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TECHNICAL SPECIFICATION

POWER CONVERTERS FOR THE CLARA LINEAR ACCELERATOR (PHASE 1 - FRONT END)

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Abstract

The Compact Linear Accelerator for Research and Applications (CLARA), a dedicated facility for research into free-electron lasers (FELs), is planned at STFC's Daresbury Laboratory. This document lays out the specification for the beamline magnets for the CLARA Front End. 4 solenoid, 2 dipole and 8 quadrupole magnet power converters are required.

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1. INTRODUCTION AND SCOPE

1.1 Introduction

The Accelerator Science and Technology Centre (ASTeC) at STFC Daresbury Laboratory is currently designing a new FEL test facility, CLARA – the Compact Linear Accelerator for Research and Applications. The facility will be used for research into efficient FEL schemes to produce ultra-short pulses of high-brightness coherent light. The electron beamline will transport an electron beam from the 5 MeV gun through a series of linacs accelerating the beam to a final energy of 250 MeV. The maximum energy in the front end is 60 MeV. The CLARA Conceptual Design Report (CDR) was published in July 2013 and can be found on the ASTeC website. http://www.stfc.ac.uk/ASTeC/resources/PDF/CLARA_CDRv2.pdf.

1.2 Scope

This specification covers the procurement of a mixture of unipolar and bipolar power converters for the CLARA Front End. A total of 14 power converters are required of which 5 shall be bipolar (quadrupole type 1). Quadrupole type 1 is required to be bipolar as magnets of this type will be used at times in a scanning mode where the current has to be run smoothly through zero from one polarity to the other.

All magnets will require their polarity to be reversed from time to time for de-gaussing purposes. This involves setting the current alternately positive and negative at reducing levels until any remanent field in the magnet core is removed.

This can be accomplished either by having bipolar power converters or by using polarity reversing switches with unipolar power converters. Therefore for all power converter types, other than quadrupole type 1, suppliers are invited to offer bipolar power converters where available (Option 1) or polarity reversing switches (Option 2). In addition Suppliers re requested to quote for earth-fault protection as an option. See section 8 for pricing options.

The Supplier shall furnish complete power converters and shall include:

- Operation and maintenance manuals
- Testing and inspection documentation
- Quality Assurance / Quality Control documentation
- Delivery to STFC Daresbury Laboratory, UK
- Rack mounting kits for mounting the power converters in standard 19 inch racks (if required)
- Mating connectors for the control interfaces (where not readily available)

As a separate option Suppliers are invited to quote for the 7 power converters required for phase 2 of CLARA. At this stage the voltage and current requirements are provisional but it is expected that the final figures will be available within 3 months of contract award. Details of contractual arrangements will be agreed at the time of contract award if STFC decides to take up this option. The delivery date for phase 2 will be several months later than that required for phase 1

2. PERFORMANCE REQUIREMENTS

2.1 Current and Voltage Ratings – Phase 1 Power Converters

14 individual power converters are required to feed 4 solenoid, 2 dipole and 8 quadrupole magnets. The output specifications of these power converters are listed in Table 1.

Magnet type	Number of Power Converters	Rated Voltage[2] V	Rated Current[2] A	Inductance mH
Gun Main Solenoid	1	38.0	330.0	TBA
Gun Bucking Solenoid	1	11.4	350.0	TBA
Linac 1 Solenoid	2	34.0	264.0	TBA
Dipole type 1	1	17.0	126.7	TBA
Dipole type 2	1	34.7	198.0	TBA
Quadrupole type 1[1]	5	±35.0	±58.1	TBA
Quadrupole type 2	3	50.0	204.4	TBA
Total	14			

Table 1: Power converter requirements for Phase 1 solenoid, dipole and quadrupole magnets

Note 1: Quadrupole type 1 power converter is bipolar

Note 2: In determining the power converter ratings operational headroom of 10% and a voltage drop of typically 3V along the length of the cables have been allowed. The Supplier does not need to add further headroom.

The manufacturer is free to propose means of reducing the number of power converter current and voltage rating combinations.

The ratings of all components in this equipment shall be continuous ratings.

2.2 Current and Voltage Ratings – Phase 2 Power Converters (option)

7 individual power converters are required to feed one series connected dipole magnet string and 6 quadrupole magnets. The output specifications of these power converters are listed in Table 2.

