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The Large Hadron Collider Project

IT-2865/SL/EXP

Technical Specification

For the

Power part of two Thyristor Power Converters

rated 950 V, 6500 A

Abstract

This Technical Specification concerns the design, manufacture, conformity tests, delivery to CERN and documentation of the power part of two thyristor power converters with passive L-C filters rated at 6.2 MW, to be used in the ALICE and LHCb experiments.

Delivery is foreseen for the end of November 2002.

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Terms and Definitions

Term	Definition
CDD	CERN Drawing Directory
EDMS	Engineering Data Management System
QAP	Quality Assurance Plan

1. INTRODUCTION

1.1 Introduction to CERN

The European Organization for Nuclear Research (CERN) is an intergovernmental organization with 20 Member States*. It has its seat in Geneva but straddles the Swiss-French border. Its objective is to provide for collaboration among European States in the field of high energy particle physics research and to this end it designs, constructs and runs the necessary particle accelerators and the associated experimental areas.

At present more than 5000 physicists from research institutes world-wide use the CERN installations for their experiments.

1.2 Introduction to the LHC Accelerator and the Experiments

The Large Hadron Collider (LHC) is the next accelerator being constructed on the CERN site. The LHC collider will mainly accelerate protons to energies reaching 7 TeV and also heavy ions such as Pb. It will be installed in the existing ring tunnel of 27 km circumference, about 100 m underground, previously housing the Large Electron Positron Collider (LEP). The LHC machine will accelerate two beams of protons or heavy ions circulating in opposite direction to each other and collide them head-on in 4 large underground experimental areas. The LHC machine magnets, which guide the beams around the 27 km ring, are super-conducting twin-aperture magnets which operate in a super-fluid helium bath at 1.9 K.

Large experiments will be installed in the underground experimental halls at the 4 interaction points to identify and measure the trajectories and properties of all secondary particles created in the head-on collisions of the two beams. For this purpose very large powerful magnets are required to deviate the produced particles in strong magnetic fields. Two of these experiments, named ATLAS and CMS, will use big super-conducting toroids or solenoids for the particle analysis. The other two experiments, ALICE and LHCb, will employ resistive dipole magnets for the same purpose. In all cases, the magnets will be powered by DC power converters.

1.3 Subject of this technical specification

The power converters covered by this specification will be used to feed the dipole spectrometer magnets for the LHCb and ALICE experiments.

* CERN Member States are: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, The Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom.

2. SCOPE OF THE TENDER

2.1 Scope of the supply

This specification concerns the supply of the power part of two thyristor power converters with passive L-C filters rated at 6.2 MW.

A total compatibility with the existing CERN environment and infrastructure is required. Therefore, CERN will provide the high-precision DCCT (Direct Current Current Transformer) sub-systems and the high-precision control electronics.

2.2 Included in the supply

The following products and services shall be part of the supply :

- The design, manufacture and factory tests of the complete power part of two power converters.
- Spare parts
- Documentation and test results
- Delivery to CERN as defined in the Tender Form.

2.3 Items supplied by CERN

The following components will be supplied by CERN to the Contractor free of charge:

- High-precision DCCT
- Pulse transformers
- Burndy connectors.

The above items shall be mounted and cabled under the Contractor's responsibility.

The Contractor shall, at his cost, handle all customs and tax formalities for temporary import of the items (see Tender Form).

2.4 Items not included in the supply

The following products and services are not included in the supply, but will be provided by CERN at the time of installation on site :

- 18 kV main circuit breaker
- Main rectifier power transformers with their cubicles
- Pre-magnetising transformer
- Control and regulation sub-systems
- External cabling and connections to transformers, earth and load
- Commissioning on CERN site.

3. GENERAL CONDITIONS FOR TENDERING AND CONTRACTING

Please refer to the commercial bidding documents for complementary information.

Tenders will only be considered from firms having been selected as qualified Bidders by CERN, as a result of the Market Survey ref. MS-2865/SL. CERN reserves the right to disqualify any Bidder whose reply to this Market Survey is found to have been incorrect.

3.1 Test equipment

The Contractor shall have the necessary test equipment to fully confirm the performance as laid down in this specification.

3.2 Tender procedure

3.2.1 *Pre-tender discussions*

The Bidder is strongly encouraged to contact CERN and discuss details of this Technical Specification before making an offer. In particular, CERN wishes to ensure that no doubt exists as to the interpretation of this Technical Specification.

3.2.2 *Alternative solutions*

If the Bidder finds that any part of this Technical Specification is difficult, or costly to meet, he is free to propose an alternative solution, provided that the deviations from this Technical Specification, together with the reasons and advantages, are clearly indicated in the tender. Such alternative solutions shall always be made in addition to the basic offer, which must comply fully with this Technical Specification.

CERN reserves the right to accept or reject the proposed alternative solutions without justification.

3.2.3 *Preliminary programme*

The Bidder shall propose a preliminary design and manufacturing schedule with the tender, based on the specified CERN provisional delivery schedule.

3.2.4 *Subcontractors*

The Bidder shall declare in the tender documents any subcontractors whose services he intends to use in the event of a contract. Refer to the commercial bidding documents for more details. If awarded the contract, the Bidder shall restrict himself both to the subcontractors and the amount mentioned in the tender document. If, for some reason, he wants to change any subcontractor, or the scope of subcontracted work, or the amount subcontracted, he must obtain CERN's prior agreement in writing.

3.2.5 *Technical questionnaire*

The Technical Questionnaire attached to this Technical Specification shall be completely filled in and returned with the Tender Form, otherwise the tender will not be considered as complete and will be discarded.

3.2.6 *Presentation of tender*

The Bidder may be required to make a formal presentation of his tender at CERN at his own expense. He shall be ready to do so within a week of notification.

3.3 *Contract execution*

3.3.1 *Responsibility for design, components and performance*

The Contractor shall be responsible for the correct performance of all items supplied, irrespective of whether they have been chosen by the Contractor or suggested by CERN. CERN's approval of the design and component choice does not release the Contractor from his responsibilities in this respect.

CERN assumes responsibility for the performance of items and sub-systems supplied by CERN.

CERN reserves the right to make minor modifications to this Technical Specification before placing the contract. These minor changes shall not affect the contractual price that shall remain fixed.

3.3.2 *Contract follow-up*

3.3.2.1 *Contract engineer*

The Contractor shall assign an engineer to be responsible for the technical execution of the contract and its follow-up throughout the duration of the contract.

3.3.2.2 *Progress report*

The Contractor shall supply, within one month of notification of the contract, a written programme detailing the manufacturing and testing schedules. The programme shall include preliminary dates for inspections and tests.

A written progress report shall be sent to CERN every two months until completion of the contract.

3.3.2.3 *Design approval and production*

The detailed design shall be submitted to CERN for approval. CERN will give its approval or refusal, in writing, within one month. Component ordering and equipment manufacture shall not start without CERN's written prior agreement.

3.3.3 *Deviations from this Technical Specification*

If, after the contract is placed, the Contractor discovers that he has misinterpreted this Technical Specification, this will not be accepted as an excuse for deviation from it and the Contractor shall deliver equipment in conformity with this Technical Specification at no extra cost.

During execution of the contract, all deviations from this Technical Specification, the tender, or any other subsequent contractual agreement, proposed by the Contractor, shall be submitted to CERN in writing for approval.

CERN reserves the right to modify this Technical Specification during execution of the contract. The consequences of such modifications shall be mutually agreed between CERN and the Contractor.

3.4 Factory access

CERN and its representatives shall have free access during normal working hours to the manufacturing or assembly sites, including any subcontractor's premises, during the contract period. The place of manufacture, as stated in the Technical Questionnaire, may only be changed after written approval by CERN.

4. TECHNICAL REQUIREMENTS

4.1 General description

The power converter (6.5 kA, 950 V) consists of two 6-pulse rectifier/filter modules, connected in parallel. The bridges are fed from the 18 kV network through two dry rectifier power transformers phase-shifted 30° (see Fig. 1). These power transformers are not part of the supply.

A mechanical polarity-reversal switch shall be provided after the passive filter.

The relevant characteristics of the total load are :

- Inductance: 1 to 2 H
- Resistance.....: 120 to 150 mΩ
- Maximum stored magnetic energy at 6.5 kA: 42.3 MJ.

The converter cubicles will be placed on a false floor.

The passive L-C filter is slightly damped (damping provided by electronic means) and the resonance frequency is 32 Hz.

All components shall be adequately rated for continuous operation at all output power levels and under the worst case of incoming mains and environmental conditions.

Voltage withstand of all power parts shall be 4 kV r.m.s., 1 min.

No fuses are incorporated in the high-power circuit; consequently, all components, conductors and connections shall be rated and supported to withstand the forces resulting from a fault condition until the circuit-breaker opens.

CERN attaches great importance to a low acoustic noise level (see § 6.2.7).

The control and monitoring connections shall be wired up to socket connectors from which direct cable connections shall be provided to the electronics chassis.

4.2 Connection to the 18 kV network

The two power converter rectifier transformers will be fed from a CERN 18 kV circuit-breaker, which will be controlled directly by the CERN converter electronics.

The topology of the power converters is 12 pulses; the phase-shift between the thyristor bridges shall be 30°. This phase-shift shall be achieved by using 2 identical transformers with 15° extended delta on the primary (Dy11.5) and swapping phase S and T on the primary as well as the secondary.

The secondary square nominal line current will be 2652 A r.m.s.

The secondary no-load voltage, line-to-line at 18 kV r.m.s. input will be 900 V.

The short-circuit impedance will be ~7%.

4.3 400 V mains supply

A separate 400 V / 230 V / 3-phase +N supply will be used to feed the auxiliary power module, the pre-magnetising system, the polarity reversal switch, the fans and the DCCTs as shown in Fig. 2.

MF (Main Fuses), F1, F2 and F4 shall have a breaking current capability of 50 kA.

MF shall be an on-load switch with fuses.

MF, F4 and F1 with its four sockets (3x400V+N+E) shall be installed on an auxiliary panel in the electronics cubicle.

