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Document Title:	Power Converters for the SIS100 Radiation Resistant Quadrupole Magnets
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Abstract

This document describes detailed specifications of power converters for Radiation Resistant Quadrupole magnets of SIS100 (Heavy-Ion Synchrotron 100).

PSP: 2.8.3.3.7.1

AID:0000618

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1. Purpose and classification of the document

This document describes technical requirements of the power converters dedicated to feed the Radiation Resistant Quadrupole magnets of SIS100 (Heavy-Ion Synchrotron) inside FAIR project.

General technical requirements for all the parts and components of the power converters are given in the Common Specifications for power converters [2]. General, legal and technical issues are given in the General Specifications [1] and technical guidelines “Electrical Design Rules and Regulations” [3], respectively.

However, statements made in this document override the ones 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 FAIR GmbH. Therefore, all further references to the term ‘the Company’ will refer to FAIR GmbH. The supplier of the equipment described in this document, hereinafter is referred to as ‘the Contractor’.

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2. Abbreviations, terms and Definitions

ACU	Adaptive Control Unit
CID	Component-ID (identification number)
CDR	Conceptual Design Review
DC	Direct Current
DCCT	DC Current Transformer
δI	Permissible deviation of the power converter output current
FAIR	Facility for Antiproton and Ion Research
FAIR GmbH	International GmbH under German law aiming to realize the FAIR project – acting as contracting body
FAT	Factory Acceptance Test
FDR	Final Design Review
Frame	19" rack IEC 297-3
FT	Freewheeling Thyristors. Antiparallel thyristors to freewheel the output of the PC.
gG	operating class / utilization category for melting fuses (see IEC 60269)
GSI	GSI Helmholtz-Zentrum für Schwerionenforschung
MFU	Multifunction module
MPS	Machine Protection System
PC	Power Converter
PSP	Project Structure Plan
RIB	Rare Isotope Beam
RR-Quad.	Radiation Resistant Quadrupole
SAT	Site Acceptance Test
SIS100	Heavy-Ion Synchrotron 100 (<i>Schwerionen Synchrotron 100</i>)
SM_x	Switch Mode_x
TSC	Temperature Stabilized Cabinet

Table 2-1: List of Abbreviations

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3. Scope of the technical System

3.1. System Overview

Heavy Ion Synchrotron SIS100 is an essential part of the new Antiproton and Ion Research Facility (FAIR) in Darmstadt. It will use the present accelerators of GSI (universal linear accelerator UNILAC and heavy-ion synchrotron SIS18) as an injector. The circumference of SIS100 is about 1090 meters; five times the circumference of the present SIS18.

The SIS100 is divided in 6 sectors. Each sector has 1 arc and 1 straight section.

Two normal-conducting Radiation Resistant Quadrupole magnets are needed in the extraction sector (sector 5) to replace the main superconducting quadrupole doublet due to high radiation levels in that area. These magnets will be ramped up to maximum field in a rather short time of 630 ms.

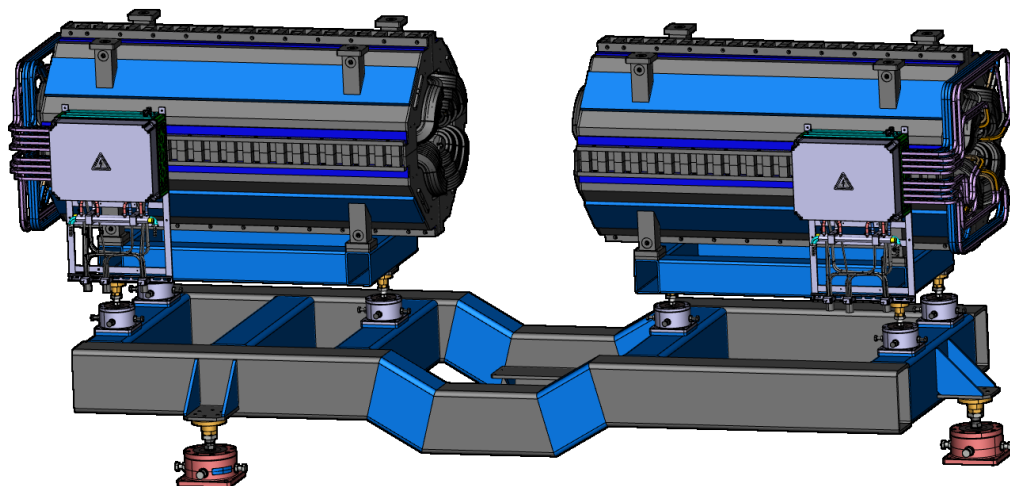


Figure 1: 3D-model of the two Radiation Resistant Quadrupole Magnets for SIS100

To feed the Radiation Resistant Quadrupole magnets, two ramped power converters capable of reaching a nominal current (I_N) of 850 A within a time of 0.630 s are needed. The maximum output voltage is of about 200 V.