Magnet type	Number of Power Converters	Rated Voltage[2] V	Rated Current[2] A	Inductance mH
Dipole type 3	1	50.0	250.0	TBA
Quadrupole type 3	6	±15	±100	TBA
Total	7			

Table 2: Power converter requirements for Phase 2 dipole and quadrupole magnets

Note 1: Quadrupole type 3 power converter is bipolar

Note 2: In determining the power converter ratings operational headroom of 10% and a voltage drop of typically 3V along the length of the cables have been allowed. The Supplier does not need to add further headroom. Ratings are provisional pending final design data.

The manufacturer is free to propose means of reducing the number of power converter current and voltage rating combinations.

The ratings of all components in this equipment shall be continuous ratings.

To maximise the available resolution it is preferred that the power converter current rating meets or is only a little higher than the current rating specified for the magnet. Suppliers able to offer current ratings no more than 20% above the specified value will be given additional credit in the tender assessment.

2.3 Technical parameters

The technical parameters listed in sections 2.4 to 2.11 should be entered in Table 4 by the Supplier for each power converter type offered. Copies of the table, duly completed, should be returned with the Tender.

2.4 Operating range

The converter shall be adjustable from 0 to 100% of maximum rated current output for the normal magnet load. This is particularly important to ensure that operation of any polarity reversing switches can occur at zero current. Power converters should exhibit no evidence of oscillation over their entire operating range into the anticipated loads.

2.5 Stability and temperature coefficient

The range of variation of output current over a period of 8 hours with no changes in operating conditions should be a maximum of 50 ppm of the figures listed in Table 1. A range of 20 ppm is desirable and Suppliers able to meet this level will be given additional credit in the tender assessment. The Supplier is invited to supply stability test data over an 8 hour period with line and load voltage and temperature constant.

The output current temperature coefficient shall be a maximum of 15 ppm/ºC. The Supplier is requested to specify the temperature coefficient of stability and to supply stability test data showing the effects of ambient temperature variations. Suppliers able to offer an improved temperature coefficient of 10 ppm/ºC or better will be given additional credit in the tender assessment.

2.6 Accuracy

The long term setting or measuring uncertainty taking into consideration the full range of permissible changes in operating and environmental conditions over one year without any re-calibration. It is accepted that some re-calibration may be required in normal operation to maintain the required accuracy. This should be a maximum of ±200 ppm.

2.7 Reproducibility

The uncertainty in returning to a set current value with the same reference following an interruption of up to 24 hours with all electronics turned off should be a maximum of 50 ppm. Suppliers able to offer an improved level of 25 ppm or better will be given additional credit in the tender assessment.

2.8 Programming resolution

The programming resolution should be a maximum of 15 ppm. This is the smallest interval in output current that can be set using the programming interface. Suppliers able to offer an improved level of 10 ppm or better will be given additional credit in the tender assessment.

2.9 Power Factor

The power factor should be a minimum of 0.92 at 100% load. Suppliers are requested to provide the power factor at 50% and 100% load. Suppliers able to offer an improved level of 0.95 or better at 100% load will be given additional credit in the tender assessment.

2.10 Ripple

The current ripple into a 1 mH inductive load should meet the requirements listed in Table 3.

Suppliers should state the worst case voltage ripple and corresponding frequency.

Frequency range	**Maximum Current Ripple (peak to peak) relative to power converter rated current (1 mH load)**
1 Hz < f < 20 kHz	25 ppm

Table 3: Voltage ripple requirements

Suppliers able to offer an improved level of 10 ppm or better will be given additional credit in the tender assessment.

2.11 Efficiency

Efficiency should be a minimum of 85% at nominal mains input voltage and full rated load. Suppliers should quote the efficiency for each power converter type at 100% and 50% load. Suppliers able to offer an improved level of 92% or better at 100% load will be given additional credit in the tender assessment.

2.12 Warm-up Period

The supplier shall state the warm-up period required to achieve the required stability for each power converter type. This should be no more than 60 minutes. Suppliers able to offer an improved level of 30 minutes or better will be given additional credit in the tender assessment.

2.13 Input Supply

A single mains feed will be provided to each power converter. This will be either a single phase supply at 230V 50Hz and/or a three-phase supply at 400V 50Hz.

Line voltage may exhibit instantaneous (< ½ cycle) fluctuations of ±3% and gradual variations of ±10%. The maximum output ratings and performance parameters shall be maintained over these limits.