The fuse holder/isolators shall be equipped with a normally closed auxiliary contact opening when a fuse has ruptured or when the isolator is open.

4.4 Thyristor bridges

Two 6-pulse, fully controlled, thyristor bridges are used, connected in parallel. The thyristor shall be double side-cooled, mounted between heat sinks for forced air-cooling.

No fuses are permitted, either in the phase lines or in series with the semiconductor devices. Parallel or series connection of thyristors to form a branch is not allowed.

The heat sinks and the airflow shall be chosen such that at full output current the maximum junction temperature does not exceed 110°C with 40 °C ambient (see § 6.2.3).

The forced air for cooling shall be drawn through the doors, not from the false floor.

The minimum ratings of the thyristor shall be :

- Average current for 120° conduction.....: 1084 A
- Repetitive forward and reverse voltage: 3200 V
- Peak, one cycle, surge-current (ITSM) at 125°C, 10 ms
and 50% V_{rrm} reapplied.....: ≥ 54 kA
- Operating junction temperature: ≥ 125°C
- dV/dt: ≥ 1000 V/μs.

The thermal design shall take into account the ambient temperature rise due to the location of the thyristors in the cubicles and the overheating coming from warm busbars.

The easy and rapid replacement of a defect thyristor or a defect fan (access and extraction facilities) shall be taken into account when the design of the bridge and its power connections is being made. The replacement time for one thyristor or one fan shall be less than 15 min. A time test shall be made at the factory.

All motor fans shall be protected by a thermal protection. The fan control shall be cabled as shown in Fig. 2 & 8. The fans shall be switched on and switched off at the same time as the 18 kV Main Circuit Breaker.

400 V / 3-phase, low speed and low noise fans having a lifetime > 40.000 hours shall be used.

The Contractor shall install a protection system with redundancy which assures that the junction temperature never exceeds the manufacturer's published maximum (continuous operation) in any case (ambient temperature > 40 °C, over current or defective fan).

For thyristor specific tests, see § 9.1.6.

The protection system (normally closed contacts) shall withstand a dielectric test of 4.0 kV r.m.s., 50 Hz.

Connections to aluminium heat sinks shall be made in such a manner that for any maintenance intervention, the aluminium/copper connection does not need to be opened.

4.5 Pulse transformers

CERN will free-issue the pulse transformers to the Contractor. It will be his responsibility to mount these adjacent to the thyristors and connect them.

Mechanical layout, electrical circuit and pulse details for these pulse transformers are shown in Fig. 4. The Contractor shall verify that the chosen thyristor will operate satisfactorily with the CERN pulse transformers and the waveforms shown.

The primary series resistor $33 \Omega (\pm 10\%)$ 1.5 W wire wound type shall be supplied and mounted on the pulse transformer body by the Contractor.

The wires between pulse transformers and thyristors (gate/cathode) shall be twisted together and very short (< 30 cm).

4.6 Bridge free-wheel diodes

One naturally air-cooled free-wheel diode shall be connected across each thyristor bridge. Devices shall not be operated in parallel, nor in series.

The diode shall be thermally rated to sustain continuously 15% of the nominal DC bridge current, i.e. 500 A DC average with superimposed repetitive current peaks up to 1500 A. The reverse repetitive voltage of the diode shall be 3200 V. Its rated operating junction temperature shall be $\geq 150^\circ\text{C}$

The thermal design shall take into account the ambient temperature rise due to the location of the diodes in the cubicles and the overheating coming from warm busbars.

The heat sinks shall be chosen such that at 500 A DC continuously, the maximum junction temperature does not exceed 110°C (see § 6.2.3).

The heat sinks shall have sufficient thermal mass to discharge the stored energy of the load following a power converter switch-off (power cut) such that the junction temperatures of the diodes do not exceed the manufacturer's published maximum (continuous operation). The load time constant is 17 s.

The worst case current sequence for the free wheel diode is : 500 A DC current followed by a current step to 3250 A and an exponential current decrease to zero with a time constant of 17 s.

Non-magnetic thermostats shall be mounted on the heat sinks. The thermostats, normally closed contacts, shall open in case that the corresponding junction temperatures exceed 130°C . In case of load discharge, the thermostats shall inhibit switch-on of the power converter until a new discharge can be safely supported by the diodes.

For diode specific tests, see § 9.1.6.

The thermostats shall be in good thermal contact, but electrically isolated. The test voltage shall be 4.0 kV r.m.s., 50 Hz.

The easy and rapid replacement of a defect free wheel diode (access and extraction facilities) shall be taken into account at the design of the bridge. The replacement time for one diode shall be less than 15 min. A time test shall be made at the factory.

Connections to aluminium heat sinks shall be made in such a manner that for any maintenance intervention, the aluminium/copper connection does not need to be opened.

4.7 Suppression

Non-inductive resistor/capacitor networks shall be connected across the thyristors and free-wheel diodes, to protect them adequately against voltage transients. The semiconductor manufacturer shall give their value and rating. The connecting wires shall be very short and twisted together.

The transformer secondary suppressions, reservoir networks, shall be fed via the fuse holder FSNA and FSNB as shown in Fig. 8.

The following ratings are required :

- Minimum capacitor rated voltage : 3000 V
- Minimum capacitor value, C : 160 μ F
- Series resistance value, Rs : 1.1 Ω
- Series resistance peak current : 2500 A
- Discharge resistance value, Rd : 5 k Ω
- Diode bridge minimum rated voltage : 3200 V
- Diode bridge minimum repetitive surge current.... : 2500 A
- Fuse working voltage..... : 1500 V
- Fuse breaking current capability..... : 100 kA
- Suppression circuit withstand voltage : 4 kV.

It is essential that the parasitic inductance in the network is kept to a minimum. Consequently, non-inductive resistors shall be used for series resistors and wire lengths kept to a minimum.

The three-pole fuse holder/isolator rated at 1500 V shall be equipped with a normally closed contact opening when a fuse has ruptured or when the isolator is open. The fuses (1500 V) shall be rated to pass the peak charging current of the reservoir network.

For capacitors, the withstand-voltage from the two terminals to case shall be 4 kV r.m.s. 1 min. The metallic cases shall be connected to earth.

4.8 Passive filter

The passive filter consists of a double LC circuit with a damping factor of $z = 0.04$ and a resonant frequency of 32 Hz.

A damping factor of 0.5 will be achieved by appropriate electronic state feedback. However, the very low natural damping factor will occur in a fault condition.

The relation between the main, damped (C1) and the second, undamped capacitance (C2) shall be $C1 = 4 C2$:

$$f = \frac{1}{2\pi\sqrt{LC}} \text{ with } L = LA // LB \text{ and } C = C_1 + C_2$$

The total parasitic inductance per capacitor bank, including cabling, shall be such that the first parasitic resonance occurs above 1000 Hz.

The total parasitic resistance per capacitor bank, including cabling, shall be such that the first corner frequency is >1000 Hz.

CERN suggests LA = LB = 1 mH, C1 = 40 mF and C2 = 10 mF, but will accept to reduce the individual choke value down to 0.5 mH with C1 and C2 multiplied by the inverse factor to find a cheaper solution.

If the passive filter suggested by CERN is changed, the values in § 4.8.1, 4.8.2, 4.8.3 and 4.9 will be modified accordingly.

$$I_{C1\ rms} = \frac{0.0028 \times Un}{\sqrt{R^2 + \left(\frac{1}{C_1 \omega}\right)^2}} \quad I_{C2\ rms} = 0.0028 \times Un \times C_2 \omega$$

with Un = 950 V and $\omega = 3770$ rd/s (f = 600 Hz)

$$I_{C1\ fault\ rms} = \frac{Un}{\sqrt{2} \sqrt{R^2 + \left(\frac{1}{C_1 \omega}\right)^2}} \quad I_{C2\ fault\ rms} = \frac{Un}{\sqrt{2}} \times C_2 \omega$$

with Un = 950 V and $\omega = 201$ rd/s (f = 32 Hz filter oscillation frequency).

4.8.1 Filter choke (LA, LB)

The choke shall be natural air-cooled and rated to operate continuously under worst-case operating conditions. A double winding choke structure is required; one winding shall be inserted into each of the two DC lines of each bridge.

4.8.1.1 Choke Ratings (LA, LB)

The following ratings apply to the series configuration of the choke LA and LB (between **a** and **d** terminals with **b** and **c** linked):

- Mean DC current range0 - 3250 A
- Small signal total inductance at 300 Hz over the DC current range, series-connected windings.....1 mH (0, +20%)
- Minimum small signal inductance at 1.5 I_{max}0.5 mH
- Fault current (100 ms)50 kA
- Ripple voltage (pk-pk, 300 Hz).....1300 V
- Voltage withstand level, 50 Hz, 1 min.5 kV r.m.s.
- Maximum DC voltage drop at I_{max}5 V
- Individual branch inductance balance± 1% max
- Individual branch resistance balance± 1% max
- Cooling.....AN
- WindingsCopper conductors
- Insulation classB or better
- Insulation.....Complete vacuum impregnation
- Temperature rise by resistance measurement≤ 60 K
- Maximum hot spot temperatureAccording to insulation class.

The thermal design shall take into account the ambient temperature rise due to the location of the chokes in the cubicles and the overheating coming from warm busbars.

The chokes shall be able to withstand the specified fault current for 100 ms. No maintenance shall be required for the first ten such faults.

The tolerance (inductance and resistance) between LA and LB shall be $\leq 1\%$.

4.8.1.2 Core

The choke shall have a laminated core. Several symmetrically placed air gaps shall be used in the design.

4.8.1.3 Thermostats

Thermostats, normally closed contacts, opening according to the insulation class, shall be mounted at the measured hottest point of each coil and series connected. The thermostats shall be in good thermal contact, but electrically isolated. The test voltage shall be 4 kV r.m.s., 50 Hz.

4.8.1.4 Choke tests

The chokes shall be type and routine tested according to IEC-76 and 289 at their place of manufacture.

