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1.0 Scope

1.1 This specification, in conjunction with other documents, defines the performance, design requirements, configuration, construction, materials, quality assurance, inspection, testing, workmanship and packaging of a regulated power supply. This power supply shall be installed by Brookhaven National Laboratory (BNL) as part of a large magnet power system and must operate continuously for long periods of time in an unmanned area. The power supply must exhibit a high level of reliability and be thoroughly interlocked.

1.2 The seller shall furnish all equipment, materials, tools, facilities and labor to perform all the work necessary to design, manufacture and test the power supply per this specification. The seller shall also provide all labor and resources to produce detailed up-to-date documentation of the power supply as built. The power supply shall be designed to have an expected service life in excess of twenty years.

1.3 The design of this power supply must be conservative, using standard techniques and commercially available component parts that insure high reliability and minimum maintenance. The detailed parameters for these units are given in the Specification Data Sheets that are attached to the end of this specification. After award of contract, no deviation from this specification is permitted unless written approval is obtained from the BNL Division of Contracts and Procurement.

2.0 Applicable Documents

2.1 The following documents are to be used as standards in the design and manufacture of the power supplies.

Number	Title
BNL - QA -101	Supplier Quality Assurance Requirements
Code of Federal Regulations Title 29, Section 1910	OSHA General Industry Safety and Health Regulation and Standards
NEMA	SG-5, Indoor Power Switch Gear
IEEE 383	Vertical Flame Test

3.0 Requirements

This section of the specification describes the performance and physical characteristics of the units required. Alternate products or schemes offered by the seller that may provide equal or better performance and reliability may be presented, but will be subject to approval by BNL.

3.1 Parts, Materials and Processes

3.1.1 Permanently installed hazardous or toxic materials such as asbestos or asbestos-type insulation, insulating or dielectric fluids containing PCB's, etc., shall not be used. Where a choice of materials is available, e.g. cables, support hardware, etc., preference shall be given to material or equipment exhibiting a higher level of fire retardancy, low oxygen content, etc. With delivery Seller shall provide to BNL any applicable Material Safety Data Sheets as required by the Occupational Safety and Health Act and applicable regulations including, without exception, as required under 29 CFR 1910.1200.

3.1.2 The specifications for the various portions of the work describe certain special materials, processes and products of manufacture, which will be required. Should the seller propose to furnish other "equal" materials, processes, or products either in substitution for, or as an alternate to the specifications, such substitutions must be approved by BNL Cognizant Engineer in writing. Decision as to the equality of any materials, processes and products to those specified shall be final, but the approval of BNL shall not relieve the seller from their responsibility concerning such work or affect the guarantee covering all parts of the work.

3.1.3 The BNL Cognizant Engineer shall have final approval as to the determination of design parameters, operational margins, specification interpretation, control, protection and testing. Differences between the seller's proposal and the standards or Brookhaven's requirements shall be resolved by the Cognizant Engineer's determination. Sellers shall obtain written approval from BNL before proceeding with the final design and fabrication. No deviation from the specification will be allowed unless specifically authorized by BNL in writing.

3.1.4 The seller will be held responsible for the design, construction and testing of the power supply. However, the seller will not be held responsible for the installation and system testing at Brookhaven.

4.0 Submittals by Seller

4.1 The seller shall submit a proposal that gives a PARAGRAPH by PARAGRAPH response as to how they intend to comply with this specification. Any exceptions the seller may make to this specification shall be clearly noted in the proposal. The seller

shall state in the proposal that they are in full compliance with all aspects of this specification which are not noted as exceptions.

4.2 The seller shall fill out the attached form entitled "Seller Data Sheet" and return it with their proposal. All proposed exceptions shall be described and attached to this form.

4.3 Three sets of preliminary outline drawings showing the power supply overall dimensions, all component placements, preliminary schematics and a preliminary manufacturing schedule shall accompany the proposal.

