Electrical and mechanical adaptation of commercially available power inverter modules for BUSSARD - the power supply of ASDEX Upgrade in vessel saddle coils

Michael Rott[a], Nils Arden[a], Horst Eixenberger[a], Kevin Klädtke[b], Markus Teschke[a], Wolfgang Suttrop[a] and the ASDEX Upgrade Team

[a]Max Planck Institute for Plasma Physics, Boltzmannstrasse 2, D-85748 Garching, Germany
[b]Technical University Munich, Arcisstraße 21, D-80333 München, Germany

To supply the ASDEX Upgrade´s B-coils with AC current up to 1.3 kA_p at 500 Hz with arbitrary waveforms, a set of 16 inverters has been designed and partially built. To keep cost and development time low, commercially available power modules are used and existing current converters feed the DC links. Three power modules are mounted in one cubicle for realizing a three level neutral point clamped (NPC) topology with lowest possible inductivity and making the most of the limited space available.

The paper presents the effort and steps required to adapt standard power blocks towards the needs of the ASDEX Upgrade power supply as well as the mechanical optimizations for good mountability, flexibility and scalability. Besides, solutions for mandatory personnel safety and plant safety are presented.

Keywords: Inverter, Semikube, Saddle-Coil, power supply

1. Introduction

Presently at ASDEX Upgrade (AUG) 16 saddle-shaped perturbation coils - so called B-coils - are installed close to the plasma (fig. 1). Up to now they are supplied with DC current and low frequency AC current by two 4-quadrant current converters. A power patch panel allows connecting the coils or groups of several coils in series in either polarity. The coils have been used for experiments mitigating the Edge Localized Modes (ELMs) [1].

For increasing the experimental possibilities e.g. for MHD control, each coil will be fed by an inverter that can provide up to 1.3 kA_p but with arbitrary waveforms from DC up to 500 Hz.

As a first step four inverters are built and recently commissioned to feed four coils each in series, each with reduced bandwidth, or four single coils with full bandwidth.

2. Mechanical design

2.1. Cubicles

Instead of designing a mounting frame, Rittal cubicles were chosen in order to use as much commercial available parts as possible. The cubicles are as small as possible to meet the space requirements for future upgrades, but with sufficient space for power and electronic parts and a good accessibility (fig. 2). Anyway close mounting of the power blocks is advantageous to minimize the interconnection inductances.

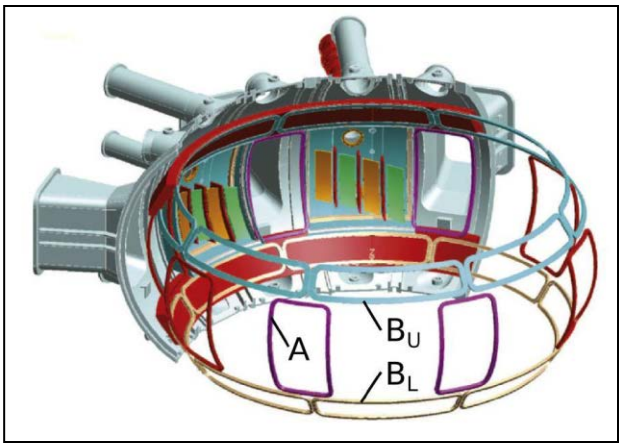

Figure 1: AUG magnetic perturbation saddle coils, called B-coils

Since the cubicles are difficult to access on their far side, the power blocks are mounted directly onto the mounting plate with riveted nuts. All holes and rectangular cutouts for the heat sinks are cut by waterjet cutting.

The inverter cubicles are mounted on a steel structure as a raised floor where cables, additional capacitors and power filters can be situated beneath.

