five cubicles plus an air-conditioned control cabinet.

In the first cubicle there is the input circuit breaker and pre-charge circuit; The second and third cubicles house the rectifier stages.
In the fourth cabinet there are the sixteen switching modules. In the fifth cubicle are located the two high-precision Direct-Current Current Transducer (DCCT) heads. Four symmetric vertical return bus-bars surround the DCCT heads, which are themselves around a single central vertical conductor.
This symmetry is important as it avoids local saturation of the DCCT cores and maximises their performance.