

HIGH CURRENT SWITCH-MODE POWER CONVERTER PROTOTYPE FOR LHC PROJECT 6kA, 8V

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Abstract

The company JEMA had during year 2002, designed, manufactured and tested a power converter prototype according to CERN specifications, particularly demanding in terms of dc stability and dynamic response.

Specific conditions of the system, concerning to accessibility, low volume, easy maintenance, high efficiency and ripple requirement, makes necessary an innovative design.

The present paper shows an effective and reliable power converter solution for supplying the dipole and quadrupole magnets in the LHC machine.

INTRODUCTION

The Large Hadron Collider (LHC) is the next accelerator being constructed on the CERN site. The LHC machine will mainly accelerate and collide 7 TeV proton beams but also heavier ions up to lead. It will be installed in the existing 27 km circumference tunnel, about 100m underground, previously housing the Large Electron Positron Collider (LEP). The LHC design is based on superconducting twin-aperture magnets which operate in a super-fluid helium bath at 1.9 K.

Very precise variable DC currents are required for bending and focusing magnets, from a few amperes to tens of kiloamperes. The power converters will be placed close to the magnets, so they should be type of high current and relatively low voltage. Because of the underground installation, power converters must be of low volume, high efficiency and very easy replacement capability, so modular construction is mandatory. The power converter is divided into different sub-converters working in parallel.

POWER CONVERTER TOPOLOGY

The power converter is formed by four sub-converters 8V, 2kA connected in parallel in order to provide the full required power. i.e 8V, 6kA. So, as three sub-converter could provide full power, there will always be one spare sub-converter. Isolation between mains input and magnet load is done at high frequency (40 kHz), which means a volume reduction and better mains perturbations rejection. IGBT inverter soft switch-mode power conversion in ZVS operation reduces dramatically commutation losses, which increases total efficiency of the power converter.

The sub-converter which is regulated by a wide bandwidth current loop in ACC mode (Average Current Mode Control), follows the current reference calculated by the overall voltage loop, providing a good sharing of the output currents and high output stability.

The design based on water cooled power converter, results in a very reduce volume and modular structure which provides the system with a very flexible reparability and exchangeability.

The modular structure divides the power converter into functional modules, so the 8V, 2kA sub-converter is based on an input module, two output module in parallel and an electronic module. Overall control for the power converter is located at the common control module.

POWER CONVERTER MAIN FEATURES

- Grid input voltage	400V @50Hz
- Nominal output voltage	8Vdc
- Nominal output current	6kA
- Sub-converter main values (x4)	8V, 2kA
- Efficiency total converter	> 82%
- Output voltage ripple	5 mVpkpk
- Low conducted noise emission	IEC 478-3 /C
- Voltage loop small signal bandwidth	> 800Hz (-3dB)

SUB-CONVERTER INPUT MODULE

Once conditioned through a RFI filter, the mains input is diode bridge rectified. A passive 75Hz dumped filter smoothes most of the 300Hz ripple frequency from the grid, and the remaining portion is rejected by the fast current loop.

A soft start system avoids high voltage peaks when connection. The DC bus voltage will be discharged, when power converter is de-energised through a security device for safety matters.

In order to achieve efficient power conversion, an IGBT bridge inverter is connected to the DC bus, switching at 40kHz to provide the sub-converter full power. Such high switching frequency requires special switching topology in order to minimise power losses:

Phase shift ZVS switching mode inverter.

The needed energy to achieve soft commutation conditions for the switching of the leading leg comes mainly from the series inductance and transformer

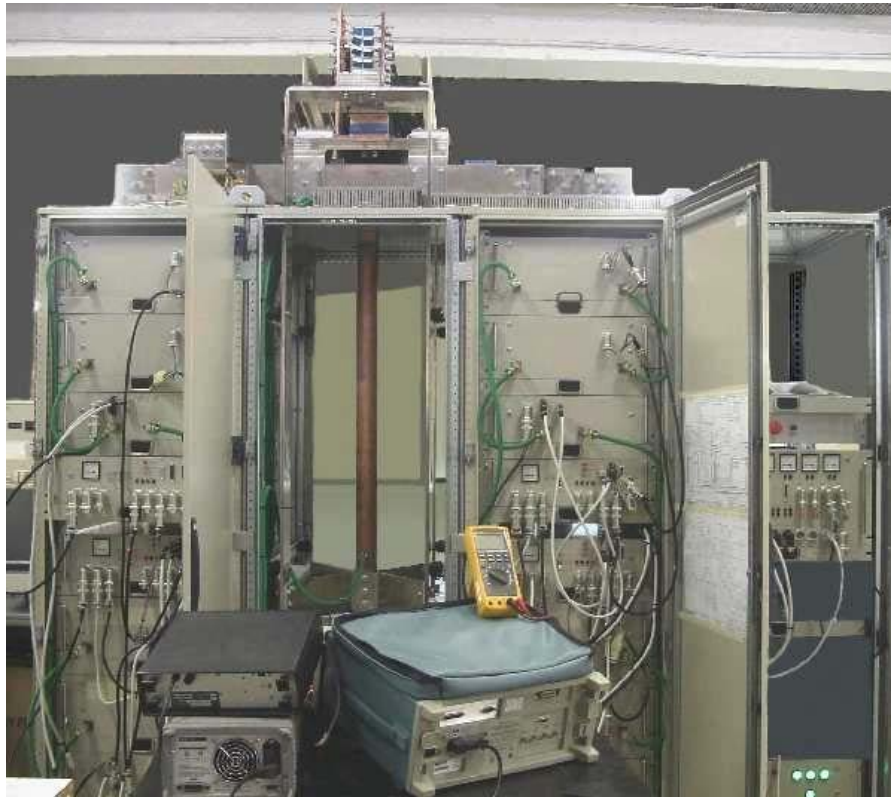


Figure 1: Overall view of the 8V, 6kA power converter.

leakage inductance, which will charge/discharge the parallel IGBT capacitance.

