GSI Helmholtzzentrum für Schwerionenforschung GmbH

Document Title

Power Converter System for R3B - GLAD Magnet

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Document Name

F-DS-PC-04e Power Converters GLAD - Magnet_v1.2

Date

2013-06-19

Abstract

The document describes Detailed Specifications for the ramped power converter system for the R3B-GLAD magnet.

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1. Purpose and classification of the document

This document describes the technical requirements of the power converter for the R3B-GLAD magnet. General technical requirements for all the parts and components of the power converters are given in the Common Specifications for power converters [3]. General, legal and technical issues are given in the general specifications [1] and technical guidelines [2], respectively.
Note: Statements made in this document override the one in all other documents: the general specifications, the common specifications for power converters and the technical guidelines.

Contracting body for the equipment described in this document is GSI Helmholtzzentrum für Schwerionenforschung GmbH (GSI). So all further references to the term 'the Company' will refer to GSI.

2. Scope of the technical System

2.1. System Overview

The R3B experiment will be built within the future FAIR Facility. However, for first tests it will be installed in GSI.
The objective of the R3B international collaboration is to develop and construct a versatile reaction setup with high efficiency, acceptance, and resolution for kinematically complete measurements of reactions with high-energy radioactive beams. The final setup will be located at the focal plane of the high-energy branch of the so-called "Super-FRS". Figure 1 shows the layout of the experiment with the large acceptance dipole magnet powered by the specified power converter system.

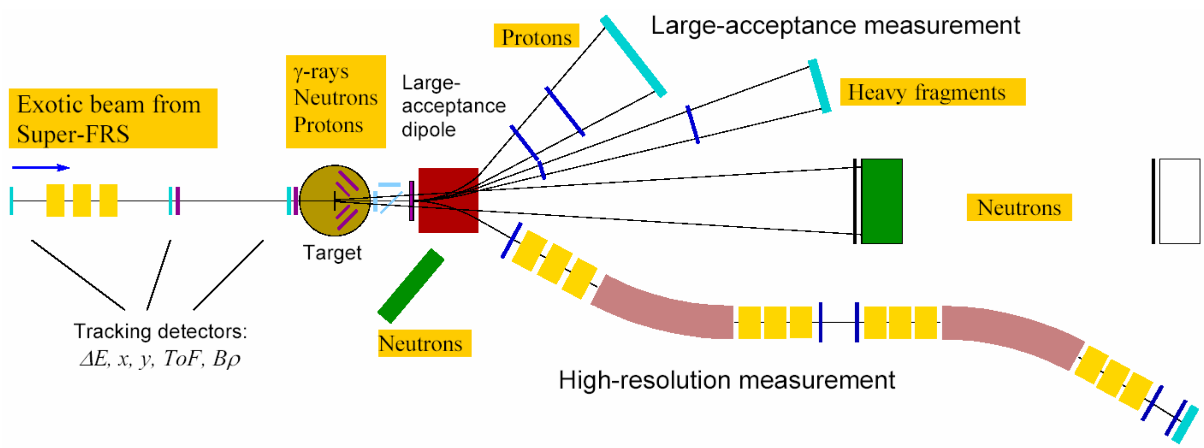

Figure 1: Layout of the R3B hall with the R3B-GLAD magnet

2.2. Brief description of the R3B – GLAD magnet

The R3B-GLAD magnet project is part of the DIRAC-PHASE 1 European contract. The IRFU, at CEA Saclay, has in charge the GLAD magnet: from the conception, the realisation, the test at Saclay up to the installation in the cave of the R3B experiment, at GSI and later on in the FAIR facility.

The R3B-Glad superconducting magnet provides the field required for the large acceptance spectrometer, dedicated to the analysis of Reactions with Relativistic Radioactive ions Beams.

One main feature of this butterfly-like magnet with tilted and trapezoidal racetrack coils is the active shielding. It makes it possible to decrease the field by two orders of magnitude within a 1 m length, despite the large opening on the outlet side of the magnet.

Some other characteristics are as follows: the magnet protection system which is based on an external dump resistor, coupled to a strong “quenchback” effect, to prevent any damage of the coils which could be caused by the 24 MJ of stored energy;

The nominal working conditions of the magnet are:

Peak field on the conductor	6 T
Operational temperature	4.6 K
Overall current density	73 A/mm²
Stored energy	24 MJ
Nominal current	3.6 kA

Table 1 magnet working conditions

2.3. Brief description of the coils

The magnet is composed of 6 coils connected in series (2 main ones and 4 lateral ones). Each coil consists of a stack of double pancakes wound with superconducting cable. The coils are cased into four coil-casings.