A heat run shall be performed on the first choke. Once thermal equilibrium has been reached, the temperature rise by resistance and the hotspots shall be measured.

Measurement of the small signal inductance at 0.1, 1.0 and 1.5 times the nominal DC current shall be part of the routine tests and the correct functioning and voltage withstand of the thermostats shall be verified.

4.8.2 Filter capacitors

Capacitor types composed of internally connected series elements or connection of individual capacitors in series is not permitted. Banks shall be composed of parallel connected capacitors. Failure of one capacitor in a bank shall not damage any other capacitor.

Discharge resistors, calculated for a discharge time constant of 30 s shall be connected across each sub-unit in a capacitor bank.

The total capacitor bank shall have the following rating :

- Type of dielectric paper, polypropylene or mixed
- Capacitance value C1 40 mF (0, +10%)
- Capacitance value C2 10 mF (0, +10%)
- Minimum rated working voltage 2000 V
- DC test voltage between terminals for 10 s 3000 V
- AC test voltage between terminals and case 4 kV r.m.s. 1 min
- Minimum rated r.m.s. current for C1 280 A
- Minimum rated r.m.s. current for C2 100 A
- Fault current r.m.s., 32 Hz, 1 s for C1 5400 A
- Fault current r.m.s., 32 Hz, 1 s for C2 1350 A
- Maximum series resistance including wiring ... 1 m Ω
- Operating life time at 50°C > 100'000 hours

- Individual can protection type.....pressure switch.

Pressure switches from each capacitor shall be wired according to Fig. 8, such that the failure of an individual capacitor, indicated by the pressure switch, shall result in switching off the power converter.

The capacitors shall be self-healing. The capacitor shall not contain PCB (Poly-Chlor-Biphenyl) or similar products.

Capacitor terminals shall be connected to fixed busbars with flexible connections.

Capacitor cases shall be connected to earth.

To minimise parasitic inductance, capacitor banks shall be split. Small banks shall be connected individually with twisted wires to main bus-bars. This design requires splitting the damping resistor. Final configuration shall be submitted to CERN for approval.

4.8.3 *Damping resistor*

The total resistance shall have a nominal value of 7 m Ω .

Individual value depends of the number of small banks for C1. CERN suggests a number between 5 and 10. Individual parasitic inductance with cabling shall be < 5 μ H.

The continuous and fault current ratings of the resistor shall be identical to those of the C1 capacitor. The resistor shall withstand the fault current for 1 s.

4.9 **Capacitors current measurement**

For measurement of the current in the damping circuit of the passive filter, capacitor C1 shall be equipped with a current measurement assembly (current transformer and burden resistor).

The total r.m.s. current in C1 bank is 280 A

The current measurement assembly shall measure the total r.m.s. current in C1. Just before the connection to the main DC bus-bar, all the small bank cables of C1 (positive side or negative side) shall go through the current transformer.

The assembly shall satisfy the following ratings :

- Nominal primary current..... : 280 A rms
- Ratio (r.m.s. burden voltage over primary current) : 5 V/280 A
- Range..... : 10 to 400 A
- Overload current (1s) : 5400 A
- Accuracy : $\pm 1\%$
- Bandwidth : 10 Hz - 5 kHz.

4.10 **Bridge current measurement**

For each bridge, one set of 3 AC current transformers (including the diode bridge and the burden resistor mounted on feedback PCBs) shall be supplied and connected as shown in Fig. 8, to provide the bridge current measurement.

The assembly (current transformer, diode bridge, burden resistors) shall satisfy the following ratings :

- Current transformers primary current (r.m.s.)..... $I_n = 2652$ A

- Current transformer max. secondary current (peak)..... : 1.0 A
- Ratio..... : 1 V/In
(DC burden resistor voltage over nominal bridge output current)
- Range : 20 – 4000 A
- Accuracy : $\pm 1\%$
- Bandwidth..... : 10 Hz to 5 kHz
- Admissible over-current for 1 s : 60 kA.

4.11 DCCT

To achieve the precision current measurement, CERN will supply 2 DCCT (Direct Current Current Transformer) heads per power converter, to be fitted by the Contractor in the upper part of the polarity reversal switch cubicle. The appropriate space, necessary for high precision results, shall be reserved. In this space, no other conductor carrying current is allowed. In addition, a symmetric current return shall be created to minimise parasitic fields as shown in Fig. 3. The busbar, through the DCCT heads, shall be round with a diameter of 90 mm and be short to minimise the temperature rise. The round busbar shall be demountable to allow exchange of the DCCT head.

4.12 Earth connection

The earth connection shall be made via a resistive/capacitive divider. See Fig. 1 and 8.

The component ratings of the divider shall be :

- C earth..... : 100 μ F, Working voltage ≥ 1000 V
- R earth..... : 100 Ω , $\pm 5\%$, ≥ 10 W
- R bal : 10 k Ω , $\pm 5\%$, ≥ 100 W.

All metal work such as choke cores, frames, panels, doors etc, shall be solidly connected to each cubicle earth. Each cubicle earth shall be an M12 stud. CERN will connect the cubicle earths to the building earthing system. An easily removable link shall be provided between the 100 Ω earth resistor and the earth stud to facilitate insulation testing.

The voltage across the 100 Ω resistor will be used for the earth fault detector, hence the resistor shall be adjustable.

4.13 Voltage measurement

All dividers for the voltage measurements shall be mounted on feedback PCBs, see Fig. 8. The overall precision of all voltage dividers shall be $\leq 1\%$. The complete dividers shall have a bandwidth of ≥ 10 kHz.

The wire lengths to the dividers shall be kept to a minimum. Therefore the hi-side (pick-up) resistors of the dividers shall be mounted as close as possible to the pick-up points. Whenever the pick-up point is a bus-bar, the pick-up resistor shall be mounted on the bus-bar. The pick-up resistors shall be : 100 k Ω , $\pm 5\%$, 30 W and working voltage ≥ 4 kV.

CERN reserves the possibility to connect one DC output terminal to earth instead of making a central earth. Therefore, all dividers for voltage measurements shall withstand continuously 1500V DC.

4.14 Monitor panel

The monitor panel (3U) shall be mounted towards the top of the door carrying the electronics (height \cong 1.8 m). The panel shall be alodine treated aluminium.

The instructions for the wiring are given in Fig. 8. The amperemeter will be connected by CERN.

The texts "ON" and "FAST STOP" shall be engraved on the panel.

The back of the front panel shall be protected under all circumstances against accidental contact.

The voltmeter and the amperemeter terminals shall be connected to a printed circuit board equipped with resistors and adjustment potentiometers.

The meters shall satisfy the following requirements :

- Minimum scale length.....: 100 mm
- Amperemeter resolution.....: 70 divisions (100 A / div.)
- Voltmeter resolution.....: 55 divisions (20 V / div.)
- Current for full scale deflection: 1 mA
- Maximum internal resistance: 60 Ω
- Precision.....: 1%
- Scale markings for amperemeter.....: 0, 1, 2, 3, 4, 5, 6, 7 kA
- Scale markings for voltmeter: 0, 200, 400, 600, 800, 1000 V.

For the amperemeters, the part of the scales between 6.0 kA and 6.5 kA, shall be marked with a dashed red zone and the part of the scales between 6.5 kA and 7 kA, shall be marked with a full red zone.

4.15 Pre-magnetising system

A pre-magnetising system shall be installed to avoid the inrush current of the power transformers.

The Contractor shall supply the pre-magnetising control (except the transformer) and its wiring as shown in Fig. 5.

The fuse holder F3 shall be installed in the thyristor bridge B cubicle. The unprotected wires between F3 and the bridge B input terminals shall be very short and cabled such that any contact between wires is impossible.

The three-pole fuse holder/isolator rated at 1500 V shall be equipped with a normally closed contact opening when a fuse has ruptured or when the isolator is open.

4.16 Polarity reversal switch

The polarity reversal switch shall satisfy the following requirements :

- Type: make-before-break
- Minimum continuous DC current: 7 kA

Insulation level..... : 4 kV r.m.s., 50 Hz.

The output polarity switch shall be equipped with non-mechanical (e.g. opto-electronic or proximity) position indication switches. The 3-phase 400 V motor shall be protected by a thermal overload protection. The polarity reversal switch control shall be cabled as shown in Fig. 6. It shall be possible to manually perform a polarity reversal. It shall also be possible to manually open the load circuit with the switch to perform a magnet insulation test.

4.17 Power connections

Sufficient space shall be left so that the input and output cables can easily enter the power converter base through the false floor.

The AC input copper terminals will receive 6 copper cables 240 mm² per phase for each bridge. Appropriate supporting facilities shall be provided. The cables shall enter the power converter from the false floor.

The DC output copper terminals will receive 14 aluminium cables of 630 mm² per pole. The cables will have bi-metal lugs. Appropriate supporting facilities shall be provided. The cables shall enter the power converter from the false floor.

4.18 Electronics connections

Connectors required for the interconnection between the electronics and the power sections will be issued free by CERN. The Contractor shall wire up the interconnection cables between the sockets in the power part and the electronics sections (see Fig. 8). Types and wiring shall be in accordance with the cable types used in the power parts.

The electronics cubicle shall house the CERN electronics made up of standard 19-inch units, with a maximum overall height of 35 U. The manufacturer shall make provision for the fitting of the electronics in the cutouts. The recessed support strip shall be drilled and tapped to accept 19-inch units along its entire height (35 U).

4.19 Mechanical construction and layout

The power converter shall be housed in indoor cubicles. The exact layout will be discussed with the Contractor.

The converter cubicles will be placed on a false floor constructed of 10 cm width I-profile beams with a grid interval of 90 cm.

Based on the suggested building layout of Fig. 7 and on the crane capacity, it is suggested to split the power converter in four cubicles.

- Crane capacity : 5 t
- Maximum cubicle height : 2.5 m.

A minimum 60 cm corridor shall be kept in the middle of the power converter to improve component accessibility.

The corridor shall have a floor, which shall be capable of supporting 150 kg/m².