3.2. Structure of Power Converters

Each power converter (PC) can be divided in two parts:

1. Power part

It is supplied by a 400V AC, 3-phase Pulsed Power supply system PP1/PP2 (Sec. 2.3 of [3]).

2. Control part

It is supplied by a 400V AC, 3-phase Common supply system C2 or C3 (Sec. 2.3 of [3]).

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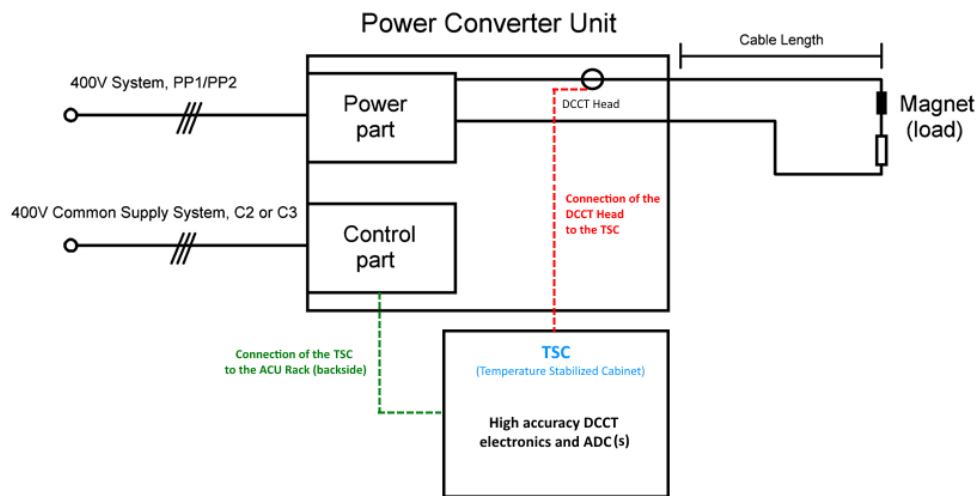


Figure 2: Power Converter Set-up

Table 4-1 gives the technical parameters for the power part. The design principles for the main components and functionalities of the power part can be found in Sec. 4 of [2] and 8.5 of [2].

Additional information is available in Sec. 8.5.13 of [2].

Each power converter shall supply the load through three coaxial power cables with 185 mm² each, connected in parallel. The technical parameters of the cables are given in Sec. 4.2. Due to the high radiation levels in Sector 5, last meters will be done with flexible water-cooled cables. An adaptor connection box will be located in the SIS100 tunnel.

From the standardization point of view, it is mandatory for the power converters (PCs) to be compatible with the ACU systems (user interface and control system) and the DCCTs (output current measurement systems), which will be provided by the Company.

One ACU system per PC must be integrated in the control part of each PC. The Company will support the Contractor by the integration of the ACU.

Further details can be found in Sec. 8.3 of [2], 8.4 of [2], [4] and in [7]. Please note that [7] is also valid for DCCTs here mentioned.

Contrary to the information in the aforementioned documents, given the high accuracy demands, all DCCT electronics (and the ADCs) will be installed in a separate temperature-stabilised cabinet (TSC). This will be done by the Company, including the provision of the TSC, cabling and the respective connection to the backside of the ACU Rack. However, these connections and the respective cable ways must be foreseen by the Contractor.

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3.3. Content of Delivery

The contractor has to deliver the following power converters:

Item №	PC Description	PC Type	PSP Code	№ of PCs
1	RR-Quad. PC	1S.Q3	2.8.3.3.7.1	2

Table 3-1: Type and PSP codes of the power converters to be delivered by the contractor

Provisions of the contractor:

- Design of the power converters listed in Table 3-1, including CDR and FDR (see Sec. 5.1);
- Manufacturing of the power converters listed in Table 3-1;
- Connectors for inputs and outputs of the interfaces listed in Sec. 3.5, (if not provided by the Company);
- Integration of the ACU systems, DCCTs and further provided electronics;
- Cable connectors and, the clamp and rack assembly (see Sec. 4.8 and [6]) for all load cables;
- Factory Acceptance Tests (FAT) for all assembled power converters (see Sec. 5.3.1);
- Packaging, shipment and unloading at FAIR;
- Internal transport, installation and assembly of the power converters at the final location;
- Site Acceptance Tests (SAT), for all assembled power converters listed in Table 3-1;
- Documentation (see Sec. 6);
- Spare parts as described in Sec. 3.4.