2.14 Duty cycle

The power converter shall be designed and constructed for continuous use. There will be occasional opportunities to clean or replace certain parts such as fans or filters.

2.15 Spares and consumables

The supplier should list consumable items such as fans and filters which may need regular replacement. A list of available spare parts should also be provided.

2.16 Fault Vulnerability

The power converter should be designed to withstand all foreseeable fault conditions without damage including:

- short-circuit on the output terminals when running at full load
- short-circuit on the output when switching on

- open circuit on the output terminals when running at full load
- failure of any internal component should not cause damage to other components
- loss of one phase or, if applicable, all three phases of the mains power input

2.17 Power Converter Cooling

All power converters shall be air-cooled.

2.18 Front panel display and Indicators

Each power converter should be equipped with a front panel display and appropriate LED indicators which should show as a minimum:

- Output voltage and current
- Interlock status
- Power converter status (e.g. ON, OFF, FAULT)

2.19 Earth-Fault Protection

Suppliers are requested to offer earth-fault protection for each power converter as an option. The system should trip the power converter if the earth current exceeds a pre-set, and preferably user-adjustable, level. Operation of the earth fault protection should be indicated on the front panel.

2.20 Load Over-voltage protection

The power converter should be protected against any over-voltages which may be generated due to the inductive magnet load, for example by fitting a free-wheel diode across the power converter output. If this protection trips the power converter then remote reset shall be possible via the control system.

2.21 Power Converter Specification Summary

Power Converter type(s):			
Parameter	Specification	Power Converter Value	Unit
Stability, 8 hours (range)	≤ 50		ppm
Stability, temp. coefficient	≤ 15		ppm/°C
Current rating	Table 1		A
Reproducibility	≤ 50		ppm
Programming resolution	≤ 15		ppm
Power factor: at 100% load at 50% load	≥ 0.92		
Current ripple: 1 Hz < f < 20 kHz Worst case ripple: Worst case ripple frequency:	≤ 25		ppm pk-pk ppm pk-pk Hz

Efficiency:	100% load 50% load	≥ 85		% %
Warm-up period		≤ 60		minutes

Table 4: Power Converter Specification summary

3. POLARITY REVERSING SWITCHES

3.1 Function of Reversing Switches

For the unipolar power converters STFC is considering the use of polarity reversing switches to enable the magnets to be de-gaussed. This involves setting the magnet current to zero, reversing the polarity and raising the current. Usually this is repeated for several cycles at reducing current until any remanent field in the magnet core is removed.

3.2 Construction

Reversing switches shall be designed to be installed into 19" rack mounting enclosures. LED indicators should be provided on the front panel to indicate the polarity of the switch and power on.

Suitable connectors or busbars shall be provided at the rear of the switch enclosure to connect to the power converter and to the outgoing circuit.

The reversing switches should preferably be powered from 230V ac mains via a connector at the rear. Alternatively they may take power from the associated power converter. Control connectors shall be provided as required to control the switch and to provide indication back to the main control system as to the polarity setting. This should be via volt-free contacts which will connect to 24Vdc to provide inputs to the control PLC. Alternatively the reversing switch can be controlled via the power converter in which case the control may be via the power converter serial interface.

It is desirable for the switches to have internal current detection circuits to prevent operation when the current is not at approximately zero. Suppliers who can offer this will be given additional credit in the tender assessment.

Reversing switches shall be air-cooled.

4. CONTROL SYSTEM

4.1 Function of Control System

The System Operators will control all the power converters from the Main Control Room, which is remote from the power converters themselves.

The control interface must be comprehensive, providing all necessary information to remotely monitor and control the equipment during normal operation and under fault conditions.

The control system consists of embedded EPICS computers and PLCs at the interface layer which connect to the equipment being controlled. The interfaces will include digital, serial communications (RS232/422/485) and Ethernet.

4.2 External Interface

The power converter shall have facilities to control and read back the output current and to monitor and diagnose faults to the control system. The power converter should have fully digital control via either Ethernet or RS-232/422/485. This will provide a command set to monitor and control all states of the power

converter. The communication protocol should be capable of operating at a rate of >10 command/response pairs per second. It should be able to recover automatically from lost characters or other transmission errors. In addition, a simple human-readable (plain ASCII) protocol is preferred.