4.4 Three (3) weeks prior to testing, the seller shall submit to BNL a copy of the final test procedure.

4.5 The seller shall specify in detail the guarantee period and its provisions in their proposal.

5.0 Documentation

5.1 Upon delivery of the equipment, five (5) sets of final as built, signed prints shall be supplied by the Seller. One set of the final as built prints shall be capable of high quality reproduction. These prints shall be made to the highest professional drafting standards. Computer CAD system drawing plots shall be provided on CD-ROM in a "AutoCAD" compatible drawing format.

5.2 Five (5) sets of bound design and operations manuals plus CD-ROM in MS Word format shall be shipped with the equipment. They shall include all test results, final parts lists, recommended spare parts lists, technical descriptions of the power supply operation and maintenance recommendations, description of critical adjustments and potentiometer settings, and data sheets on gauges, meters, fuses, semiconductors, relays, valves, and other pertinent components.

5.3 A log shall follow the power supply through production. This log shall contain critical settings for the power supply and shall serve as a history of its production. A copy of this log shall be supplied to Brookhaven. The log shall contain as a minimum potentiometer settings, torque settings, test results, trip settings, etc.

6.0 Design Reviews

6.1 Prior to awarding a contract under this specification a pre-award meeting shall be held. At this time a preliminary review of the submitted design will be done, and the capability of the seller to comply with this contract in a timely manner will be evaluated.

6.2 The final design review (FDR) shall be held ten (10) weeks after receipt of order and prior to the start of fabrication. Three (3) sets of all electrical schematic drawings, mechanical assembly drawings, a manufacturing schedule, a preliminary acceptance test procedure, and a complete parts list shall be submitted to BNL at least two (2) weeks prior to the FDR date. Agreement shall be reached during the FDR not only on the drawings and material submitted, but also on the seller's manufacturing plan, preliminary test procedure and schedule. Components and materials used in the cooling system shall also be reviewed at this time. The results of the FDR shall be documented by the seller and submitted to BNL for approval. After written approval of the FDR by BNL the seller shall promptly begin assembly.

7.0 Power Supply Nameplate

7.1 The vendor shall supply a stainless steel type "C" nameplate, mounted in plain sight, giving all standard information, including the following:

- 7.1.1** Manufacturer's name and address.
- 7.1.2** Manufacturer's part number.
- 7.1.3** BNL's part number.
- 7.1.4** Manufacturer's Type and Serial Number.
- 7.1.5** Complete Input Ratings.
- 7.1.6** Complete Output Ratings.
- 7.1.7** Cooling Requirements.
- 7.1.8** Gross Weight of the Unit.
- 7.1.9** Date of Manufacture.
- 7.1.10** Specification Number.

8.0 Mechanical Considerations

8.1 The equipment shall be constructed in an all-metal cabinet which shall be in accordance with NEMA standards for Indoor Power Switch-gear as per publication SG5, latest edition.

8.2 The power supply shall be partitioned into separate high voltage, high current ac and dc compartments, as well as a separate low voltage or control compartment. The purpose of these compartments is to insure that electrically dangerous potentials are isolated, and through a Kirk key coordinated locking arrangement, exposure to electrical hazards can be prevented.

8.3 The power supply shall have a control compartment which shall be used to enclose all of the power supply controls, over current devices, relays, protection, interlocks, system monitoring and status indications. This compartment shall be physically isolated from the high power compartments and shall be behind an unlocked door. The door shall not be interlocked. This compartment shall not contain any

voltages greater than 125 volts AC or DC. Voltages greater than 10 volts AC or 50 volts DC shall be barriered.

8.4 Provisions shall be made for lifting the equipment by both overhead crane (e.g. lifting eyes) and fork lift (e.g. channels or I-beams). Such requirement will be finalized at the Design Review. The frame shall be made sufficiently rigid so that lifting and relocation shall not cause deformation or door misalignment.