Provisions of the Company:

- The input and the output power cables, including installation and respective connection, as well as the connection boxes;
- External interlock (i.e. magnet interlocks) cables including respective installation and connection
- 1 Temperature Stabilized Cabinet for the DCCT electronics of both PCs;
- Water hoses and connection to the water system;
- 1 DCCT head¹ and the corresponding electronics (per PC) (Sec. 8.4 of [2]);
- 1 ACU system¹ (per PC) (Sec. 8.3 of [2]);
- 1 Interface Card¹ to connect the PC and the MPS (per PC).

¹ Components will be delivered to the contractor, by the Company, as per the schedule.

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3.4. Lifetime and Spare Parts

3.4.1. Spare Parts

At least the following spare parts are necessary (if present in the design):

Device Name	Quantity in relation to the total device number of the same type ²
Power semiconductors (rectifier diodes or thyristors)	25%
Power fuses	25%
Power semiconductors (IGBTs, FT thyristors)	25%
Power capacitors (DC-link, output filter)	5% or at least 1 device per PC
Contactors (main contactor, auxiliary contactors)	1 device per type
Water flow control meter	1 device per type
Line voltage monitoring	1 device per type
IGBT driver cards	15% or at least 2 devices per PC
Thyristor driver cards	15% or at least 2 devices per PC
Voltage sensor cards	5% or at least 1 device per PC
Current sensor cards	5% or at least 1 device per PC
Further electronic cards	5% or at least 1 device per PC
Control part fuses	5%

Table 3-2: List of spare parts

It is to be noted that if the components are assembled in stacks (e.g. IGBT/Thyristor stacks), at least one complete stack of each type with the corresponding mechanical, electrical and/or cooling components per system have to be provided, including the respective special tools (if needed) for servicing.

3.4.2. Lifetime of the components

The power converters must be designed to operate for 7250 hours (excluding natural degradation processes) per year for at least 25 years. The operating cycles and the respective portion of operating hours are given in Table 3- and Figure 3. Column "Fraction" in Table 3- represents the fraction of the operating or commissioning hours per year driven with the respective cycle.

Cycle	T _{bottom} [S]	T _{up} [S]	T _{top} [S]	T _{down} [S]	T _{total} [S]	Fraction
Triangular	0	0.5	0	0.5	1	0.1

² At least one piece of each device has to be delivered, if not stated otherwise.

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High intensity slow extraction	Short	1	0.5	2	0.5	4	0.2
	Intermediate	1	0.5	5	0.5	7	0.5
	Long	0	0.5	10	0.5	11	0.2