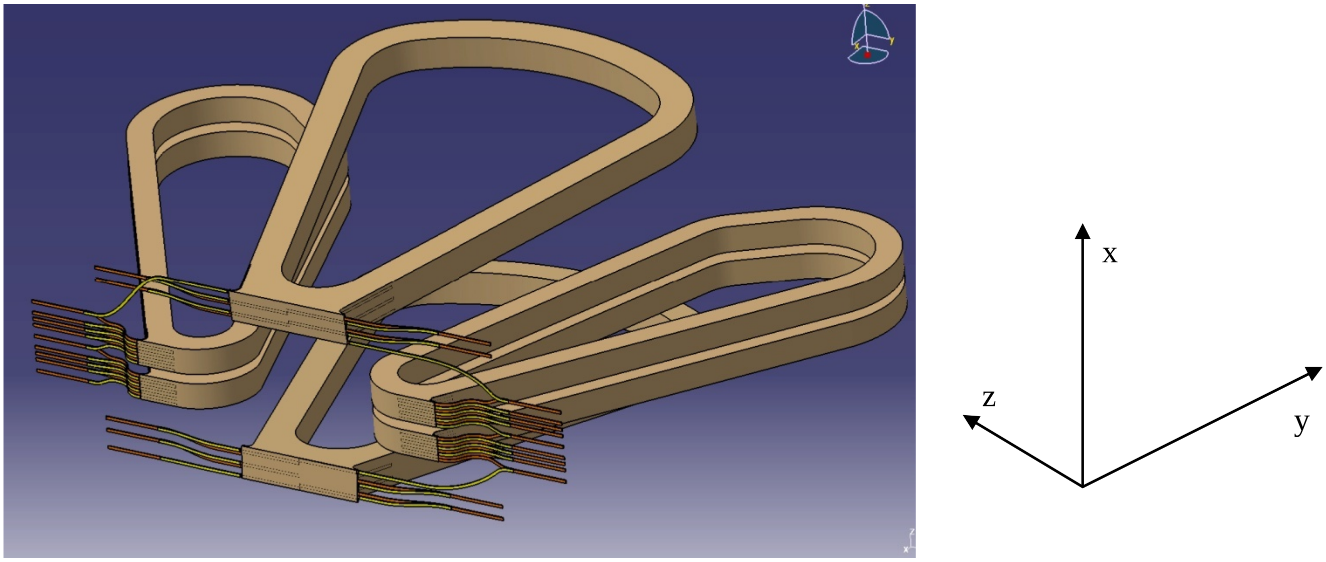

Figure 2: Coil configuration

2.4. Power Converter System

The power converter system consists of two separate units.
The power converter unit (PCU) contains the converter circuit and the control part. This unit is placed outside the R3B Cave (see section 5.9).
The quench protection unit (QPU) which is mounted on the supply part of the magnet contains the quench protection circuit which consists of several dc circuit breakers and a dump resistor. Both units are interconnected by water cooled cables (see Figure 3).

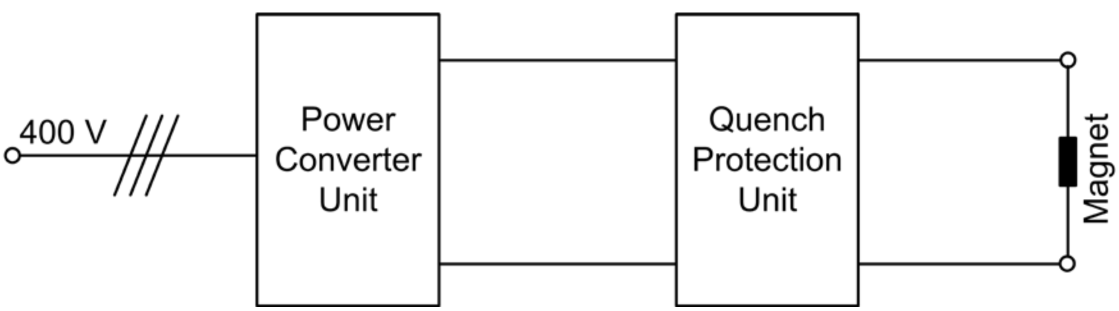

Figure 3 basic structure of power converter system

3. Scope of the delivery of the power converter system

The contractor has to deliver:

- one power converter unit according to Table 2
- one quench protection unit consisting of
  - two mechanical dc-circuit breakers (CP) as described in section 5.4.1
  - one mechanical dc-circuit breaker (CDL) as described in section 5.4.3
  - one dump resistor (RD) as described in section 5.5
  - one disconnector as described in section 5.4.5
- one set of interconnecting water cooled cables between PCU and QPU (2 x 12m) as described in 5.6.
- all necessary control cables between PCU and QPU

Included in the delivery is:

- manufacturing and preliminary test
- FAT (see [3])
- transportation (including packaging)
- assembly at GSI site
- installation of interconnecting cables
- commissioning and SAT at GSI site
- documentation according to the common specification

Not in the scope of the delivery is

- connection to the electrical supply system (400V)
  to the load
  to the water system.
- the ACU system and the control systems MSS and MCS (see chapter 5.2)
- the DCCTs
- cable trays

For standardisation reasons it is mandatory for the power converters to use the ACU system and the DCCT which will be provided by the Company (see [3]).

For the power converter, only the MFU of the ACU system must be used. This unit delivers the digital set value for the load current via a serial protocol (USI). Other components of the ACU system can be used, too.

The output of the DCCT electronic can be an analogue signal or a digital signal converted by an ADC with a resolution of 18bit and transmitted via the USI protocol to the MFU.
There will be two 4kA-DCCTs for each power converter. One will be used for the power converter control (DCCT1) and one for the the Magnetic Safety System (MSS) and the Magnet Control System (MCS) (DCCT2). Both DCCT heads must be integrated in the power converter system.

4. Order processing

4.1. Documentation

Refer chapter 10 of [3]. The Company reserves the right to carry out modifications if they are necessary for the functionality and the installation of the system.

4.2. Quality Assurance, Tests and Acceptance

See chapter 8 of [3] . A prototype and pre series production is not necessary. For the FAT the procedure described in chapter 8.2.1 of [3] has to be done (8.2.2 of [3] will not be carried out).
SAT Ab (8.3.1 of [3]) will be done at the final position of the power converter in GSI and has to be done by the contractor. The necessary equipment will be provided by the Company.

5. Technical specification

5.1. Power Converter description

The power converter must be able to ramp up and ramp down the current in the 3.71 H superconductive magnet (see Figure 4). The CP1 and CP2 breakers connect the power converter to the magnet. In case of a major fault like a quench detected by the MSS the 2 CP breakers are opened and the magnetic energy stored in the coil is dumped in the 0.28 Ω dump resistor (RD) with a time constant of 15 s. The midpoint of the dump resistor is grounded by the 50 Ω RM resistor and the closed CM breaker of the ground leakage detector, thus to discharge at a maximum voltage of ±532 V to ground. See also section 5.7.
The breakers CP are located in the cabinets of the QPU very close to the magnet to keep the voltage drop of the cabling to the magnet small.