8.5 The Seller shall provide an estimate of the power supply size, weight, and a preliminary layout drawing in their proposal. The maximum dimensions of the units shall be within the values given in the Specification Data Sheets.

8.6 All bolted buss bar, fuse, and rectifier joints shall use Belleville washers, flat steel washers, lock nuts and a joint compound approved by Brookhaven. All bolts, washers and nuts shall be stainless steel. All copper bus bar connections shall be silver plated at all joints.

8.7 All bolts in blind locations shall have captive hardware.

8.8 All air filters shall be mounted on the outside of the unit and be of a size and type acceptable to BNL.

8.9 The accessories, materials and supplies used in power supply design shall be of the highest quality or specification grade wherever possible. The Seller shall list in their proposal the manufacturer of fuses, relays, receptacles, terminal strips, wire, hardware, etc. Auxiliary relays shall be enclosed in dust proof cases and mounted in the power supply control compartment. Gold plated pins should be used in all IC sockets and critical connectors.

8.10 The finish of the cabinets shall consist of degreasing of the unit followed by a coat of rust-proofing paint and two coats of synthetic resin enamel, color "light blue" as per Federal Standard No 595A, Color No 35240.

8.11 The noise level three feet away from the power supply from all sources within the cubicle including cooling fans, shall be less than 70 dBA when the unit is on and operating.

9.0 Electrical Considerations

The detailed electrical requirements and parameters for this power supply are given by the Specification Data Sheets attached as the last section of this specification. All power supplies must also meet the general electrical specifications which are given in the following sections.

9.1 The input power shall be three-phase, 60 Hz. The input voltage shall be 460 Volts rms, +10%, -5%.

9.2 The three-phase incoming power lines shall connect directly to a set of current limiting fuses or input circuit breaker, followed by an appropriate contactor for normal on/off and fault generated interlocks. The voltage ratings of these devices shall be 600 Volts AC, with a minimum interrupting capacity rating of 50,000 amperes symmetrical rms.

9.3 The contactor and fuses or circuit breaker shall be of adequate current rating. The contactor shall be rated for $\geq 10^6$ operations. The vendor must specify the manufacturer and the model number of the contactor chosen in their proposal. A key switch shall be in series with the contactor closing coil to enable a mechanical lockout of the power supply. The contactor shall have two form C auxiliary contacts for BNL use.

9.4 When operating in constant current mode, a voltage feedback loop shall be used as a minor loop within the major current feedback loop to enhance regulation against the fast line changes.

9.5 In normal operation, the analog current reference is a BNL supplied signal source.

9.6 Current and voltage limit potentiometers shall also be supplied by the vendor. The voltage and current limit potentiometers shall limit the voltage and the current from 30% to 100% of the full rated voltage or current. Voltage and current limit controls shall be easily accessible and verifiable by potentiometer dial settings and/or monitoring test points.

9.7 The power supply shall have connectors or terminals properly applied for the use of remote reference.

9.8 The power supplies shall have a full power current bandwidth greater than or equal to the value given in the specification data sheet.

9.9 The p.s. units shall be capable of operating at the maximum dI/dt and dV/dt specified by specification data sheet.

9.10 The output voltage ripple of the power supply shall be less than the value given in the Specification Data Sheets. This value shall apply over the full range of output voltages.

9.11 Any electrical cable and bus-work used shall be made of copper and of sufficient ratings and cross-section such that they shall not exhibit a temperature rise of greater than 50 degree C at maximum load.

9.12 All low level control wiring shall be type AWM appliance wire, 600 volt, 105 degree C, stranded copper conductor or approved equal. All wires shall be labeled for circuit identification at all termination points. Proper insulators and supports shall be used.

9.13 All cable insulation used in this system shall be of a self extinguishing, low flame propagation, low smoke type and meet IEEE 383 vertical flame tests. The Seller shall include in their proposal a list of the insulating material that will be used.