Table 3-3: Yearly operating and commissioning hours of the systems

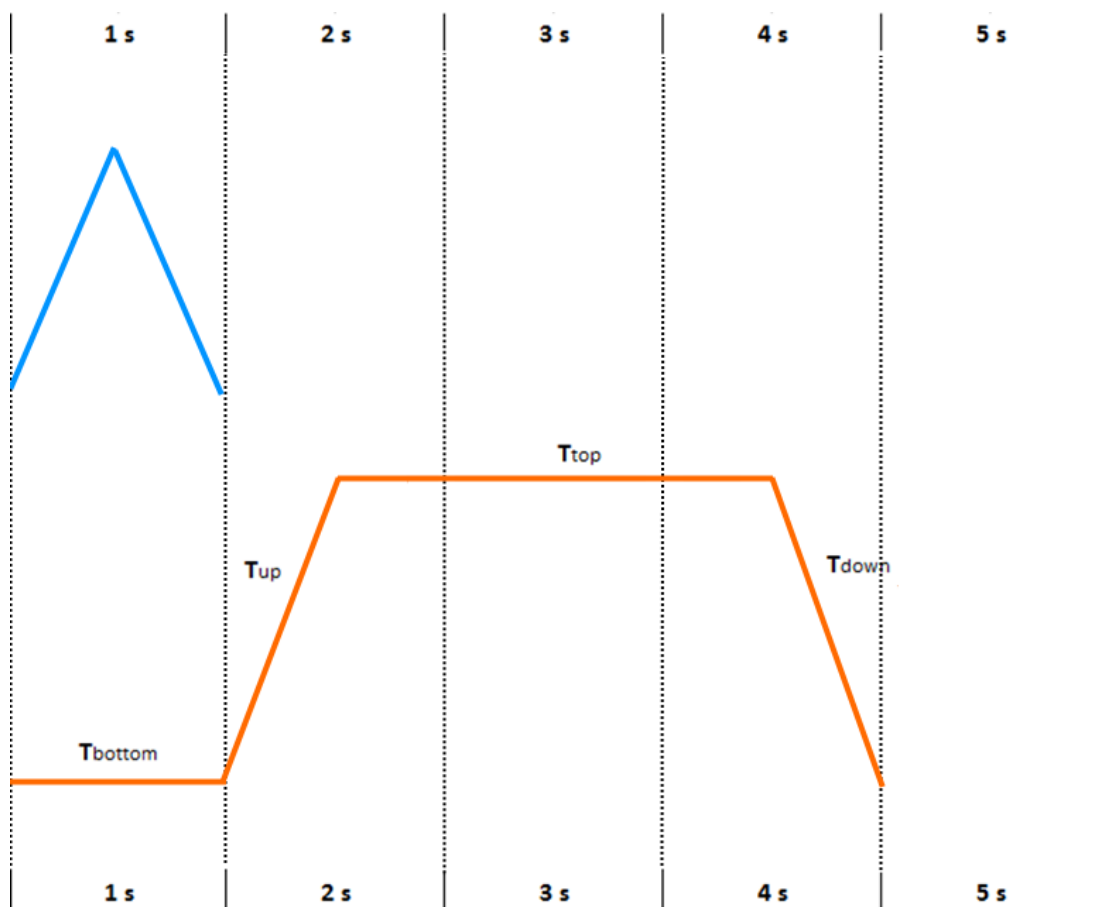


Figure 3: SIS100 Operation Cycles

3.5. Interfaces

Each power converter will have the following interfaces:

1. Electrical inputs for the electrical supply systems (see Sec. 3.2 and 4.8)
2. ACU system [local user and Accelerator Control System interface] (see Sec. 8.3, 8.4 of [2] and [7]);
3. Inputs for external interlocks (see Sec. 4.5);
4. Connection (inlet/outlet) to the water system (see Sec. 4.9);
5. Electrical outputs (see Sec. 4.2);

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6. Mechanical dimensions (interface to building, see Sec. 4.10);
7. Interface to MPS system (see Sec. 4.6);
8. Ground connection (see Sec. 4.4);
9. Connection to TSC (DCCT Electronics see also Sec. 3.2).

4. Technical Specification

4.1. Technical Parameter

PC type	1S.Q3
PC description	RR-Quad. PC
Maximum current, $I_{\max}$, A	935
Nominal current, I_N , A	850
Minimum current, $I_{\min}$, A	65
Range of load current, $I_{\min} \dots I_{LN}$, A	85 ... 850
Maximum current ramping rate, di/dt , A/s	± 1000
Minimum bending time, ms	50
№ of magnets in series	1
Resistance of the magnet, R_m , mOhm	90 ... 98,4
Inductance of the magnet (@ $I_{\min}$), L_m , mH	109
№ of cables in parallel	3
Cross section of each conductor, mm ²	185
Total resistance of the load cables, R_L , mΩ	7 ... 9.2
Maximum length of load cables, m	115

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Cycle frequency, f, Hz	2.15
Permissible total deviation in the range $[I_{Lmin} \dots I_{Lmax}]$, A relative: $\delta_I I (= \Delta I / I)$	$\pm 1 \times 10^{-4}$
Permissible total deviation in the range $[I_{min} \dots I_{Lmin}]$, mA	± 85
Max. cabinet dim. (W x D x H), m	2.4 x 0.8 x 2.2

Table 4-1: Technical Parameters

Beside the technical parameters of Table 4-1 the following aspects have to be considered:

1. The power converters must operate in Ramping mode and in DC mode (type A and C in Subsec. 8.1.3 of [2]). It is to be noted that the cycle frequency mentioned in Table 4-1 is calculated by assuming an extreme case, ramping up from 0A to I_N with no flat top and back to 0.
2. In DC mode, constant load currents up to I_{max} will be applied.
3. The permissible voltage ripple of the output voltage must be as per given in Section 8.2 of [2]. Additionally, the normalized voltage ripple during flattop ($U_{NFTripple}$) at any current level from 85 to 850 A (I_{FT}) must fulfil the following requirement (limits in Section 8.2 of [2] still valid):

$$U_{NFTripple}(f) \leq \pm I_{FT} \times 1 \times 10^{-5} \times 2\pi \times f_{min} \times L(I)$$

f_{min} – the smallest existing ripple frequency (depending on the power converter);

$U_{NFTripple}(f)$ – measured ripple amplitude of frequency f, normalized to f_{min} ;

$L(I)$ given in Table 4-2.