The interconnections between the two bridges and the polarity reversal switch shall be made in the most symmetrical way to achieve a precise current sharing between

the bridges. The power connections inside the corridor shall be made close to the roof above 2 meters.

A duct shall be installed all along the corridor at the top to support auxiliary wiring.

All nuts etc. which are not easily accessible shall be adequately secured, e.g. captive nuts, fixed studs.

Each cubicle shall have a welded metal frame that supports all the equipment mounted in the cubicle. The frame shall be fitted with eyes located symmetrically around the centre of gravity for lifting of each individual cubicle by an overhead crane

The cubicles shall be equipped with doors on the perimeter of the assembled converter. The doors shall cover the full height of the cubicle. The width of the doors shall not exceed 800 mm.

A steel screen plate shall separate the power and electronics compartments.

In the electronics compartment, any part still having a voltage higher than 50 V shall be protected under all circumstances against accidental contact.

Each door shall be equipped with adequate earth straps and have one lockable handle. For reasons of standardisation a 7 mm female square lock shall be used

The complete enclosure (including corridor roof) shall have a protection degree corresponding to IEC 529, IP20.

4.20 Door interlock switches

Except for the electronics cubicle door, switches shall be mounted on the cubicles whose contacts open whenever a door is opened. These will be used to switch off the main circuit-breaker. However, the switch shall have an override facility allowing a specialist to disable this function. The override shall be reset by the closure of the door. CERN suggests BURGESS switch type DS3.

5. SERVICE CONDITIONS

5.1 General

The power converter shall be rated for continuous operation.

5.2 Ambient conditions

Altitude above sea-level.....300 m to 600 m
 Temperature variation (operation indoor).....+10°C to +40°C
 Temperature variation (storage).....-25°C to +50°C
 Relative humidity30% to 90%.

5.3 Mains Supply 400 V

Nominal value (3-phase with neutral).....400 V / 230 V r.m.s. 50 Hz
 Operating variations, permanent± 10%
 Mains transientsStep changes within the mains

tolerance

Phase imbalance..... ± 1.5%

Maximum total harmonic voltage-distortion 5% r.m.s.

Frequency variation ± 0.5%

Short-circuit power 5 MVA to 20 MVA

Peak mains surges..... 1200 V for 0.2 ms

Mains over-voltage 1.5 x nominal value for 10 ms.

Dips in the mains supply of up to 100 ms duration and varying amplitudes occur frequently during thunderstorms in one or more of the 3 phases.

6. ENGINEERING STANDARDS

6.1 Workmanship and materials

6.1.1 Materials

Materials used in the manufacture of the specified equipment shall be of the kind, composition and physical properties best suited to their various purposes and in accordance with the best engineering practices. In particular, insulating materials shall be self-extinguishing and not release any toxic or corrosive products when subjected to fire.

6.1.2 Workmanship standard

Workmanship shall be of the highest quality and conform to the best modern practice for the manufacture of high-grade machinery and electrical equipment. CERN will upon request give examples of the minimum acceptable level.

All work shall be performed by mechanics and electricians skilled in their various trades and holding relevant recognised national qualifications.

Auxiliary wiring and electronics assemblies shall conform to the Workmanship Standard Manual, Ray Skipp, 2nd Ed. (ISBN 0-632-02554-9) published by BSP Professional Books.

6.1.3 Metric system

The design, systems, parts and components shall be in accordance with the metric system.

6.1.4 Paint and anticorrosion treatment

All metal parts shall, unless non-corrosive, be surface treated against corrosion and painted with a primer before final colour.

Cubicle exterior	Finish	:	Spatter (leather)
	Colour	:	German standard RAL 5014 Pigeon blue
Cubicle interior	Finish	:	Smooth
	Colour	:	White

6.1.5 *Wiring and Colour codes*

The following international and CERN colour codes shall be used for all cabling, busbars and terminals :

R-phase	:	Orange	Neutral	:	Light blue
S-phase	:	Green	Earth	:	Yellow / Green
T-phase	:	Violet	Positive	:	Red
Non specified phase	:	Brown	Negative	:	Dark blue

The minimum cross-section for all wiring is 0.5 mm². Flexible multi-stranded wire, of at least 25 strands, shall be used. The ends shall be terminated by a crimped connection and clearly identified with the same code at both ends according to the circuit diagrams. Not more than 2 wires can terminate together on a screw-terminal.

All wiring shall be adequately supported and collected in harnesses, wherever appropriate. Main cable runs shall be housed in plastic cable channels.

All wiring and cables shall have halogen- and sulphur-free insulation and sheath. CERN can name possible suppliers on request.

Earth wire cross-sections shall be calculated considering prospective fault currents and respecting applicable norms. Nevertheless, earth wire cross-section shall always be greater than 2.5 mm² when mechanically protected and greater than 4 mm² otherwise.

6.1.6 *Busbars and connections*

All busbars shall be made of nickel-plated or tinned copper.

Connections to aluminium heat sinks shall be made in such a manner that for any maintenance intervention, the aluminium/copper connection does not need to be opened.

6.2 **Design principles**

6.2.1 *General*

Unless stated otherwise in this specification, the following design principles shall be used.

CERN attaches great importance to a design which is extremely reliable, requires a minimum of maintenance and enables easy replacement of faulty components.

All components shall be rated according to the worst-case design principle. All components shall have sufficiently high individual Mean Time Between Failure (MTBF) figures under the worst-case operating conditions in this specification, in order to reach an overall MTBF > 100'000 hours. Any supporting calculation shall be made according to MIL-HDBK217.

6.2.2 *Voltage rating*

Voltage rating of all components shall be chosen conservatively. In particular, components exposed directly to the mains input shall be rated, or adequately protected, to withstand main surges of three times nominal voltage.

6.2.3 Thermal design

The power dissipation in any component, under any foreseen service condition shall not exceed 50% of the rated power dissipation for the component. All power semiconductors shall be of the silicon type and derated such that the junction temperature does not exceed 110°C under any service condition. Busbars shall be designed with a maximum temperature rise of 30 K. The surface temperature of power resistors shall not exceed 150°C.

6.2.4 Cooling

The thyristors shall be forced air-cooled. The forced air for cooling the thyristors shall be drawn through the doors, not from the false floor.

All other components shall be natural air-cooled. The air for natural cooling shall be drawn from the false floor.

6.2.5 Mechanical layout

The layout shall be executed so as to minimise thermal stresses on all components, facilitate access to components for replacement and simplify inspection and maintenance. All power components shall be directly accessible and easily dismantled for repair.

6.2.6 Second source

All components shall be available from a second source independent from the one used by the Contractor. Any exception to this rule shall be submitted to CERN for approval.

6.2.7 Acoustic noise

CERN attaches great importance to a low acoustic noise level. The design shall minimise any noise emission. The Contractor shall guarantee that the sound level of the completed converter does not exceed 75 dBA at any point 1 metre from the cubicle with the doors closed and under any specified operating conditions.

In order to meet the above requirement it is recommended to apply the following :

- Cubicles shall be made of a heavy welded steel structure
- Chokes, thyristor bridges etc. shall be mounted on silent blocks and connected to fixed busbars with flexible connections to avoid vibration transmission. The silent blocks shall be locked for transport
- Low noise fans shall be chosen
- Adequate seals shall be mounted on the doors.

6.2.8 Rating plates

An easily visible rating plate shall be attached to the front of the equipment giving, in English or French, input and output electrical parameters, total mass, Contractor's serial number, year of manufacture, etc. Each magnetic component shall have a rating plate according to IEC.

At the top of the door carrying the electronics, a space of 3U height shall be reserved for a CERN identification panel.

6.2.9 Printed-circuits boards

The Contractor shall be responsible for the production and quality control of all unpopulated printed-circuits boards (PCB). CERN requires an electrical test of each circuit board. Marking with non-conducting material by a silk-screen process is required on both sides. The boards shall bear the manufacturer's special mark and the date of manufacture. All PCB documents shall be supplied.

6.3 Information and documentation management

6.3.1 General

All documentation, information, circuit diagrams and drawings shall be produced in MS Word and AUTOCAD format. One complete set of printed documents and 3½" diskettes with all files, shall be supplied to CERN with the equipment delivery.

6.3.2 Manufacturing drawings

The Contractor shall supply a complete set of drawings to CERN at the delivery. The drawings shall be neat and to a good professional standard. A complete set includes :

- mechanical construction drawings
- electrical power circuit diagrams
- auxiliary circuit diagrams
- wiring diagram
- complete parts list including details of all components, manufacturer, type number, second source manufacturer, etc.
- PCB layout drawings (Gerber file on diskettes).

If modifications are performed subsequently by the Contractor, new drawings shall be supplied free of charge.

6.3.3 Marking

Marking of components on the drawings shall correspond with those in the equipment. All wiring coding shall appear on the diagrams such that it is easy to follow the circuit on the drawings as well as in the equipment.

The mechanical drawings shall be executed with all dimensions marked according to the metric system.

7. APPLICABLE DOCUMENTS

Please refer to the Covering Letter for the complete list of documents attached to this Invitation to Tender.

7.1 Standards

The following standards, in order of priority, are applicable for the execution of the contract.

7.1.1 CERN standards

The equipment shall comply with the CERN Electrical Safety Code C1 issue 1990. Insulating materials and cables shall comply with CERN Safety Instruction N°23, Rev. 2 (included on the CERN CD-ROM).

7.1.2 International standards

Unless noted otherwise in this specification, all equipment and drawings shall comply with the relevant I.E.C. standards, recommendations and reports including the latest revision.

7.1.3 On site work regulations

If work is to be carried out on the CERN site, attention is drawn to the fact that CERN has specific rules concerning safety regulations applicable to works of Contractors at CERN, access to and activities on the CERN site, occupational health and safety on the Organization's site and special health and safety matters.

8. QUALITY ASSURANCE PROVISIONS

The Contractor shall plan, establish, implement and adhere to a documented quality assurance program that fulfils all the requirements described in this Technical Specification and drawn up according to the Quality Assurance Plan for the LHC Project.

