Application of NPC topology in a 2.4 MW IGBT converter for a synchrotron particle accelerator

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Introduction - Objective

For **E**lectron **S**ynchrotron **R**adiation **F**acility ramping injector power supplies are developed. The power supplies will drive the voltage for the dipole electromagnets of the booster of the synchrotron in a triangular like current.

Core requirements:

Rated voltage	1500 V
Maximum voltage	1650 V
Rated current	1600 A
Output ripple frequency	6400 Hz
Repetition rate of load cycle	4 Hz
Maximum peak to peak voltage ripple	40 V
Synchronization	Synchronized pulse pattern of 2 converters
Load cycling capability	> 90 million load cycles

Design aspects

9-level PWM cascaded Neutral Point Clamped topology

An in-series combination of two IGBT based neutral point clamped topologies was used to feed the dipole electromagnet offering 9-level pulsed width modulation.

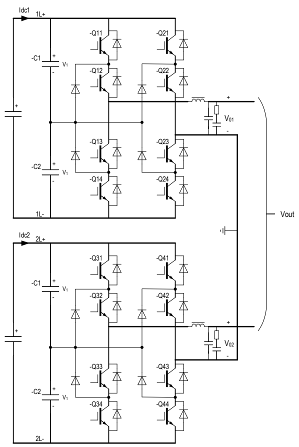

Fig.1 Cascaded neutral point clamped

Control method

The switching technique is based on a carrier based 3-level PWM that results to a 9-stage output voltage as shown in Fig.[2].

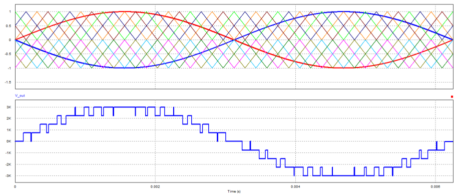

Fig.2 Derivation of 9-level output voltage after a carrier based PWM

- Oversampled digital feedback control is used for higher dynamic performance implemented in FPGA board
- Step response overshoot: < 3% (1 kV step)
- Step response settling time: < 5 msec (1 kV step)
- Feed forward control for eliminating input voltage variations

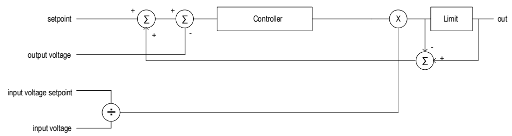

Fig.3 Feedback loop, desaturation loop and feed forward control

Neutral Point Control / Balance loop

Design of a neutral point control method to sustain the DC-link capacitors' voltage always equal (balanced) by controlling the current on the neutral point (NP) without influencing the output voltage.

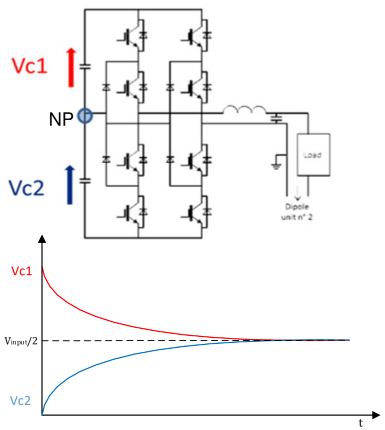

Fig.4 Balance control (Vc1=Vc2)

High power cycling capability

- Thermal behavior simulations for maximum number of power cycles
- Water cooling applied for power losses extraction

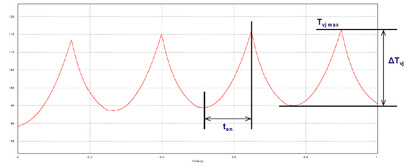

Fig.5 IGBT junction temperature deviation during the nominal load cycle

Implementation – Test results

Dipole converter

Fig.6 & Fig.7 Dipole converter (outside and inside view)

- Cabinets are equipped with HMI offering read access to the operational state of the converters
- All relevant signals can be extracted for evaluation on an oscilloscope

Fig.8 Dipole cabinets on site

Test results

- Test results with the dipole converters connected to the electromagnets and driven by external set-point for the current injection:

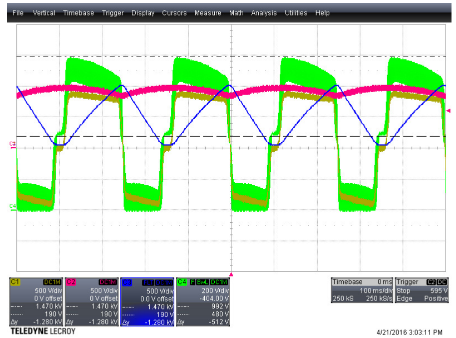

Fig.9 Blue: output current, yellow: output voltage driven by external set-point, red: input voltage, green: common mode voltage

- Results from activating the neutral point control in an unbalanced situation:

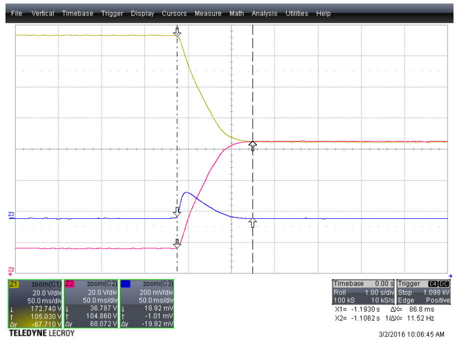

Fig.10 Yellow: DC-link capacitor Vc1, red: DC-link capacitor Vc2, blue: controller's output

End achievements

Development of ramping injector power supply for a synchrotron particle accelerator

- Precise high current injection
- Synchronized operation of 2 converters
- High accuracy and stability
- High load cycles capability
- Low peak to peak ripple voltage
- Human machine interface

Ampulz Energizing Ambitions