However, the aim is that the total ripple (amplitude of the sum of the different frequency components is not exceeding the tolerance given by the previous expression).

4. Variation of the magnet inductance due to the saturation effects are given in Table 4-2.

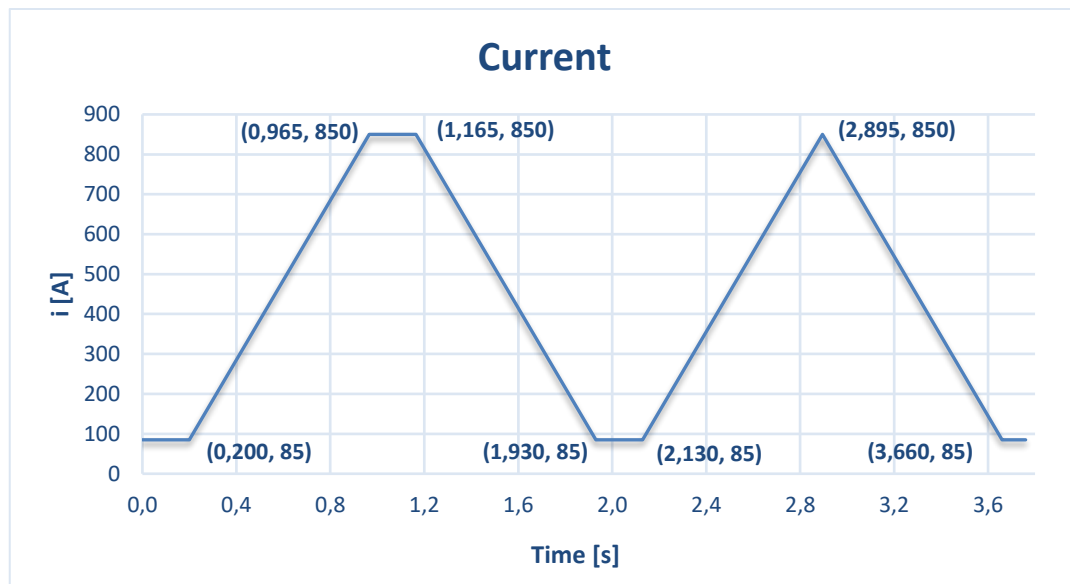
Current [A]	Inductance [mH]
12,6	108,79
135,5	107,14
434,0	106,72
521,8	107,57
562,7	103,67
603,7	101,85
633,0	101,06
662,2	97,13

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691,5	92,09
773,5	79,88
861,2	67,42

Table 4-2: Inductance change due to saturation of the magnets

5. The di/dt as well as the constant magnet inductance value specified in the Table 4.1 must be used to calculate the maximum necessary output voltage of the PCs.
6. In the load saturation region, in order to keep the magnetic field of the magnet constant, a higher di/dt of up to 1400 A/s is needed. This will not affect the maximum load voltage which must be calculated using di/dt and constant inductance value specified in Table 4-1.
7. An example of the PC output current profile can be seen in Figure 4 (without bendings).



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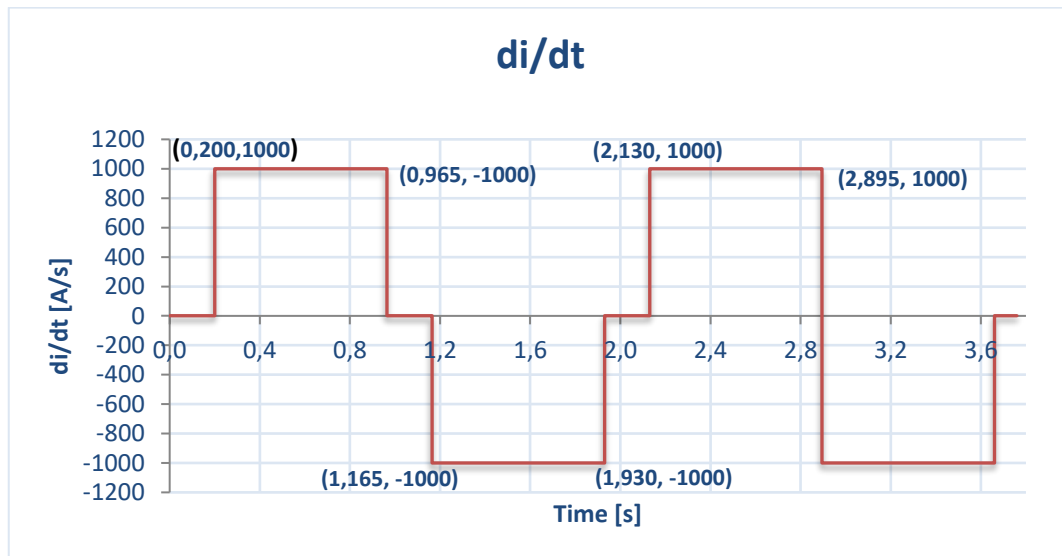