The list of relevant topics covered by the LHC Quality Assurance Plan, together with the corresponding documents, is given in Table 1 below and available on the provided CD-ROM (Version 2.0).

Table 1 - LHC QAP topics and documents

Topic	Document Title	Doc. Number
Policy and Organisation	Quality Assurance Policy and Organisation	LHC-PM-QA-100.00
	Glossary, Acronyms, Abbreviations	LHC-PM-QA-203.00
Design	Quality Assurance Categories	LHC-PM-QA-201.00
	Drawing Management and Control	LHC-PM-QA-305.00
	Drawing Process-External Drawings	LHC-PM-QA-306.00
Manufacturing and Inspection	Manufacturing and Inspection of Equipment	LHC-PM-QA-309.00
	Handling of Non-conforming Equipment	LHC-PM-QA-310.00
	LHC Part Identification	LHC-PM-QA-206.00

9. TESTS

9.1 Tests to be carried out at the Contractor's premises

9.1.1 Quality control

The Contractor's quality system shall be equivalent to the requirements of ISO 9001.

9.1.2 Factory tests

The factory tests shall establish that the equipment completely fulfils the CERN specification. If the tests show that any part of the specification is not met, then the Contractor shall correct the fault and the tests shall be repeated at the Contractor's cost. The Contractor shall fully test the equipment in the factory, but CERN reserves the right to repeat any of the tests on the CERN site.

9.1.3 Completeness

Before factory tests commence, the equipment shall be complete and in a finished state. If modifications are necessary during factory tests, then all tests shall be repeated after the modifications have been completed.

9.1.4 Witness tests

CERN reserves the right to have a representative present to witness the factory tests of the completed equipment as well as of major subsystems. This right shall also apply to any subcontractor. The Contractor shall give at least 2 weeks notice to CERN of the proposed date for each test.

9.1.5 Test record

A test record with the individual test results shall be established for each complete unit as well as any major subsystem. Two copies of this record shall be delivered with the equipment.

9.1.6 *Semiconductor test*

1) **Thyristor test**

Specific tests before installation in the cubicles :

A heating test with junction temperature estimation from measurement shall be made at 1084 A DC with 40 °C ambient.

A protection system test shall be made.

- After temperature stabilisation at nominal current, the fans shall be switched off and the opening of the protection system will cut the test power supply. The junction temperatures shall be estimated from measurements. This test shall be repeated 3 times.
- After temperature stabilisation at nominal current, the current shall be increased by 30% until the opening of the protection system which will cut the test power supply. The junction temperatures shall be estimated from measurements. This test shall be repeated 3 times.

2) **Free-wheel diode test**

Specific tests before installation in the cubicles:

- A heating test with junction temperature estimation from measurements shall be made at 500 A DC with 40 °C ambient.
- Thermostat test : After temperature stabilisation at 500 A, the current shall be increased by 30% until the opening of the thermostat which will cut the test power supply. The junction temperature shall be estimated from measurements. This test shall be repeated 3 times.
- An equivalent worst case current test shall be made. At 500 A, after thermal stabilisation, a current step of 3250 A shall be applied for 17 s with 40 °C ambient. The junction temperature shall be estimated from measurement and shall not exceed the manufacturer's published maximum (continuous operation). This test shall be repeated 3 times.

9.1.7 *Power converter voltage withstand test*

For the voltage withstand test the following levels shall be applied :

Test Description	Level
Voltage withstand to earth of all power parts connected together. With : - earth link open - resistive dividers disconnected - all connector pins connected to earth - anode, cathode and gate of semiconductors connected together	4.0 kV r.m.s., 50 Hz, 1 minute
Insulation resistance 2.5 kV DC same conditions	>100 MΩ
Voltage withstand of all other circuits (including fan motors and Polarity Reversal Switch motors) with : - power part to earth	2.0 kV r.m.s., 50 Hz, 1 minute

9.1.8 *Power test*

CERN will supply a set of test electronics to control the converter during the factory tests. This comprises firing circuit and control devices so that the performance of

the power converter can be evaluated. CERN will instruct the Contractor on the operation of the test electronics whereafter he shall be responsible for keeping it in an operating state. In the event of failure of this electronics set CERN will attempt to repair or replace the faulty equipment within 10 working days of notification.

After the interlock test, the power tests will be carried out in 2 stages :

- 1) Nominal current test
- 2) Nominal voltage test.

A special 380 V 3-phase transformer of about 120 kVA will be sent by CERN to the Contractor. The main characteristics are :

- Configuration: D0, d11, d11
- Primary voltage (r.m.s. 50Hz).....: 380 V (-5%, +10%)
- Secondary 1 nominal line current (r.m.s. 50 Hz): 4400 A
 - Voltage line-to-line at full load (r.m.s. 50Hz).....: 15 V
- Secondary 2 nominal line current (r.m.s. 50Hz): 30 A
 - Voltage line-to-line at full load (r.m.s. 50 Hz).....: 880 V.

The transformer is thermally rated to support continuously one secondary line current at a time. It will be returned to CERN with the unit at the Contractor's expense.

1) **Nominal current test**

The secondary 1 of the test transformer is connected to the thyristor bridge A. The positive terminal is connected via the test DCCT to the negative terminal.

Under those conditions a heat run will be carried out until the power components have reached their continuous working temperature.

During these tests, temperatures of components throughout the equipment will be recorded. On completion of the test the power converter will be visually inspected and no damage must be evident.

The same test will be applied to the second bridge of the power converter.

2) **Nominal voltage test**

In this case, secondary 2 of the test transformer is used. A resistive load of about 40 Ω , 35 A is connected between the output terminals. The Contractor shall supply the resistor.

Under those conditions the bridge voltage will be increased to the maximum value and be maintained for two hours. During these tests, the temperature of the components throughout the equipment will be recorded. Precision of all voltage dividers will also be checked.

The same test will then be applied to the second bridge of the power converter.

9.2 **Tests to be carried out at CERN**

9.2.1 *Provisional acceptance*

Provisional acceptance tests will be carried out at CERN to establish that the equipment meets the specification and that no damage or changes have occurred during

transport. A representative of the Contractor is not required for these tests but may be present.

In the event of any errors found during the provisional acceptance test, the Contractor shall correct them immediately at his cost at CERN.

Provisional acceptance will only be granted after successful tests and approval of the documentation.

9.2.2 Final acceptance

Final acceptance shall take place at the end of the two-year guarantee period (Art. 16, General Conditions of CERN Contracts, FC/1814-II), during which time the equipment shall fully meet the CERN specification. In the event of doubt CERN reserves the right to repeat the provisional acceptance tests. Any deviations from the specification shall be corrected immediately at CERN at the Contractor's cost.

10. DELIVERY AND COMMISSIONING

10.1 Delivery schedule

CERN shall be informed in writing of the date of delivery at least five days in advance.

The equipment shall be delivered to the CERN, Prévessin Site (France).

The following stages apply :	Maximum allowed time
Design report (mechanical, electrical, cooling, etc.)	2 months
CERN approval	1 month
Factory construction	8 months
Factory tests and modifications	1 month

10.2 Packing and transport to CERN

The Contractor is responsible for the packing and the transport to CERN. He shall ensure that the equipment is delivered to CERN without damage and any possible deterioration in performance due to transport conditions.

10.3 Commissioning

The equipment will be commissioned by CERN.

10.4 Purchase options

CERN reserves the right to purchase additional power converters according to this specification after the initial order. See tender form.

10.5 Compulsory spare parts

The Contractor shall include in his offer the price for a set of compulsory spare parts with their unit prices. The set of spare parts shall contain the following items :

- One complete six-pulse thyristor bridge with heat sinks and fans

- Six thyristors without heat sink
- One free-wheel diode with heat sink
- Two free-wheel diodes without heat sink
- Four fans
- One filter choke
- 20% of C1 and C2 filter capacitor banks
- One damping resistor
- five door switches
- One complete polarity reversal switch with two additional position indicator switches
- Two R/C suppression circuits
- One complete transformer secondary suppression with fuse holder
- Ten suppression fuses
- Three current transformers (bridge current measurement)
- One current transformer (capacitor current measurement)
- One voltmeter
- One amperemeter
- Four pick-up resistors : 100 k Ω , \pm 5 % , 30 W
- Two PCBs of each type with mounted components.

10.6 Recommended spare parts

The Contractor shall give a list of additional recommended spare parts with their unit prices. The prices shall be fixed for orders placed within the contractual guarantee period. See Tender Form.

11. PERSONS TECHNICALLY RESPONSIBLE AT CERN

Name	Tel & Fax	Email
Roger GENAND	Tel: 00 41 22 767 65 96 Fax: 00 41 22 767 53 00	Roger.Genand@cern.ch
In case of absence: André BEURET	Tel: 00 41 22 767 41 10 Fax: 00 41 22 767 53 00	Andre.Beuret@cern.ch