5.2. Power Converter operation modes

5.2.1. Normal operating

In normal working conditions, contactor CDL is open, contactors CP1 & CP2 are closed and breaker CM is closed. The power converter is connected to the magnet and powers the superconductive 3.71 H coil up to nominal current.

5.2.2. Fast discharge DR

In case of a severe fault such as a quench (a superconducting to resistive transition) in one of the coils is detected by the MSS, the redundant CP1 & CP2 contactors are opened. The magnet coils discharge in the 0.28 Ω RD dump resistor with a time constant of 15 s at a maximum voltage of 1064 V (±532 V to ground). The power converter is interlocked by the MSS and has to be turned off.

5.2.3. Slow discharge DL

In case of any power converter fault, the power converter has to be turned off and the CDL contactor must be closed, shorting the magnet. The contactors CP1 & CP2 are kept closed and the coils discharge very slowly through the closed loop in the electrical line resistance (below 0.1 mΩ); this is done to avoid a fast discharge resulting in a magnet quench leading to a long stop (a few days are necessary to cool down the magnet again).

During slow discharge the power converter must be able to carry or limit the short circuit current resulting from the closed CDL contactor.

During slow discharge and closed CDL it must be possible to disconnect the power converter unit from the quench protection unit. Therefore a disconnector (CD in Figure 4) has to be foreseen in the QPU.

This CD disconnector could be opened to work on the power part of the PCU during slow discharge. It is only allowed to open CD when CDL is closed and the power converter unit is turned off. Therefore this disconnector opens in zero current condition.
The CD can only be closed when the power converter is off.

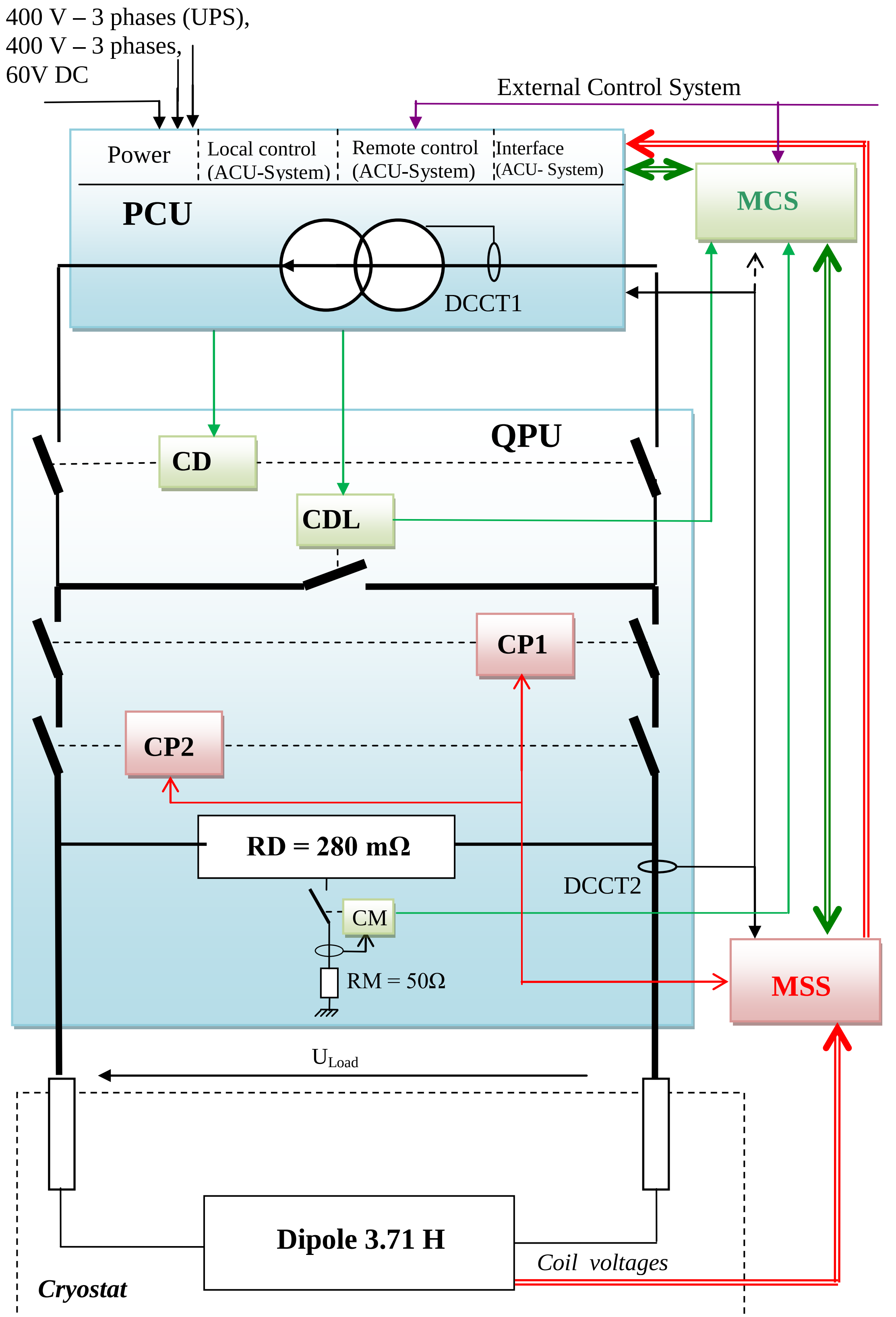

Figure 4 power converter system overview

It has to be guaranteed that the CD contactor is closed and the current in the power converter circuit is equal to the magnet current before opening CDL after a power converter fault.
Therefore the ACU system internally will use the actual current value from DCCT2 as a set value while CDL is closed.
After CDL is opened the ACU system switches over to the actual set value and starts with the normal operation mode.
Figure 5 shows the principle of the logic to control CDL.