Figure 4: Example of a current profile needed for SIS100 RR-Quad magnets

8. The minimum bending time, mentioned in Table 4-1, is specified taking into account that the derivatives of the current set value, up to 2nd order will have no discontinuities. Additionally, load voltage set value will be available.
9. The power converters must be equipped with Free-wheeling Thyristors (FTs). In case of an interlock, the FTs must be activated simultaneously with the PC turn off. The current through the FTs must be monitored (for example using AC current transducers) in order to identify the respective malfunctioning.

4.2. Electrical Outputs

Three Coaxial cables will be used to connect the power converter output to the respective load. The cable dimensions are given in Table 4-1. Suitable output connectors to the used cable type must be provided and installed by the Contractor in the PC.

The principle of the connection of this type of cables is explained in [6].

A possibility to reverse the polarity of the power converter outputs without unscrewing cable terminals has to be foreseen.

4.3. Electrical Inputs (Power Part, Control Part)

As mentioned in Sec. 3.2, the power converter has to be equipped with two electrical inputs.

The input supply of the power part will be done using N2XCH 4x150/70 cable protected by a 630 A circuit breaker. The protection threshold values could be reduced down to 200 A.

The Input terminals for the control part must be equipped with terminals of 2.5mm² and the fuse rating in the low voltage distribution will be 16 A (B characteristic, see EN 60898).

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4.4. Grounding of the Power Converters

The power converters are usually grounded by the input cable. In addition to that they have to be connected to the equipotential bonding rail (copper bus bar) inside the false floor. Therefore, a connection point on the mounting plate (the plate where the switch mode circuit is located) to connect a copper braid have to be foreseen and accordingly marked. The size of the connector screw of the copper braid is M10.

Output terminals of the power converters shall be grounded as described in Sec. 8.5.14 of [2].

4.5. Interlocks

Most of the interlocks to be applied, are listed in Subsec. 8.5.10 of [2]. In addition to that, Beam interlock system (version 'A' in Subsec. 8.5.11 of [2]) have to be foreseen. Any additional interlocks necessary to protect the power converters must be identified and integrated by the Contractor.

The type of connectors needed for external interlocks is to be found in Subsec. 8.5.10 of [2]. The pin assignment is presented in Subsec. 4.3.2 of [4].

Due to the use of water cooled cables, an additional 12 pin connector for the monitoring of water flow and temperature is needed.

For additional information on the actions to be taken in case of an interlock, see Sec. 4.6.

4.6. Interaction of the PC with the MPS

The protection of the SIS100 machine is coordinated by the Machine Protection System (MPS). In case of a problem of an accelerator component, like power converter, MPS will, after receiving the information from the respective device, decide what should happen to the particle beam in order to avoid damages.

The PC shall interact with the MPS as shown in Figure 5.

An interface card to connect the PC and the MPS will be provided by the Company. In case of an interlock, this card will send the information from the Interlock Control Module of the PC to the MPS (see Figure 5).

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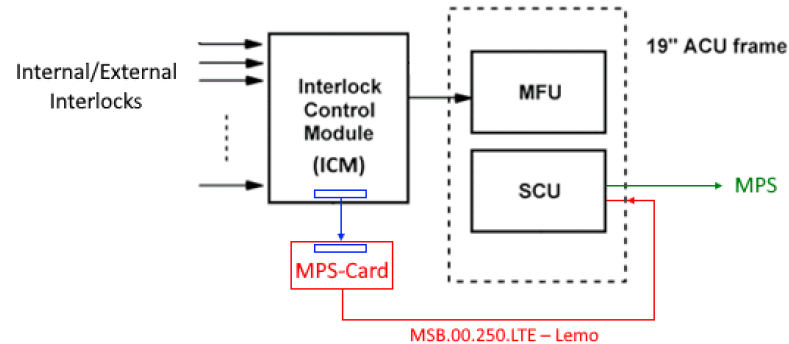


Figure 5: Action diagram during an interlock

The signal sent from the interface card to the MPS can be either optical or electrical. In any case it must be taken into account that an electrical signal cable (MSB.00.250.LTE – Lemo), which shall be provided and installed by the contractor, will be connected to the front panel of the ACU Frame (SCU card). This connection will be done by the Company. The integration of the interface card shall be done by the contractor.