Annex A: List of Drawings

Fig. 1 : Power Converter Configuration

Fig. 2 : Auxiliary Supply

Fig. 3 : DCCTs Assembly

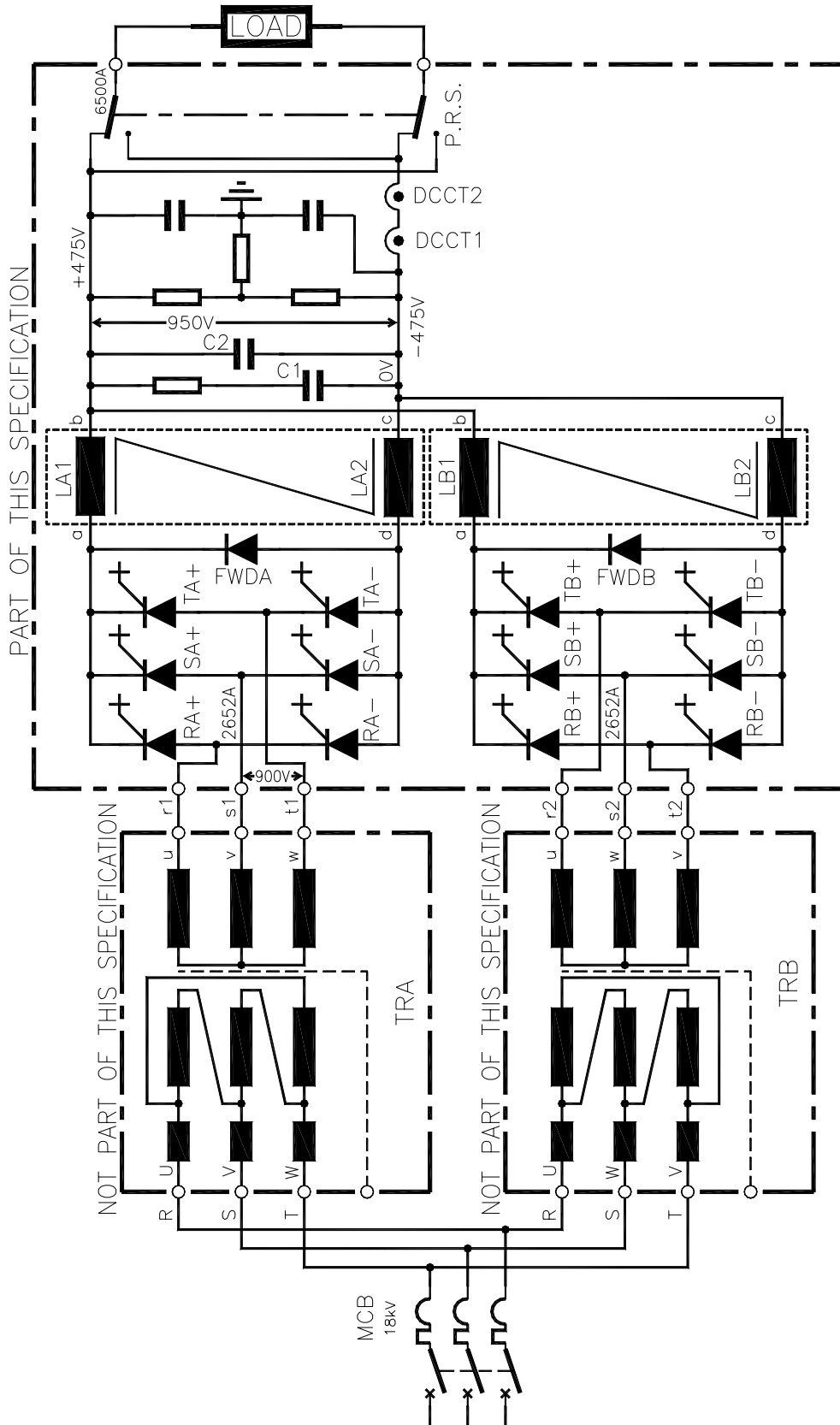
Fig. 4 : Pulse Transformer Details

Fig. 5 : Pre-magnetising control

Fig. 6 : Polarity Reversal Switch Control

Fig. 7 : General Layout

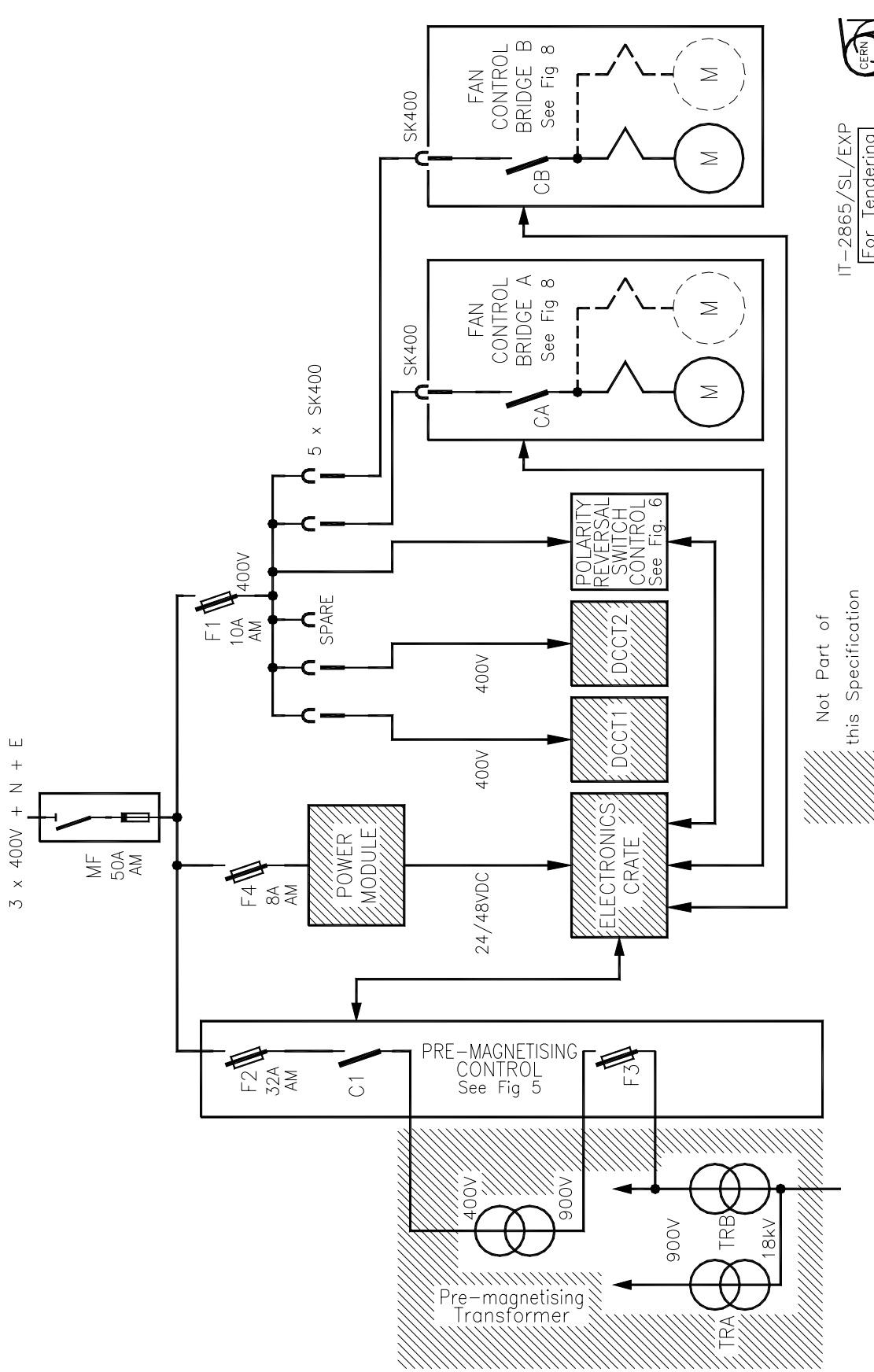
Fig. 8 : General Circuit Diagram



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Fig. 1 POWER CONVERTER CONFIGURATION