9.14 Each phase of the AC input terminals shall be sized for at least 150% of rated current. The AC terminals shall be phased A-B-C, from left to right when facing the AC compartment door and shall be clearly labeled.

9.15 The AC input shall be through the upper center or rear of the power supply. Access doors shall be provided for AC input hookups and for servicing. The doors shall be electrically interlocked with micro switches and be capable of being mechanically locked with Kirk type locks.

9.16 The DC output buss compartment shall be located in the rear of the power supply. This area shall be isolated from all other compartments. Access doors shall be capable of being mechanically locked with Kirk type locks and shall be electrically interlocked with micro switches. All AC, DC, and interlock signals shall be entering from the top. Since this power supply unit will be stacked side-by-side with other units, no side access will be available after installation.

10.0 Acceptance

For purpose of warranty under an order for these power supplies, final inspection (acceptance) is defined as the successful completion of acceptance tests at Brookhaven to substantiate the compliance of the power supplies with this specification. Final acceptance shall be completed within three (3) months after receipt of the units at Brookhaven. The seller will be notified of the test dates and may have a representative present to witness the tests. The seller shall be held responsible for the contracted performance of the equipment produced and delivered to BNL.

Final Acceptance testing at BNL shall include any or all of the tests specified in section 15 of this specification, or any other standard tests deemed necessary by the BNL cognizant engineer to confirm conformance to the specification.

11.0 Quality Assurance and the Responsibility of the Seller

11.1 The Seller shall furnish a manufacturing plan and acceptance test procedures for approval by Brookhaven. Approval by Brookhaven shall not release the Seller from their responsibility for conceptual design, manufacturing, or any other mistakes committed in the fabrication of the power supply.

11.2 All purchased articles from subcontractors included in this power supply shall be clearly identified to indicate conformance to Seller's receiving inspection.

11.3 All elements of this equipment shall be covered by a guarantee against material and manufacturing faults. The Seller shall specify in detail the guarantee period and its provisions in their proposal. The guarantee period shall be for a period of at least two (2) calendar years from the final acceptance test date.

11.4 These quality assurance requirements are in addition to the following quality assurance requirements which will be found in Brookhaven document BNL-QA-101, attached to the purchase order. The following sections apply: 3.1.2, 4.1, 4.3, 4.4, 4.4.2, 4.4.4, 4.5, 4.6, 4.7, 4.7.1, 4.10, 4.10.1, 4.10.2, 4.10.3, 4.10.5, 4.13, 4.16, 4.19 and 4.21.

11.5 Traveler sheets shall follow each piece of equipment through production. These sheets shall document critical processes and settings for each article and shall serve as a history of its production as per section 5.3. Copies of these travelers shall be supplied to Brookhaven.

11.6 Copies of the test data sheets shall include lists of the instruments used to perform the tests, and the calibration due date of each instrument. Only calibrated test equipment shall be used.

11.7 The Seller shall establish those controls and processes necessary to ensure uniformity of all deliverable articles. All controls, inspections, tests and quality provisions established during development and pre-production tests shall be indicated on the applicable drawing and shall be performed on each deliverable article.

12.0 Preparation for Delivery

All units and parts of this equipment shall be properly packaged and delivered in undamaged condition to BNL. All water circuits shall be blown free of any water prior to packaging to prevent damage during shipping or storage under freezing conditions. The seller shall ship all power supplies via air ride trucks.

13.0 Notes

13.1 Definitions

13.1.1 BNL - BNL shall mean the Brookhaven Science Associates, Inc., Upton, NY 11973-5000, operating Brookhaven National Laboratory, acting by and through its Division of Contracts & Procurement. BNL is responsible to the Department of Energy for the article described by this specification.

13.1.2 Seller - Seller is the agency responsible to BNL for supplying the article described in this specification. The seller shall be directly responsible to BNL for all approvals, submittals, proposed changes or deviations to this specification.