4.3 External Interface Standards

All digital interface signals, (control, monitor and interlocks) should be designed to be failsafe. A safe state should normally be indicated by a closed contact providing a +24V signal or volt-free contacts. On power failure the system should indicate an unsafe state.

4.4 External Interlocks

A minimum of two interlocks shall be provided which disable the power converter output. The power converter control system will monitor this interlock which will be operated from external volt-free contacts to indicate conditions such as magnet over-temperature and magnet cooling water flow failure.

5. TESTING

5.1 Factory Tests

The supplier shall detail the tests that will be applied to each power converter at the factory before shipping and should supply copies of these test results. As STFC may wish to witness some or all of the factory tests the supplier shall give a minimum of 3 weeks' notice of the date of such tests.

5.2 Tests at Daresbury Laboratory

STFC may subject each power converter to some or all of the following tests. Any power converter whose results differ significantly from this specification or typical values for that type of power converter may be rejected. This testing may include:

- Control functions
- Interlock functions
- Isolation testing
- Thermal run
- 8 hour stability run
- Resolution check
- Accuracy check
- Reproducibility check
- Visual inspection
- Ripple voltage/current measurement
- Efficiency test
- Mains regulation tests
- Accessibility assessment
- External connections evaluation
- Diagnostics facilities and ease of repair

6. ENGINEERING REQUIREMENTS

6.1 Mechanical Requirements

6.1.1 Manufacturing good practice

The equipment should be manufactured in accordance with the best existing techniques and recognised good engineering practices available at the time of construction. Power converters and reversing switches should be designed and constructed with an expected operational lifetime of greater than 20 years. It is understood that maintenance may be required during this period. Sub-assemblies should be designed for repair rather than replacement.

6.1.2 General access convenience

Power converters and reversing switches should be manufactured with strong consideration for unit reliability and serviceability. Safe and easy access to all external connection points must be incorporated into the overall design.

Easy access should be made available to all components, especially solid state power components, fuses, and printed circuit boards. For smaller power converters where complete replacement may be the appropriate response to a fault the supplier should offer a repair service.

6.1.3 Equipment housing enclosure

All equipment shall be capable of being housed in a standard 19" rack mount enclosure.

Each power converter will be contained within an enclosure to IP2X (IEC Standard 529 Classification of degrees of protection provided by enclosures). Enclosure covers should only be removable with the use of tools. Following the removal of covers to allow access to the internal components, any high voltage conductor (greater than 25 Vac or 60V dc) should be shielded against contact to IP2X.

6.1.4 Laboratory Thermal Environment

The power converter racks will be located in an indoor equipment room. Ambient air will be drawn through the front of the rack for cooling purposes and exhausted from the top and also through the rear door if necessary. The air temperature within the room is expected to be maintained at approximately 24ºC with day to day variations of ±2ºC.

The equipment should operate within a relative humidity range of 30% to 80% non-condensing.

6.1.5 Location and identification of terminals

Incoming and outgoing terminals shall be located at the rear of the unit.

Incoming AC terminals should be clearly marked with voltage and phase (if applicable). DC output terminals should be clearly marked with polarity and channel number (if applicable).

Connectors used for AC input power and DC output power should enable safe, secure and quick connection and disconnection.

Connectors for controls and interlocks should enable safe, secure and quick connection and disconnection without the use of tools.

The manufacturer should supply the mating partner for each of the interface connectors and any special tools for wiring these.

A safety ground connection shall be provided at the rear of the unit.

6.1.6 Arrangement of power converters and reversing switches

All equipment is to be mounted in one or more 19" racks dependent on size and spacing requirements. Sufficient rack mount kits and blanking plates to cover unused slots within a rack-mount kit shall be provided.

6.2 Engineering Standards

6.2.1 European CE mark

All power converters shall have full CE certification and display the CE mark.

6.2.2 International Electro-technical Commission Standards

The equipment and drawings must in all respects comply with the relevant I.E.C. standards, recommendations and reports.

6.2.3 COSHH Requirements

Materials defined as Hazardous to Health in the Control of Substances Hazardous to Health Regulations 1994 and the HSE publication EH40/95 Occupational Exposure Limits 1995 shall not be used without written permission from the Laboratory.