Not Part of
this Specification

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Fig. 2 AUXILIARY SUPPLY

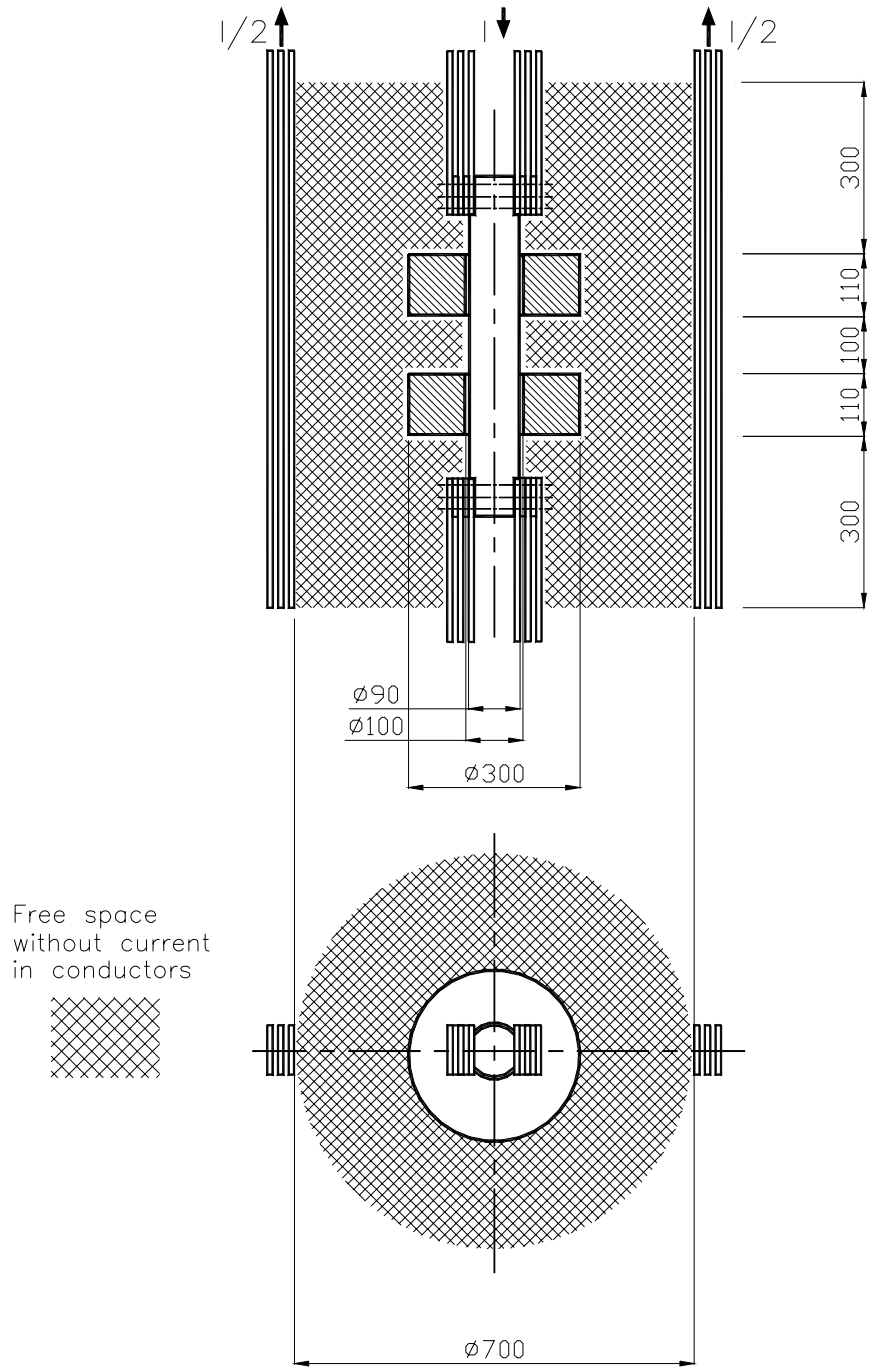


Fig. 3 DCCTS ASSEMBLY

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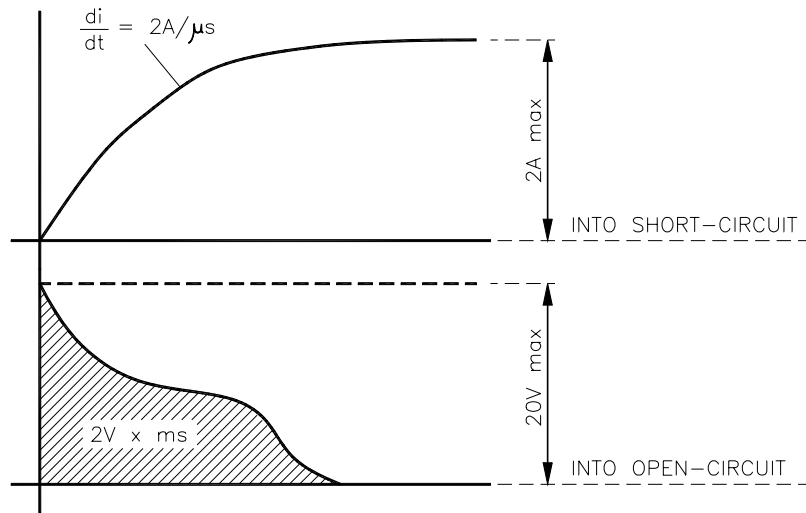
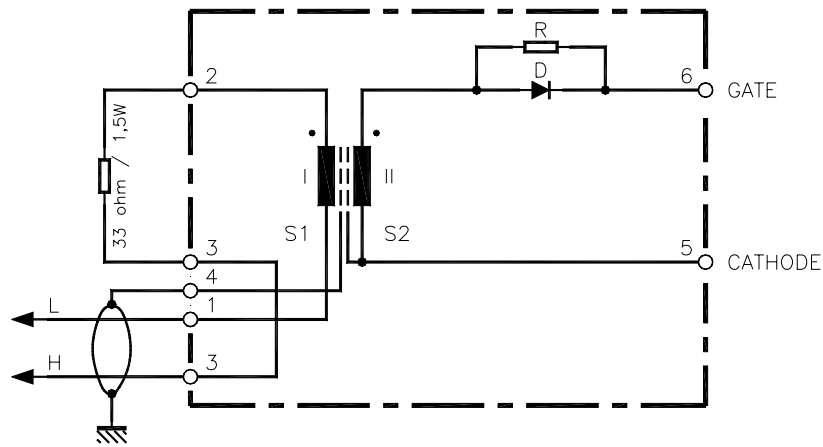
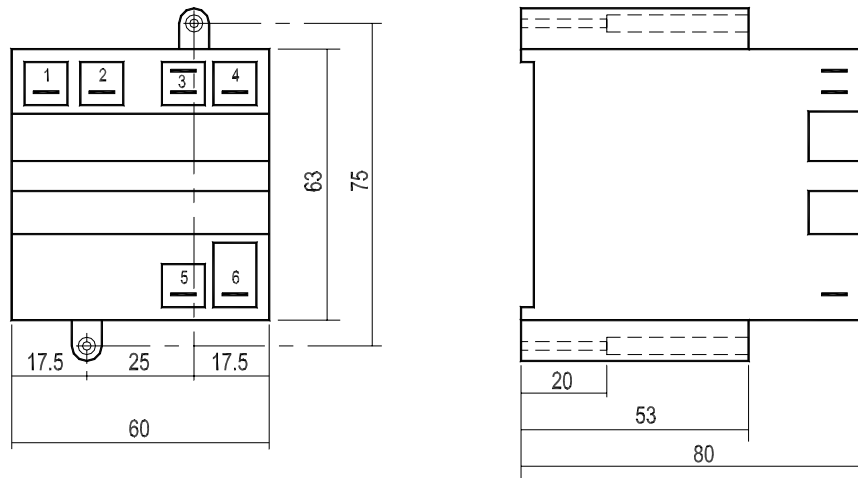
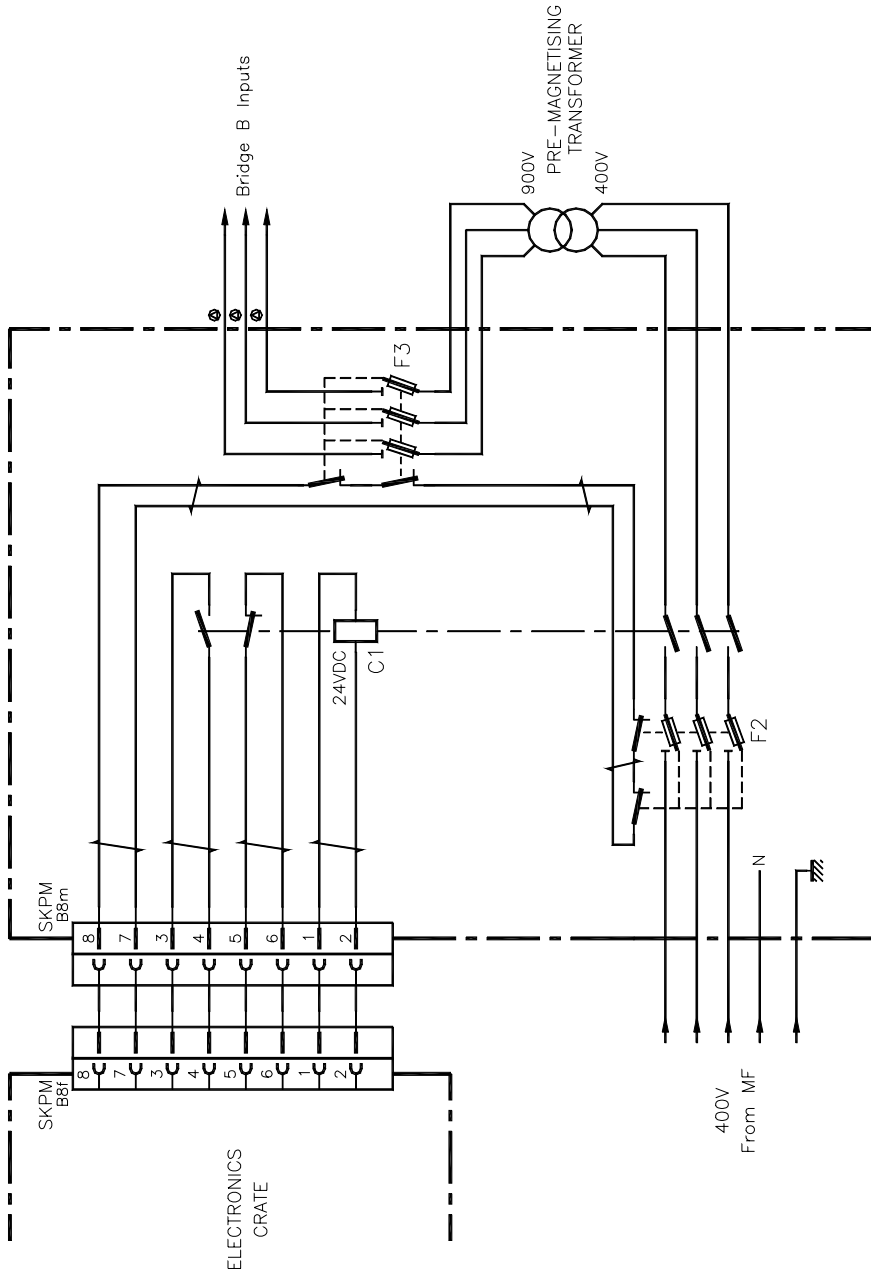


Fig. 4 PULSE TRANSFORMER DETAILS

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⚡ = UNPROTECTED WIRING - KEEP VERY SHORT!!!