13.1.3 Failure - A failure shall be defined as any occurrence, including one time non-repeatable anomalies either sudden or gradual in nature which causes the power supply performance to deviate from specified limits without adjustment of controls other than normal operating controls.

13.1.4 ANSI - American National Standards Institute.

13.1.5 ASTM - American Society for Testing Materials.

13.1.6 IACS - International Annealed Copper Standard.

13.1.7 IEEE - Institute of Electrical and Electronics Engineers.

13.1.8 NEMA - National Electrical Manufacturers Association.

13.1.9 NEC - National Electrical Code.

13.1.10 PLC - Programmable Logic Controller

14.0 Performance and Design Characteristics

This section of the specification describes the performance and physical characteristics of the units required.

14.1 General Configuration and Characteristics

14.1.1 The power supply shall be a completely assembled unit that will be installed and interfaced via a WFG (Waveform Generator) and a PSI (Power Supply Interface) to a remote PSC(Power Supply Controller) by BNL. The power supply shall include all the hardware, both analog and digital (off/on, interlock, status) to enable this interface. The analog part consists of sending a reference (I_{ref}) to the power supply as well as reading

back of four analog signals (Iref, Iload, Vload, and Ierr) from the power supply. The reference shall be derived from a BNL supplied WFG (Waveform Generator). The vendor must provide space to house this WFG inside the power supply and prepare to receive this signal via a 9-pin D connector. The conversion of the analog to digital readback signals are handled by fast ADC's in the PSC. The vendor shall supply the readback signals at the terminals of a 25-pin D connector. The sending of remote commands (off/standby/on) and status readback (interlock, status) are handled by a BNL supplied PSI (Power Supply Interface) unit. The vendor shall supply the status signals (Active high, 15V CMOS level, 1 mA sink or source) at the terminals of a 25-pin D connector. Also, the vendor must provide space to house the PSI unit and prepare to receive the remote command signals (Active high, 15V CMOS level, 1 mA sink or source) via a 9-pin D connector.

14.1.2 The power supply shall contain the proper input terminals or a connector suitable for high accuracy signals, and an analog isolation amplifier with at least a 20 kHz bandwidth, to receive the remote analog reference signal in a differential mode. Its magnitude will be 10 volts full scale. The input impedance of the vendors receiver shall be 10 kilo-ohm or greater. The remote analog reference to the power supply shall be from a BNL supplied WFG.

14.1.3 The power supply shall operate in either "Local" or "Remote" mode. In Local the supply will be controlled from vendor supplied controls and reference. In Remote the power supply will be controlled via the outputs of a BNL PSI and external analog reference.

14.1.4 The power supply shall be controlled and protected by the vendor supplied input fuses or circuit breaker, contactor, AC (timed) and DC over-current relays, over and under voltage relays and phase sequence circuitry.

14.1.5 These supplies will operate at the potential of several hundred volts with respect to ground. It is essential that all low level control, protection and monitoring circuits operate near ground potential and be isolated from the high level circuitry. The AC and DC terminals and systems shall be high potential tested with respect to the low-level systems (see 15.2).

14.1.6 The peak reverse/forward voltage (PRV and PFV) rating of all rectifiers shall be at least 3 times their operating voltage. The maximum average current rating margin for the semiconductors under worst case cooling conditions shall be such that the maximum junction temperatures remain under 100° C.

14.1.7 All transformers and reactors shall be designed with class H insulation.

14.1.8 The units shall normally operate in the current regulate mode over the maximum rated current, but will switch to a voltage limit mode when a set-point or maximum (+ or -) voltage is exceeded.

14.2 Instrumentation

14.2.1 There shall be a front panel AC voltage meter to monitor input voltage line to line. There shall be a selector switch to allow metering of all three phases. The seller shall supply the necessary potential transformers.

14.2.2 There shall be a front panel AC ammeter to monitor input line current. There shall be a selector switch to allow metering of all three phases. The selector switch shall be a 'make before break' type, so as not to open circuit the CT's. The seller shall supply the necessary current transformers.