author's email: Michael.Rott@ipp.mpg.de

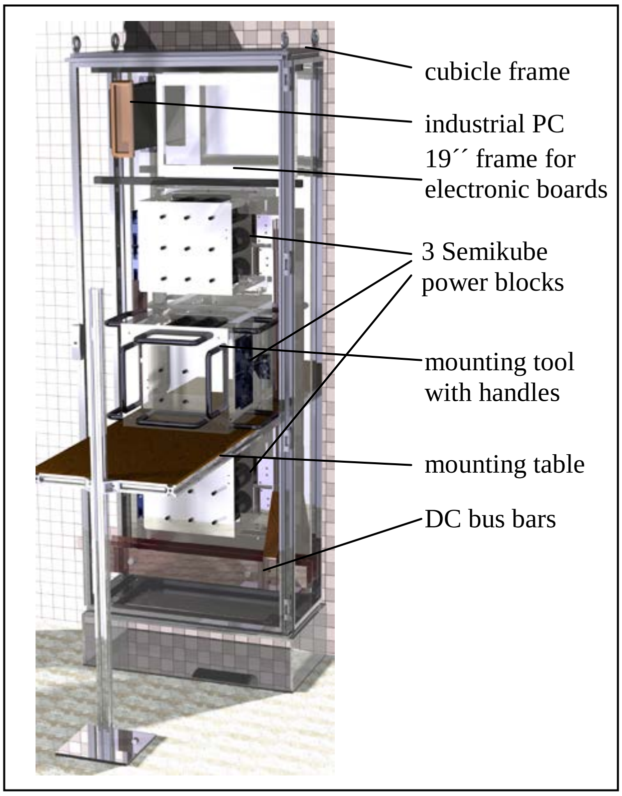

Figure 2: Drawing of the inverter cubicle with mounting tool and mounting table

The power block´s weight is about 50 kg and there is no handle for a safe mounting and carrying (fig. 4). Thus a mounting frame and a mounting table (fig. 2) have been designed. These tools make it possible to mount and dismount ergonomically in the constricted room between the cubicles while reducing the risk of damaging electronic devices mounted on the power blocks.

2.2. Air flow

Due to the briefness of the pulses of up to 10 s and a long pause time of minimum 180 s, heat removal is not critical. This allows the usage of only one cooling fan to ventilate all three power blocks in series through a cooling duct. The heat sinks of the power blocks and the fan are mounted on the far side of the mounting plate of each inverter cubicle. In order to ease the replacement of a fan, they are connected via a plug and mounted on M8 riveted nuts.

To extend the lifetime of the fans, vibrations had to be eliminated and the fans are only operated for a while after a pulse depending on the measured temperature of the Semikube heat sink.

3. Electrical Design

An overview of the BUSSARD inverter system is given in Figure 3.

The Semikube power modules from Semikron were chosen electrically oversized with sufficient operational margin. Their nominal current is 1470 Arms whereas only 919 Arms with a duty factor of 5.6 % are required. Thus having a half bridge topology, the Semikubes allow to realize a NPC topology consisting of three identical power blocks [2].

3.1. Bus bars

The DC bus bars are made of 10 mm x 100 mm copper bars. The L and F shaped inverter interconnecting bus bars (5 mm x 50 mm) are waterjet cut of copper plates and bent afterwards. The usage of stiff copper bars minimizes space requirement in the cubicle and inductances between the closely mounted bus bars but with disadvantages in mounting and parts replacement.

The cross section is chosen to minimize heating and thermal lengthening that would lead to mechanical stress for the insulators.

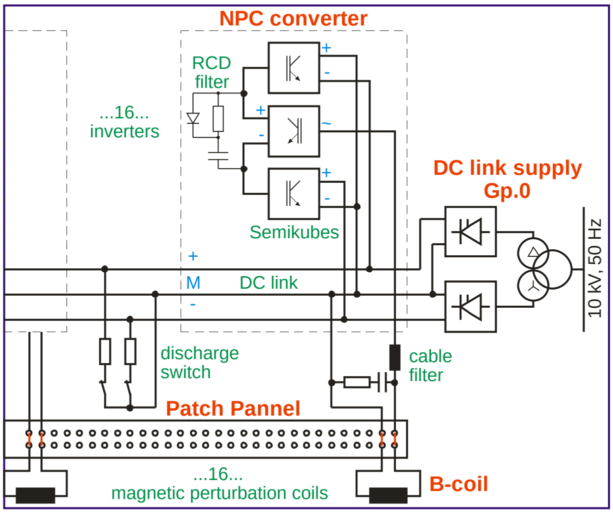

Figure 3: Schematic diagram of the BUSSARD inverter system

The DC bus bars in the bottom of the cubicles are stiffly connecting 4 inverters. They are mounted on the 3 mm bottom plate on top by each other.

3.2. Design of DC-supply

The DC bus bars of the BUSSARD inverter are supplied by two legacy thyristor-based 2-quadrant current converters. To load the Semikube´s capacitors with moderate current, their output voltage is controlled, further details are described in [3].

4. Design of cable filter for commissioning

In order to reduce switching overvoltage due to cable capacitance and inductance, an LCR cable filter was built [4]. It is designed to easily change resistance, capacitance and inductance for different tests during commissioning.

The choke carries the nominal current, so it is difficult to change the inductance because of its weight, size and cost. However the design as a two windings core choke allows to change the inductance in a wide range by changing the windings connections.

Table 1 shows the six connection possibilities, the resulting inductance and the underlying equations with main (L_1, L_2), stray (L_σ) and mutual (M) inductance. In this way a stepwise reduction of the inductance between 112 μH and 15 μH is possible.