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Fig. 5 PRE-MAGNETISING CONTROL

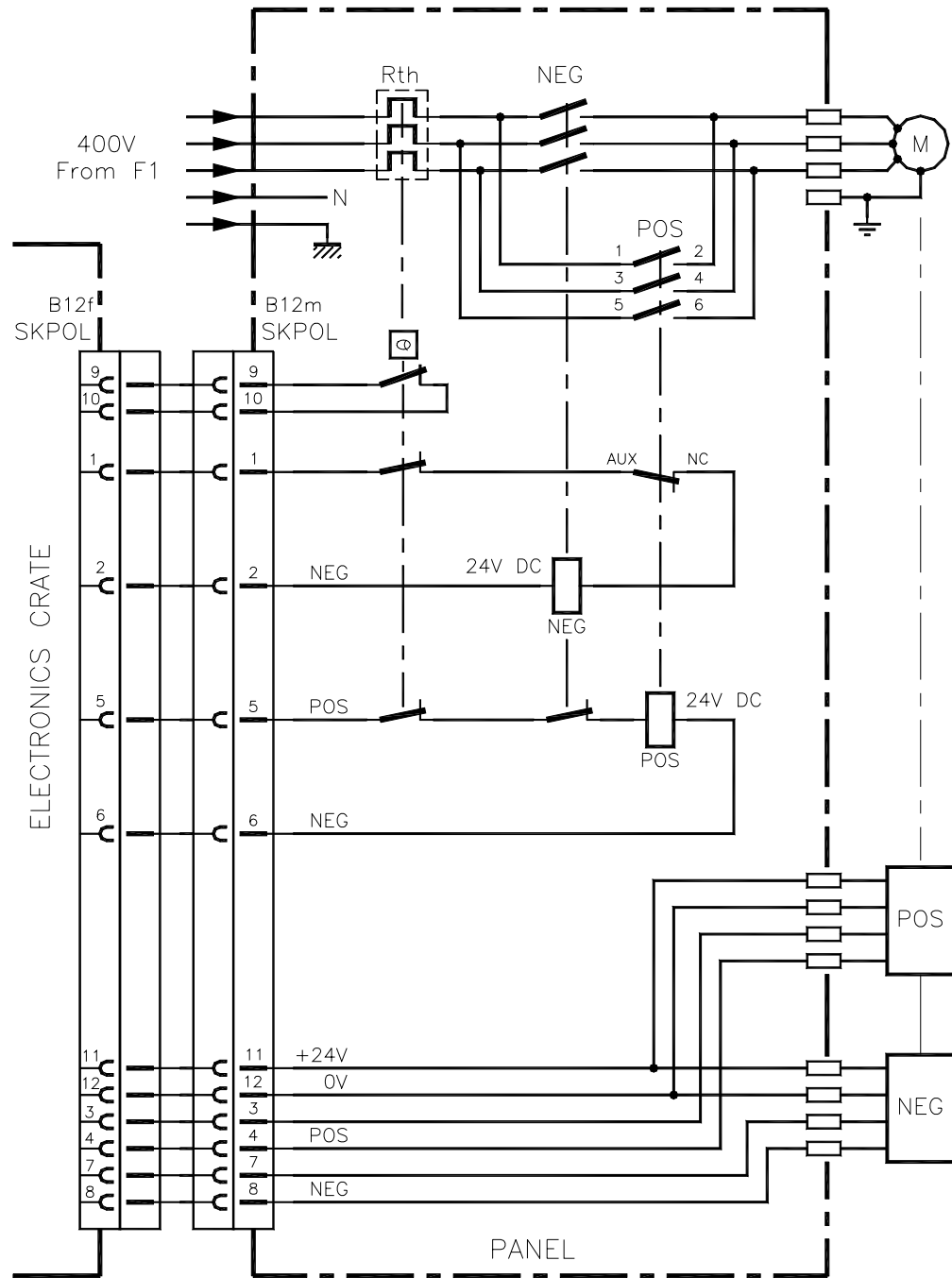


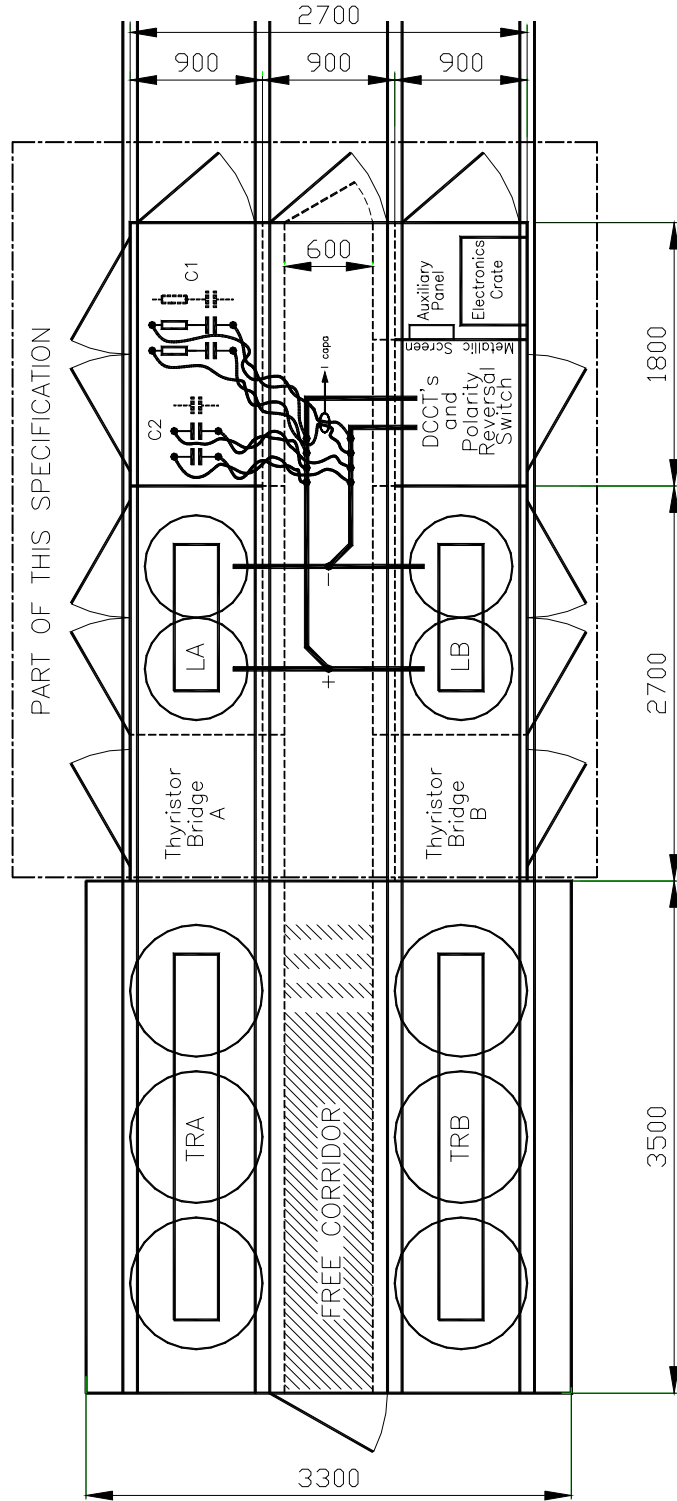
Fig. 6 POLARITY REVERSAL SWITCH CONTROL

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Fig. 7 GENERAL LAYOUT

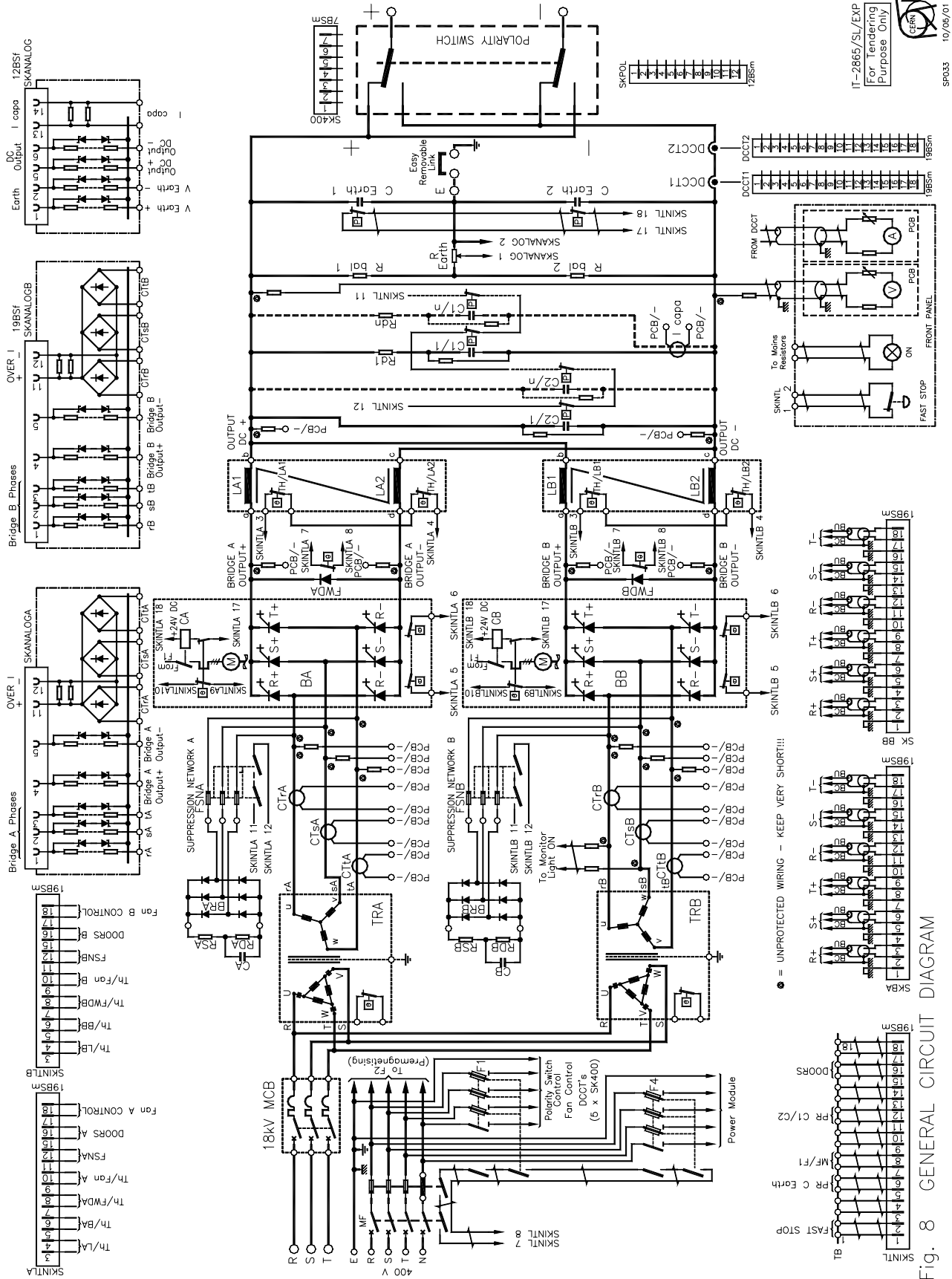


Fig. 8 GENERAL CIRCUIT DIAGRAM

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