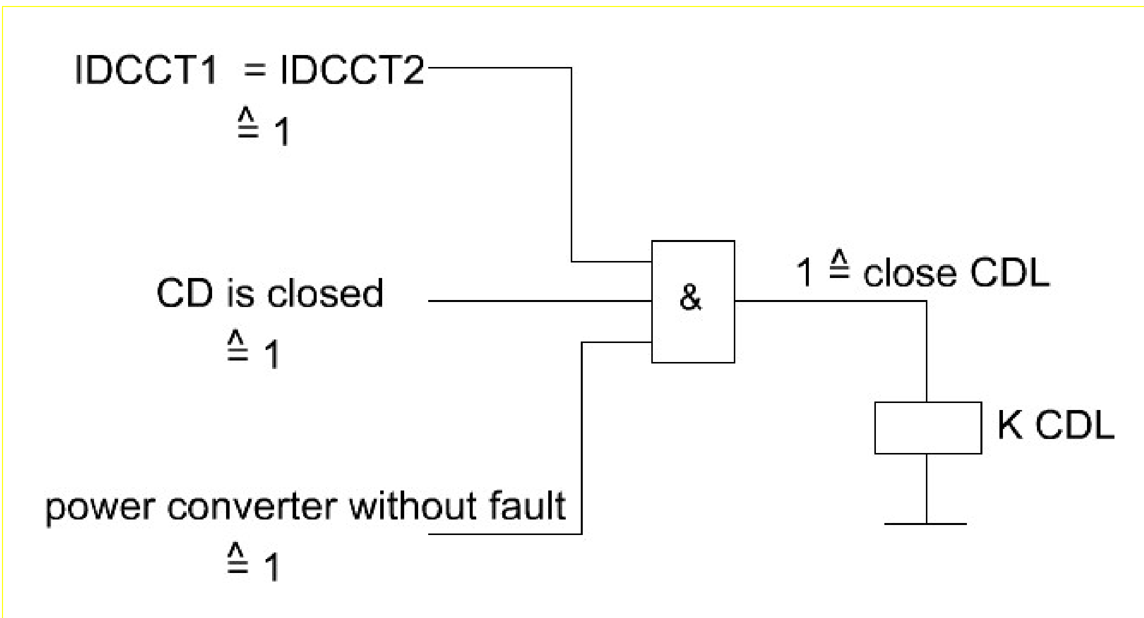

Figure 5 logic for opening and closing CDL

5.2.4. Normal discharge DN

The power converter is connected to the ground reference in the middle of the dump resistor RD, with the contactor CM closed. In case of an insulation fault, given by a current threshold of 10 mA, the contactor CM opens and the main DC current is ramped down with a current rate of 0.2 A/s.

5.3. Technical Parameters

Pos.	**1**
power converter type	R3B-PC-D
number of power converters	1
range of output current	100A …3800A
nominal output current I_n	3584A
current ramping rate $\left(\frac{di}{dt}\right)$ [1]	0,1A/s … 2 A/s
rise time from I_{Lmin} to I_{Lmax}	6350s
fall time from I_{Lmax} to I_{Lmin}	6350s
number of magnets in series	1
resistance of magnet	0
low field inductance of magnet	3,71 H
min. cross section / total length of load connection	2400mm² /6m
total resistance of load connection R_L	44 µΩ
inductance of load connection L_L	--
capacitance of load connection C_L	--
output voltage U_{Load} DC	0,17V
maximal output voltage U_{Load} (postulated)	±8 V
allowed total deviation (peak/peak) absolute: **δ_2I** ($\Delta I/I_n$)	$5 \cdot 10^{-5}$
bending time	≤ 200ms
max. cabinet size (PCU,QPU) (B x T x H) in m	2 x 2,4x1,0x2,1

Table 2 technical parameters

[1] Current ramping rate depends on the actual magnet current see Table 3

The power converter must operate in the ramped mode (type A) defined in chapter 7.1.3 of [3].
In case of SCR topology at minimum a 12 pulse system has to be realized.

The total time for the magnet loading is expected below 2 h. Table 3 defines the max allowed ramp rate which depends on the actual current value and will be generated by the ACU system.

Current (A)	Ramp rate $\left(\frac{di}{dt}\right)$ (A/s)
0 < I < 360	2
360 < I < 2160	1
2160 < I < 3240	0.4
3240 < I < 3584	0.2

Table 3 current ramping rate

5.4. Contactor requirements

5.4.1. CP characteristics

The two CP contactors must support each an opening voltage up to 1500 V and a breaking current up to 3800 A. They are mounted in full redundancy and open both polarities of the circuit to fully disconnect the PCU from the magnet. They are air cooled and contacts are of “normally open” type. They are housed in the cabinet of the QPU, close to the magnet.

5.4.2. CP contactor parameters

Control voltage	60V DC
Main pole contact type	2 normally open
Voltage	1500 VDC
Insulation voltage test	3000 VDC
Maximum breaking current	3800 A
Opening time	< 100 ms
Closing time	< 500 ms
Control contacts	2 NO / 2 NC
Electrical lifespan at Imax	> 100 operations
Mechanical lifespan (without maintenance)	> 1000 operations

5.4.3. CDL characteristics

The CDL breaker is able to open and close the circuit up to 3800 A maximum current. It shall be an air cooled contactor with 1 main pole of “normally open” type. It is housed in the cabinet of the QPU. To minimise power consumption it can be held closed by an electromechanical switch, a mechanically latched contactor or can be a bistable type.