6.2.4 Asbestos and poly-chlorinated bi-phenyls (PCBs)

Asbestos or asbestos-type insulation, insulating or dielectric fluids containing PCBs shall not be used. Where a choice of materials is available (e.g. cables, support hardware), preference will be given to materials or equipment exhibiting a higher level of fire resistance.

7. PROJECT MANAGEMENT

7.1 Quality Assurance

The Supplier should maintain and apply a quality assurance program compliant with ISO-9001 or equivalent for the design, manufacture and testing of all components.

7.2 Pre-tender questions

If Suppliers have any contractual or technical questions these must be made via the "Emptoris" on-line Procurement System. Queries must not be made directly to the Laboratory.

7.3 Contact person

The supplier shall assign a named person who will be responsible for all contacts with the Laboratory.

7.4 Responsibility of supplier

The supplier will be responsible for the final design, the production methods and the correct performance of all of the items supplied.

7.5 Delivery

Delivery shall be made to: STFC Daresbury Laboratory
Sci-Tech Daresbury
Daresbury
Warrington
Cheshire
WA4 4AD
United Kingdom

Suppliers shall state the delivery time in weeks from receipt of order for the specified power converters.

7.6 Documentation

7.6.1 Documentation with Tender

The supplier should include with the tender information on the functionality and performance of each type of power converter including:

- The specific model, rating and dimensions of the type of power converter offered for each magnet type
- Complete documentation on the functionality of the control interface.

- The resolution and accuracy of any signal which is controlled or monitored through a serial interface and converted using a DAC or ADC (if applicable).
- Update rate of the serial interface (if applicable).
- Full details of the serial command/response protocol (if applicable)
- List and function description of all external interface signals.
- The performance parameters of the power converter (see Table 4)
- The reliability of the power converter and test results for reliability
- Information on rack mounting and cooling arrangements
- Details of the harmonic emissions and inrush current on the mains input.
- Details of the power factor and efficiency over the operating range
- Stability test data over 8 hour period
- Proposed delivery schedule

7.6.2 Initial progress report

The supplier shall produce within two weeks of notification of the order, a written report comprising the definitive manufacturing and delivery schedule

7.6.3 Interim progress reports

Further reports shall be produced at four week intervals detailing manufacturing progress.

7.6.4 Final Documentation

The Supplier shall provide complete documentation for each power converter type comprising at least one hard copy and one electronic copy. This documentation should include:

- User/operation/maintenance manuals containing specifications, operating instructions, control system interface commands/protocols, set-up instructions, block diagrams, maintenance procedures (both operational and preventative), normal adjustments and calibration set-up procedures.
- A general mechanical arrangement drawing of each power converter type.

7.6.5 Language

All labelling, manuals and other documentation shall be in English.

7.6.6 Nameplate

The power converter shall have a nameplate on each unit that should include the following information

- Supplier's name and address
- Power converter type and serial number
- Input voltage rating, voltage tolerance and frequency range
- Output voltage and current rating(s)

7.6.7 Shipping documentation

All shipping containers should be marked or tagged with the following information:

- Laboratory purchase order number

- Shipping address as specified within the contract.
- Supplier's name.
- Components contained within each package.
- Gross weight
- "This way up" if required.
- "Fragile" if required.

7.7 Warranty

The Supplier should guarantee the Power Converters against failure due to either faulty components or faulty manufacture for a minimum period of 12 months after delivery of the equipment to the Daresbury site.

This guarantee should not be invalidated by the opening of the case for visual examination and diagnostic tests, but it is warranted that no modifications will be undertaken without the written permission of the supplier.

Additional credit will be given to suppliers able to offer a longer warranty period than that specified.

8. PRICING

Suppliers are requested to provide prices for power converters and polarity reversing switches (where available) based on the following options.

Pricing Schedule Section	Equipment
A	Phase 1 power converters. All except Quadrupole type 1 to be unipolar. Quadrupole type 1 to be bipolar.
B	Option for all Phase 1 power converters to be bipolar. (Where a supplier cannot offer a bipolar module for a particular magnet then a unipolar option may be offered).
C	Option for Phase 2 power converters. To be unipolar/bipolar as specified
D	Option for polarity reversing switches for each power converter type (except Quadrupole type 1).
E	Option for Earth–Fault Protection

Section A is mandatory but prices for sections B, C, D and E may be supplied at the Supplier's discretion depending on whether they are able to offer the equipment requested.

Prices should be entered on the separate Pricing Schedule supplied with the tender documents.