The connection between ICM and MPS-Card must be done through the 34-pin plug X1 in Figure 6, using a ribbon cable. The output X3 is the trigger to the MPS.

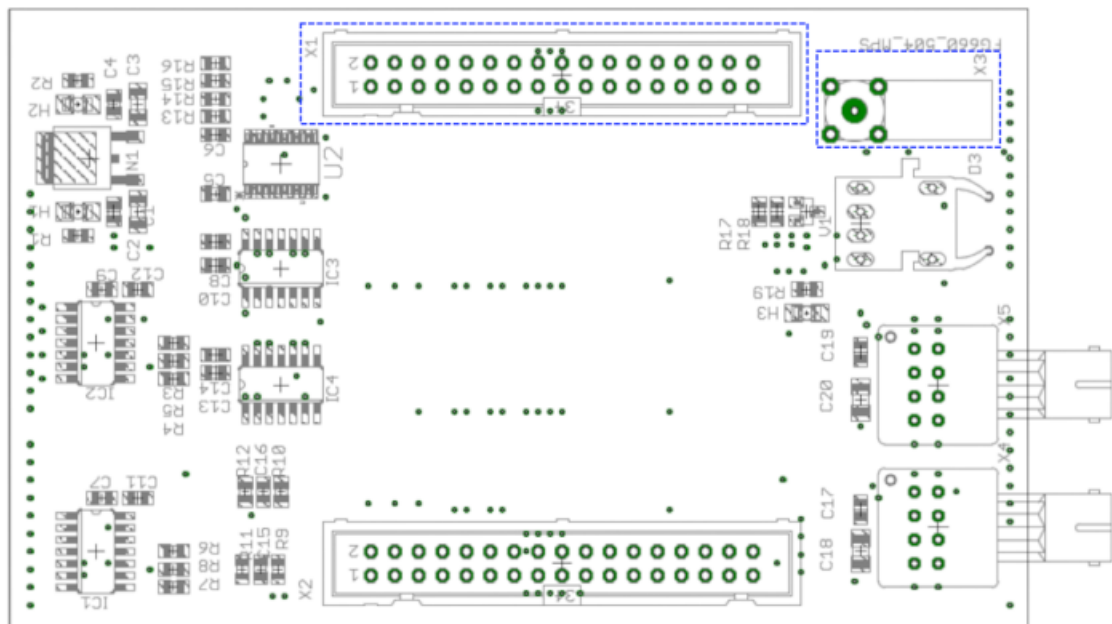


Figure 6: MPS Card

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4.7. Labelling of Power Converters

The labelling of the power converter has to be done according to Subsec. 8.5.8 of [2]. The reference to the document [8] in Subsec. 8.5.8 of [2] is replaced by [5] of this document. The CID numbers for the specified power converters are given in [8].

Additionally, a plate indicating the type and the number of the power converter has to be centrally placed on the front door where the user interface (ACU) is positioned.

4.8. Electrical Supply System

All the power parts of the power converters described in this document are going to be fed by the 20 kV/400 V transformer on the feeder PP1 or PP2 (Sec. 2.3 of [3]).

All the electrical interfaces for electronic parts are going to be fed by a 20kV/400V transformer in the common supply system feeder C2 or C3 (Sec. 2.3 in [3]).

4.9. System Environment and Constraints

All the environmental conditions and constraints that shall be considered, like water cooling system and mechanical properties of the installation location as well as the interactions of the power converters with the installation location environment, are described in Sec. 6.1 of [2], Sec. 6.2 of [2] and Sec. 7 of [2].

The dimensions of the maximum available installation space are given in Table 4-1.

4.10. Transportation of Power Converter

The transportation and installation of the produced power converters shall be performed taking into account Sec. 10 of [2].

Additionally, transportation within the Company will be assisted by the Company.

The packaging of the power converters has to be labelled with the cabinet name (to ensure their appropriate distribution to the respective places for testing).

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5. Quality Assurance, Procedures for Construction and Production

General design aspects, quality assurance and, tests and acceptance are specified in the General Specification [1] and in the Contract. Main and specific points for the systems specified in this document are listed below and they substitute what is mentioned in Sec. 9 of [2] and Sec. 9.1 of [2].

The realization process of the specified systems consists of the following phases:

- Design and preparation of the production:
 - Design;
 - Conceptual Design Review (CDR);
 - Creation of manufacturing documents;
 - Final Design Review (FDR).
- Production of the systems, FAT and shipping;
- Installation, commissioning and testing at the Company site (SAT).

Bi-weekly status reports are mandatory during all the phases. The deliverables of each phase and the corresponding rights will become property of the company.