5.4.4. CDL contactor parameters

Control voltage	60V DC
Main pole contact type	1 Normally open
Voltage	500 VDC
Insulation voltage test	2000 VDC
Maximal making and breaking current	3800 A
Closing time	< 100 ms
Opening time	< 100 ms
Auxiliary control contacts	2NO / 2 NC
Electrical lifespan at Imax	> 500 operations (opening and closing)
Mechanical lifespan (without maintenance)	> 1000 operations

5.4.5. CD characteristics

The CD disconnector could be opened during slow discharge to allow service and repair work on the power part of the PCU during slow discharge. It is only allowed to open the CD when I_{DCCT1} is zero, CDL is closed and the PCU is turned off. Therefore this disconnector works in zero current condition. It shall be an air cooled contactor with 2 main pole of “normally closed” type. It is housed in the cabinet of the QPU.

5.4.6. CD contactor parameters

Control voltage	60V DC
Main pole contact type	2 normally closed
Voltage	500 VDC
Insulation voltage test	2000 VDC
Maximal making current	3800 A
Auxiliary control contacts	2NO / 2 NC

5.5. Dump resistor requirements

The dump resistor shall be made of stainless steel and is air cooled by natural convection. The dump resistor shall be housed in the cabinet of the QPU, close to the magnet.
The dump resistor is an essential part for the magnet protection, so it is permanently connected across the magnet to maintain a closed loop able to discharge the magnet. To increase the reliability of this circuit, all connections, bolted or welded, must be at least doubled.

5.5.1. Characteristics

Maximum energy	26.3	MJ
Maximum current	3800	A
resistance	0.28	Ω (non inductive)
Accuracy at 20 °C	0/-5	%
Discharge time constant	13.2	s
Temperature increasing for 26.3 MJ	500	°C (hottest point)
Maximum voltage	1064	V
Insulation test	3000	VDC

5.5.2. Thermal characteristics

During a fast discharge, it is estimated that nearly 30 % of the energy is dumped into the coils; so the average temperature increase of the resistor should be about 300 °C for the energy of 18.4 MJ.
The dump resistor is air cooled by natural convection (forced air cooling is allowed in addition), the assembly of the resistor elements should be designed to limit the temperature increasing of the hottest point below 500 °C for the maximal energy of 26.3 MJ.

5.6. Water cooled cables

The cable connection between the PCU and the QPU must be done by water cooled cables. The maximum length is 12m per cable connection.
The minimum cross section per cable connection is 500mm².
Each cable connection must be equipped with a temperature sensor at the hottest point of the connection.

5.7. Electrical Interfaces

5.7.1. Interface to the electrical supply system

The parameters of the main electrical supply system are described in 5.8.1.
To avoid an unwanted opening of CP breakers two additional (redundant) electrical supply systems are foreseen. These are a 400V AC supply from an UPS system and a 60V DC supply system buffered by an external battery.

The CP breakers must be supplied from a DC voltage which will be powered by both systems in full redundancy according to Figure 6.

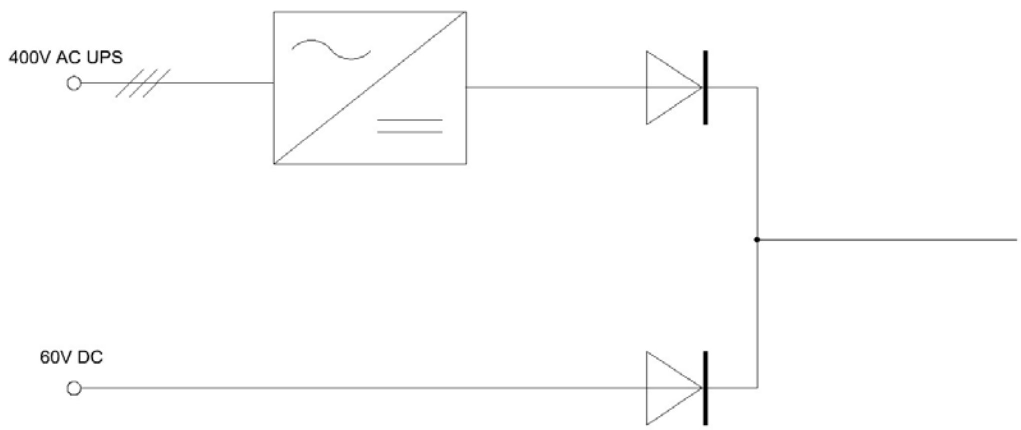

Figure 6 supply of CP breakers

For the 400 V supply system and for the 60V supply system a MCB (miniature circuit breaker) must be foreseen.

The ACU system must be powered from the 400V UPS system.

5.7.2. Interface to MSS and MCS

The interface between the power converter system and the MSS is given in Figure 7 while the interface between the power converter system and the MCS is given in Figure 8.

The contacts DR1 and DR2 in Figure 7 are open in case of a quench otherwise closed. The coils KCP1 and KCP2 in Figure 7 controls CP1 and CP2.