Table 1: Possible inductances to be realized with a two windings iron core choke

L [μH]	L/L_{max}	Connection of windings	Equation L =
112	1/1	series	$L_1 + L_2 + 2\,M$
58	1/2	anti-series	$2\,L_\sigma$
43	1/3	one winding	$L_1 = L_2$
40	1/3	2nd winding short circuited	$L_1 - M^2 / L_2$
28	1/4	anti-parallel	$L_1 / 2 + M / 2$
15	1/8	parallel	$L_\sigma / 2$

5. Safety-System

5.1. Personnel Safety

Detailed personal and plant safety considerations are mandatory. Several emergency push buttons and door contact switches are installed and signal lights show the plant´s operational status. If the emergency circuit is disconnected, the circuit breaker of the converters as the inverters itself are switched off and the DC capacitors are rapidly discharged. The discharge is realized with a DC switch with normally closed main contacts to be safe even if a cable break is occurring. Two Steel resistors of 7.5 Ω discharge the capacitors of 4 inverters with a time constant of 0.1 s and the envisaged 16 inverters within 0.5 s. To accelerate debugging the PLC monitors and displays the device that caused the emergency off.

A short circuit between DC bus bars would cause a strong arc fed by the DC converter up to 4 kA for 10 s with corresponding heat, explosive expansion and possible fire. Additionally, the energy stored in the capacitors of about 2.4 kJ in 4 inverters would feed the arc. This is prevented by extensive isolation of the bus bars and the fast arc detection system PGR-8800 by Littelfuse, which detects an arc with sensors in every cubicle and one fiber optic line sensor mounted beneath the DC bus bars.

5.2. Overcurrent protection

Coil damage by overcurrent would require a technically challenging repair with long downtime and the associated expense.

The B-coils´ windings are covered with an alloy sheet [5] for mounting and vacuum compatibility. This casing is 1.2 mm thin to minimize eddy currents that reduce the resulting flux density at the plasma edge. Hence the maximum coil current is strictly limited to 2.2 kA in order not to overstress the casing by JxB forces.

Three staggered trip levels make sure not to exceed this 2.2 kA limit:

- 1.35 kA software limit in the pulse vector generating software running on the industrial PC
- 1.5 kA electronic hardware limit in the Gate-driver Interface Board (GIB)
- 1.7 kA electronic hardware limit on the Semikube IGBT driver board

The current is measured in the Semikube by four current transformers. Balance of the four measurements is supervised by the driver board. To adjust the current limit some SMD resistors on the driver board have been replaced, which also led to a change of the current output signal rating.

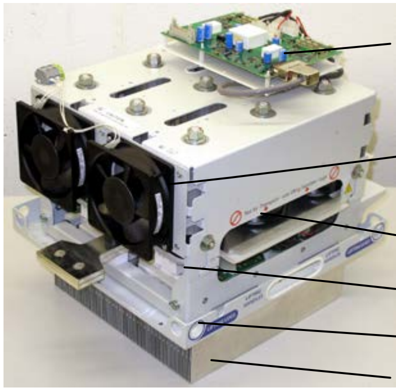

Figure 4: Semikron´s Semikube

The system safety is highly improved by the means of using the NPC topology, because always two power blocks are carrying the current in series. So if one device in one power block fails, there is always another power block in series that can measure and switch off the current.

5.3. Differential current detection

A high energy arcing in a vacuum insulated duct can cause massive destructions, at least in a B-coil. To detect such an event a fast differential current detection has been developed and will be implemented in the system [6]. This allows a fast de-energization of the arc by switching the inverter´s output to middle potential M (see fig. 3).

The differential current is detected by means of a ferrite core over the cable with a secondary winding. During the IGBTs switching there is a differential common mode current due to cable capacitance, which has to be neglected.

Tests showed that a differential current of 5 A can be detected and switched off in less than 6.5 μs.

6. Outlook

The project has achieved another milestone by commissioning the first four inverters parallel to ASDEX Upgrade (AUG) operation. Further EMI tests e.g. with respect to AUG diagnostics are underway.

Next step is to extend the plant to full 16 inverters, to supply all 16 B-coils independently. One spare inverter cubicle will be assembled to reduce down time in case of a fault - the spare parts have to be purchased anyway.

Later on the patch panel will be dismounted and every inverter hard-connected to a B-coil. This reduces the cable inductance by eliminating the area spanned by the patch cables.

The arrangement of the inverter cubicles considers a possible upgrade of further 8 inverters supplying the planned 8 A-coils. These coils will be arranged in the midplane of AUG (fig. 1), mounted without a metal casing [7] and will be supplied with AC current up to 3 kHz.

7. Summary and conclusions

This project is realized with a small team that is also occupied with AUG operation and with a limited budget.

The availability of commercial components, e.g. with integrated driver board, facilitated the fast results. But it turned out, that a lot of details have to be treated to adapt the components for the ASDEX Upgrade requirements.

Attention had to be concentrated on the safety of the system to avoid arcing, overvoltage or EMC problems.

The compact mechanical design of the inverter cubicles achieved an optimal utilization of the available space and good accessibility of all components.

Acknowledgements

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