Additionally, must be taking into account:

- The set of documents, listed in Sec. 11.1 of [2], have to be delivered during the tendering process;
- Oppositely to what is mentioned in [1], no pre-series prototype and the corresponding acceptance procedures will be done;
- The shipment of the power converter must be regulated and released by the Company.

5.1. Design Reviews

Conceptual Design Review (CDR) and Final Design Review (FDR) between the company and the Contractor shall be done to complete the “Design and preparation of the production” phase, mentioned in Sec. 5.

During CDR, design documents will be discussed. More in detail, the following information have to be provided:

1. Functional description of all the components;
2. Explanation of design criteria according to Sec. 8.5 of [2];
3. Technical data;
4. Block diagrams;
5. Manufacturer/type of all main components;
6. Description of interface (control interfaces and interfaces to the environment);
7. Simulation of the operation modes given in the corresponding detailed specification;
8. Drawings or preferably 3D-models of the outer physical configuration of the power converter (cabinet(s));
9. Draft version of the production plan;
10. Test concept to ensure testability during FAT and SAT;

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11. Definition of the critical components which are operated on the verge of or beyond to their specification limits;
12. Draft version of the Risk Assessment.

During FDR, additionally to the design documents, manufacturing documents will be discussed. More in detail, the following information have to be provided:

1. A description of the complete power converter;
2. Detailed specification of all main components (technical and mechanical data) (i.e. Cabinet, transformer, inductor, capacitor bank, arrangement of semiconductors, placement of DCCT-head);
3. Drawings or preferably 3D-models of the physical configuration of the complete power converter (components placement inside the cabinet);
4. Block diagrams and schematics of the control loops;
5. Complete schematics of all the electrical circuits;
6. Complete specification of all the interfaces (electrical, mechanical, building, media, software, etc.);
7. List of recommended spare parts;
8. Provision of design and production documents (production plan, quality plans, work instructions and test instructions);
9. Test plans and templates of test protocols for FAT and SAT;
10. Adjustment plan if necessary;
11. Draft version of the transportation specification (dimensions and weights with and without packaging).
12. Declaration of Conformity;
13. Risk assessment;
14. Draft version of the operating manual.

Draft versions of documents must be available at least 14 days before each design review respectively.

A formal acceptance given in written form by the Company after each review is mandatory. This means that the production of the documents for FDR shall start only after the CDR is complete and the respective design documents are accepted by the Company.

In general, design and manufacturing documents together contain all needed information to start the production without any further R&D activities.

5.2. Production of the systems

The production phase starts after successful completion of the FDR.

During this phase, the contractor shall fabricate the systems by implementing the production plans approved during the FDR (see Sec. 5.1).

No pre-series prototype shall be produced and approved.

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5.3. Tests and Acceptance

Concerning the details about the tests and acceptance refer to Sec. 9.2 and 9.3 of [2]. Additionally, consider the following points:

5.3.1. Factory Acceptance Test (FAT)

The FAT has to be performed according to the procedure described in Subsec. 9.2.1 of [2]. An inductive load is strongly recommended to be used.

Additionally, it is to be noted that the TSC will not be delivered to the Contractor for the FAT. To perform FAT, only the DCCT electronics (without temperature stabilization) will be delivered to the Contractor.

5.3.2. Site Acceptance Test (SAT)

SAT comprises of 3 parts (SAT Aa, SAT Ab and SAT Ba, see Sec. 9.3 of [2]). It will be performed by the Contractor at Company's site and must be approved by the Company. In addition, oppositely to what is mentioned in Section 9.3.1 of [2], during the SAT Ab, the passivating of the cooling system doesn't need to be done. SAT Ab only involves the scouring of the cooling system with de-ionised water.

6. Documentation

Concerning the details about the documentation refer Sec. 11 of [2]. According to 2006/42/EG, the assembly, operation or service manual has to be supplied by the contractor at least in German or preferably in English and German (in contrast to Sec. 11.2 of [2]).

7. Related Documents

- [1] General Specifications, F-GS-F-01e
- [2] Common Specifications on Power Converters, F-CS-PC-01e
- [3] Electrical Design Rules and Regulations, F-TG-ET-01e
- [4] Integration of ACU for switched mode Power Converters, F-TN-PC-01e
- [5] Component ID and Barcode System, F-TG-B-05e
- [6] Connection of the Coaxial power cables inside power converters, F-TN-PC-02e
- [7] DCCT class 3 Installation in Power Converters, F-TN-PC-0005e

8. Attached Documents

- [8] List_with_CID_numbers_for_F-DS-EPS-en-PC_0045_PCs_for_SIS100_RRQuad_Magnets