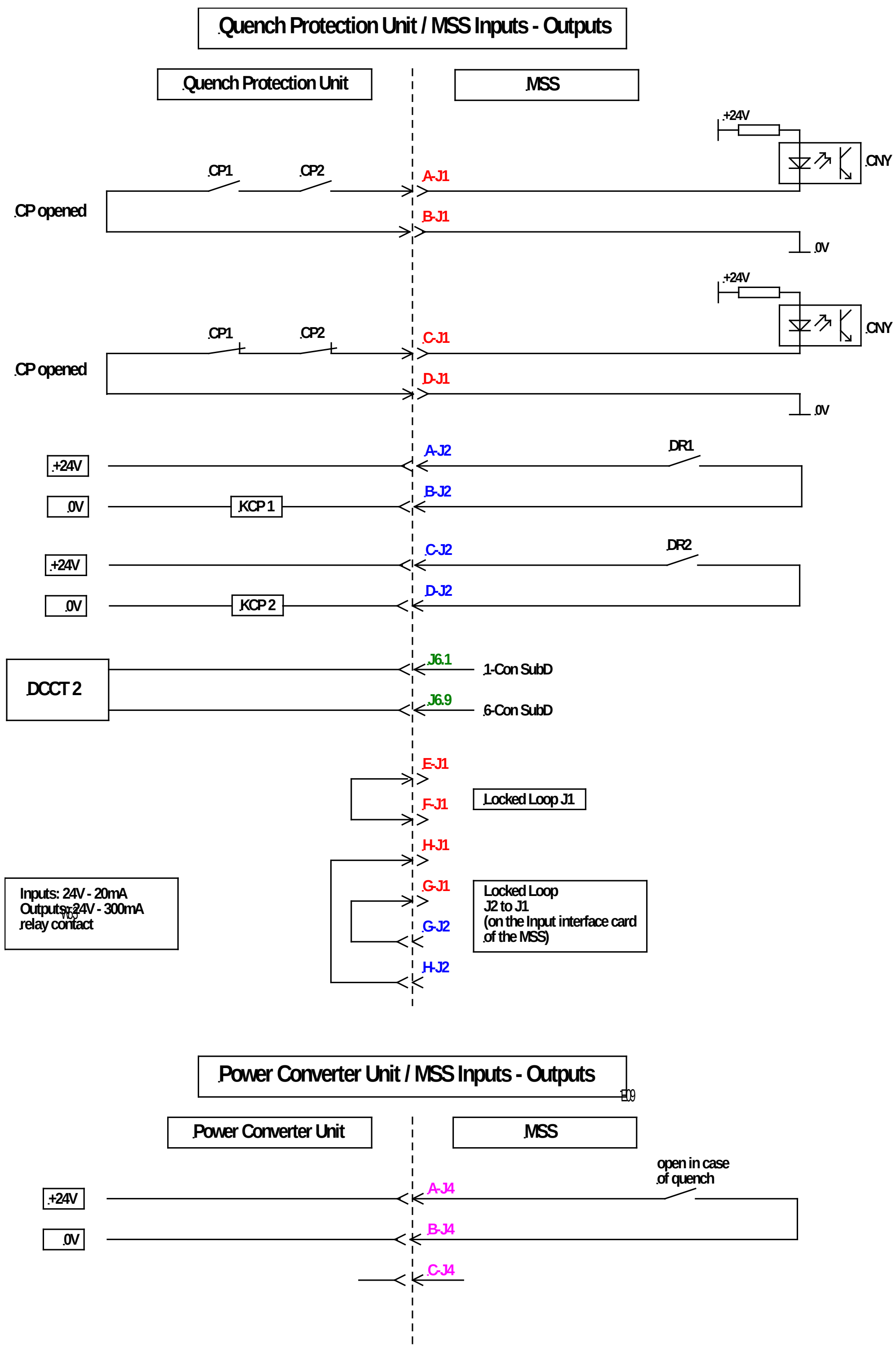

Figure 7 interface between quench protection unit and MSS

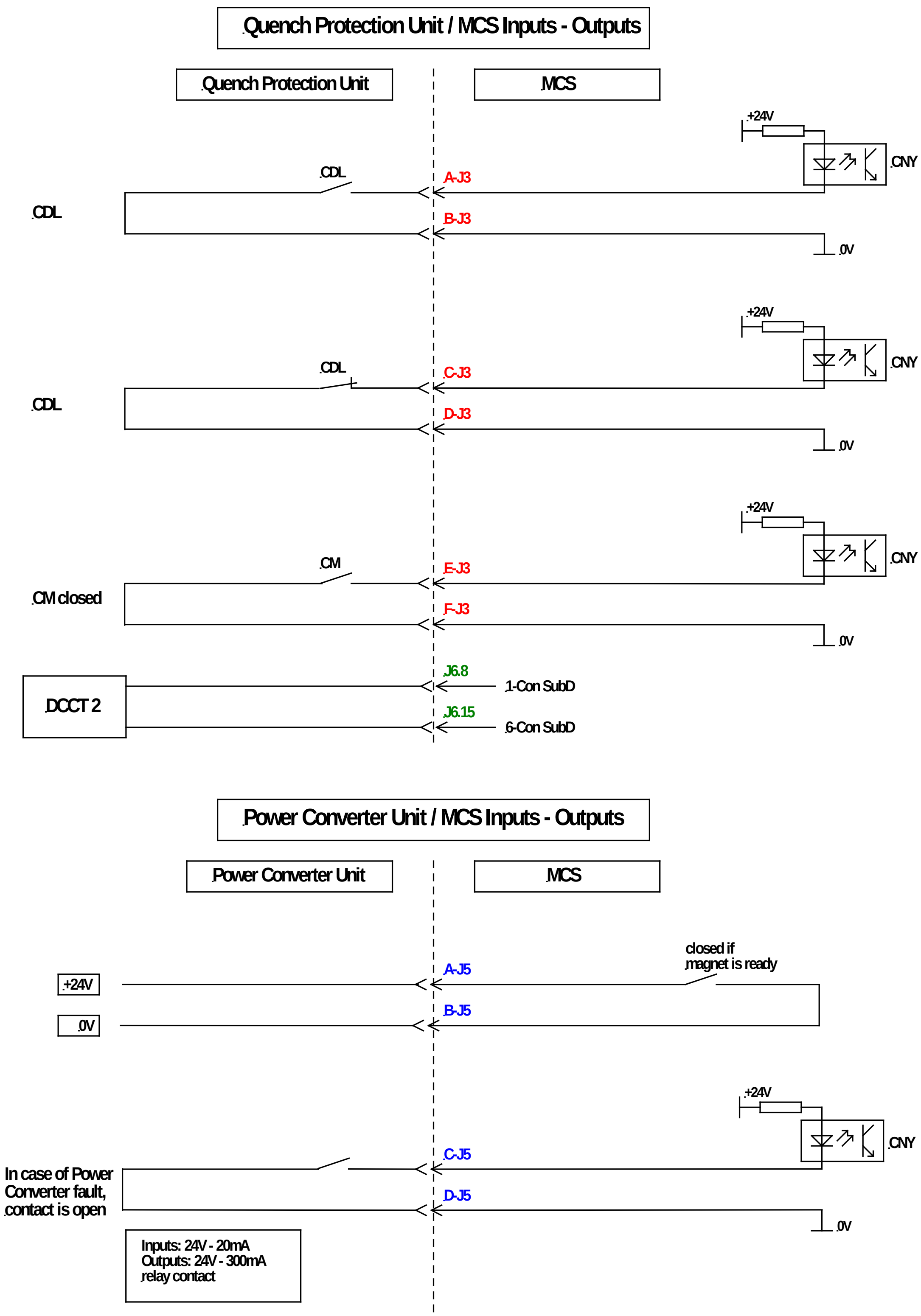

Figure 8 interface between power converter unit and MCS

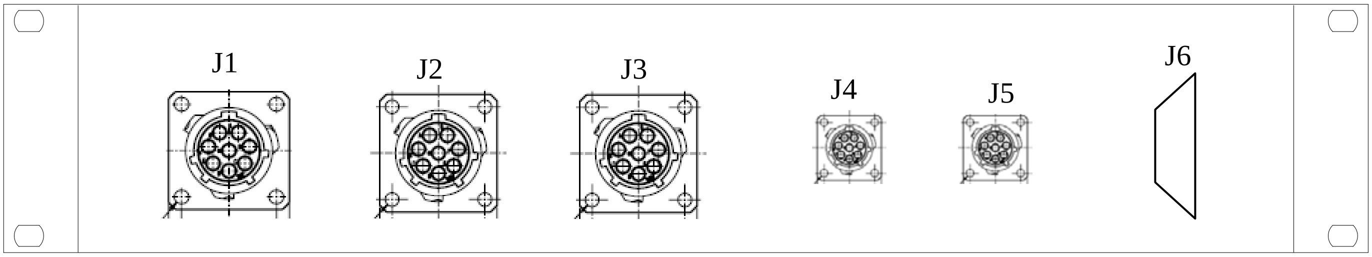

Figure 9 interface patch panel

Connector Name	Manufacturer	Type	
J2-J3	SOURIAU	UT001412SH6	12 sockets contacts
	SOURIAU	RC24M9K	Sockets contacts AWG 26-24
J1	SOURIAU	UT001412PH6	12 pins contacts
	SOURIAU	RM24M9K	pins contacts AWG 26-24
J4-J5	SOURIAU	UT00104SH6	4 sockets contacts
J6	ITT/Cannon	Sub D	15 pins contacts

Table 4 interface connectors

Figure 9 shows the patch panel for the interface between MCS and MSS and the power converter system. This panel has to be mounted inside the QPU. Table 4 gives the type of connectors has to be used.

A Beam interlock system of type A has to be installed (see subsection 7.5.11 of [3])

Mechanical layout of the output terminals

The mechanical layout of the output terminals of the power converter system is given in Figure 9. The connections to the magnet will be done by two parallel copper bus bars with a total cross section of 2400mm².