SUB-CONVERTER OUTPUT MODULE

The HF coming from the inverter is adapted and isolated to required voltage through two HF primary series connected transformers. Fast and low loss Schottky diodes rectify the signal in a current doubler rectifier topology, which reduces the power losses.

In order to achieve the demanding low output ripple, a two ladder step passive filter is connected in series. A 7kHz cutting frequency is obtained using high-tech polypropylene low stray capacitors and soft magnetic alloy inductors.



Figure 2: Sub-converter 8V, 2kA output module

SUB-CONVERTER ELECTRONIC MODULE

The electronic module manages all sub-converter tasks to work as an independent current source.

A very high speed current loop is made up, which will reject the remaining 300Hz ripple from the mains, as well as ensuring the current sharing and balance when connecting several sub-converters in parallel which responds linearly to an analogue common control input signal.

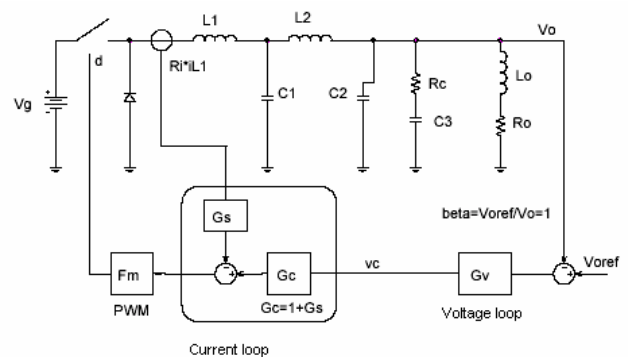


Figure 3: Simulation model for control loops.

A model of the sub-converter was done in order to simulate the designed control loops and fit the most suitable parameters. Advanced simulation tools made

possible to sense the loops according to specified requirements.

The internal fast current loop 8kHz bandwidth based on Average Current Mode control (ACC), was linked to an overall lower bandwidth voltage loop.

CONVERTER COMMON CONTROL MODULE

Common control module manages all tasks related to the whole converter, as well as the coordination of the operation of the four sub-converters in parallel.

A wide bandwidth voltage loop was defined as the overall control. The voltage reference coming from CERN high-precision current loop, had to be converted on four current references and send them back to each sub-converter. The output voltage stability is achieved for any number of sub-converters in operation, although any trip and stop of sub-converter during operation.

Due to the specified low output ripple requirement, the voltage loop provided a synchronised phase-shift concept, for shifting the inherent ripple at the inverter switching frequency.

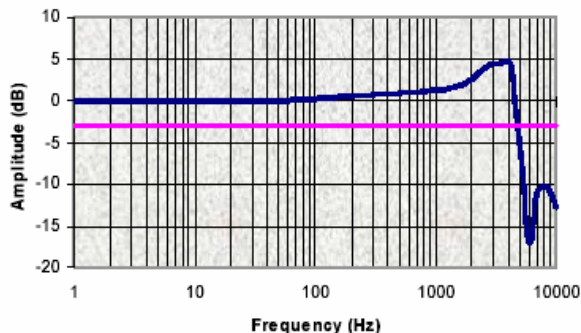


Figure 4: Voltage loop Bode diagram of Vref vs Vout. Testing conditions: Three sub-converters connected in parallel and setting a voltage reference

$$V_{ref} = 5V + 0.1V_{rms} \cdot \sin(\omega t)$$

Load: 1mOhm, 1mH

Measurement apparatus: Transfer function analyser

SPECIAL FEATURES

In order to protect the magnet in case of a sudden stop of the power converter, the stored energy had to be dissipated through a set of free-wheeling diodes. Three different free-wheeling paths were included to provide enough redundancy, capable to withstand all stored energy.

Maximum output ripple and conductive noise emission levels requested, imply to consider, from design stage indeed, special mechanical layouts as well as common and differential mode filtering concepts. The resulting very low noise level obtained, provides a clear and clean way to make measurements.

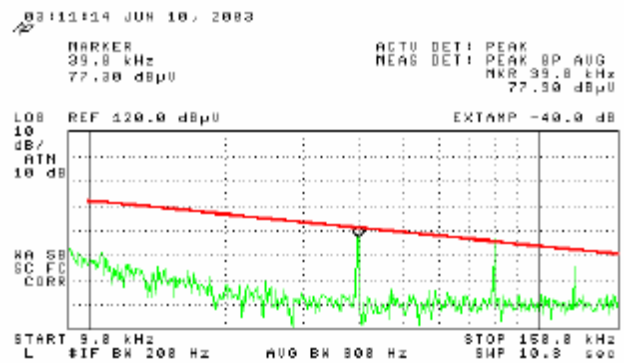


Figure 5: DC side common mode noise.

Test conditions : Three sub-converter connected in parallel providing full power (8V, 6kA)

Measuring apparatus: EMC analyser

CONCLUSIONS

A prototype of 50kW Hi-tech power converter, switching at 40kHz in soft-commutation ZVS topology, was designed, manufactured and tested by the company JEMA during 2002. The power converter prototype was tested and accepted by CERN in 2003. Some minor points were left and should be adjusted during the pre-series stage, in case of being awarded to the company.

The power converter concept, incorporates advanced know-how in terms of DC stability, efficiency in HF power conversion and control loops strategies.

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