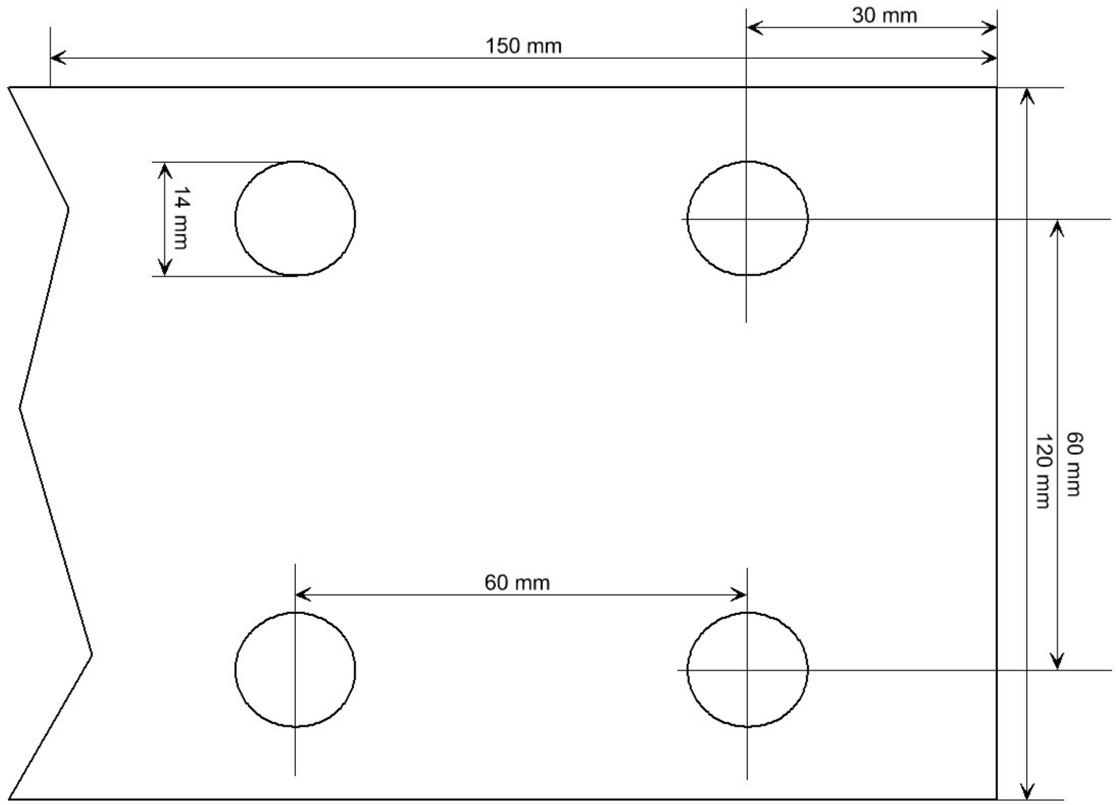

Figure 10 mechanical layout of main output terminals

5.8. Environmental conditions

5.8.1. Characteristics of the electrical supply systems

According to chapter 4 of [3] the 400V electrical supply system will be a 1MVA transformer connected to the 20kV electrical supply C1.

5.8.2. Water cooling

Water cooling is mandatory for cooling electronic power components (IGBTs, thyristors, power diodes, power transistors). To avoid high losses to air also the high current smoothing inductors have to be water cooled. With regard to [3] the following parameters have to be considered:

- Max. operating pressure : 10 bar
- Peak pressure : 12 bar
- Inlet temperature : 25°C ± 2°C
- Difference pressure : min. 8 bar
- Max allowed outlet temperature : 45°C
- Conductivity : < 1 µS/cm

The materials in the cooling circuit shall be compatible with the use of demineralised water. Any material other than stainless steel and copper must be identified in the design report and need formal acceptance of the Company.

5.9. Locations of Power Converters

The power converter system is foreseen for indoor installation. The cabinets of the PCU will be placed outside the R3B Cave while the cabinets of the QPU are placed on the supply part of the magnet (see Figure 9). It is placed on a metal frame of a maximum size of 2,4m x 1m.
All incoming and outgoing connections (electrical, water) are bottom up. The interconnecting water cooled cables have to be installed in the floor channel (see Figure 9).

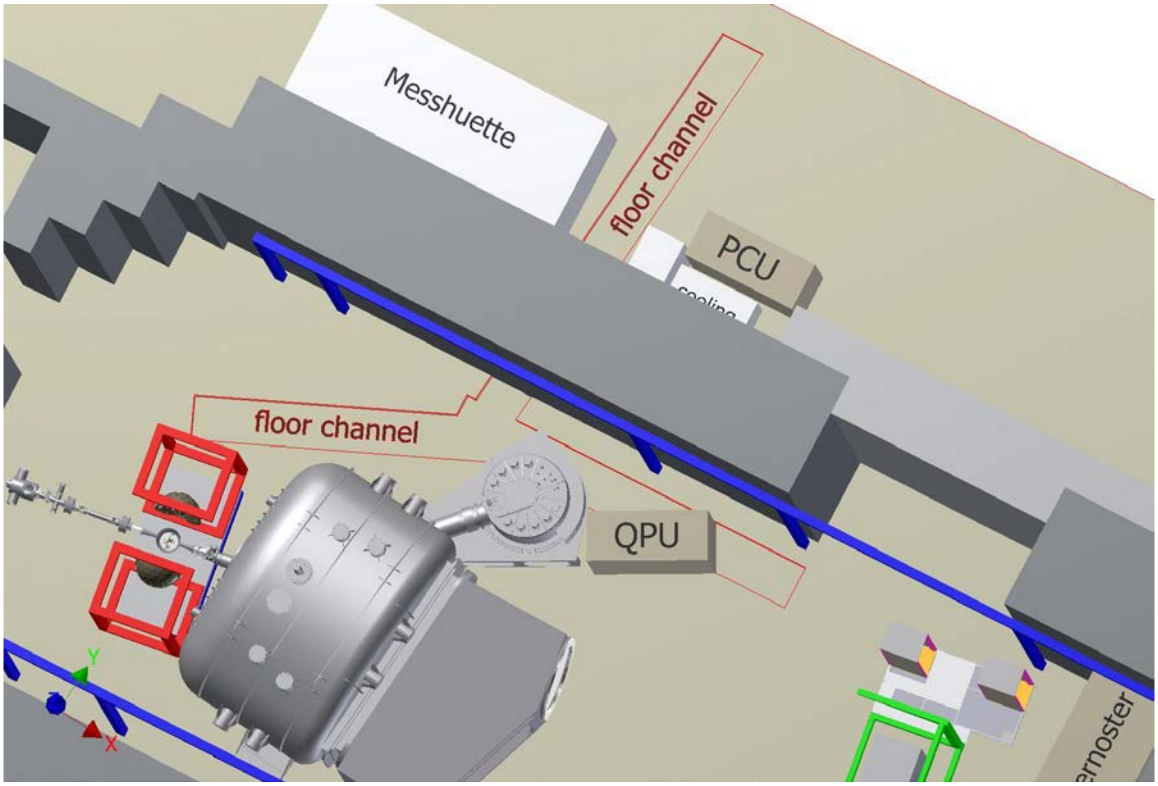

Figure 11 location of power converter system

I. Attached Documents

none

II. Related Documentation

[1] General Specifications v0.4 F-GS-B-01e

[2] Electrical Design Rules and Regulations F-TG-ET-02 01e

[3] Common Specifications on Power Converters F-CS-PC-01e

[4] F-TG-C-03e ACOS Interlock Interface

III. Document Information

III.1. Document History

Version	Date	Description	Author	Review / Approval
0.1	2013 03 21	Draft version	H.Welker	
1.0	2013 16 04	First version	H.Welker	
1.1	2013 26 04	First version	H.Welker	
1.2	2013 19 06	Final Version	H.Welker	