14.2.3 There shall be a DC voltmeter operated from an isolated DC potential transformer (DCPT) connected across the power supply output terminals. The DCPT shall have a tolerance of +/- 1 %. The DCPT shall have a bandwidth greater than 10 kHz and be similar to the Liaisons Electroniques Module LV series. An isolated and buffered output shall be provided for voltage monitoring. In addition an isolated buffered output shall be supplied to the BNL control computer. The bandwidth of the monitoring and read-back voltage signals provided to BNL shall be at least 20 KHz. A second DCPT shall monitor the output voltage before the filter. Isolated buffered outputs shall be provided by the seller for this DCPT identical to those described above.

14.2.4 There shall be a DC ammeter that shall operate from an isolated current transducer (DCCT). An isolated and buffered output shall be provided for local load current monitoring. In addition an isolated buffered output shall be supplied to the BNL control computer. The bandwidth of the monitoring and readback current signals provided to BNL shall be at least 20 KHz. The DCCT shall be installed after the passive filter (if any) so that it measures the load current only.

14.3 Power Semiconductor Ratings

14.3.1 The peak inverse voltage (PIV) and peak forward voltage (PFV) rating of all power semiconductors shall be rated for three (3) times their peak circuit operating voltage or greater.

14.3.2 The seller shall limit ON/Off or other induced switching transients to 50 percent of the published inverse and forward voltage ratings of all power semi-conducting devices.

14.3.3 All rectifiers shall be protected against high di/dt stress and dV/dt break-over. The protection may include, but not be limited to, RC snubber networks, series inductors, symmetrical avalanche suppression devices, metal oxide varistors, or selenium surge suppressors. Appropriate over-voltage limiting devices shall be placed at the three AC input lines of each bridge. In RC snubber network designs, the resistors

shall be non-inductive and the capacitors shall be of extended foil construction and made for commutation service. Fuses shall be required to isolate failed protection devices such as MOV's and surge suppressors on the high power circuits. In these cases, fuse status monitoring shall be provided to interlock and computer controller.

14.3.4 The continuous current rating of all silicon rectifiers shall be at least two (2) times greater than the maximum RMS current the device will conduct during operation of the power supply.

14.3.5 The number of rectifiers used in a bridge shall be limited to one (1) per leg; series or parallel combinations shall not be permitted. The seller shall provide in their proposal data sheets, the device chosen and its ratings.

14.3.6 The rectifiers shall be water-cooled. The units shall be mounted and clamped on water cooled heat-sinks according to the recommendations of the semiconductor manufacturer. The maximum junction temperature shall not exceed 100° C under worst case load conditions with a maximum inlet water temperature of 40° C. Individually cooled rectifier heat sinks shall have an over temperature protection scheme, such as thermostat type switch, mounted close to the rectifier which shall be set to trip before the device junction temperature reaches 100° C. The output of these switches shall interlock power supply and give status to computer controller. The seller may elect to support over temperature protection using an alternate procedure. The seller shall provide calculations showing the expected temperature rise with their proposed cooling and protection scheme. The over temperature monitoring circuitry must meet the high potential test in section 15.

14.3.7 All rectifiers shall be mounted with consideration for replacement and maintenance accessibility, the sellers preliminary drawings shall show their position in the power supply.

14.4 Protection Devices and Control Circuits

14.4.1 The following devices or systems, (section 14.4), shall be incorporated in the power supply and shall be used to interlock the power supply to internal and external control devices. All of the interlocks and controls of each power supply shall be connected to a computer controller (See section 14.1.1). Some interlock and control devices shall be wired directly to terminal strips and to external protection circuits as well as to the computer controller. These interlock circuits are defined under each device section. All control, interlock devices and circuits must meet the high potential tests of section 15.

14.4.2 The control voltage for the power supply shall be 24 VDC. The input voltage for the 24 VDC power supply shall be 120 volts AC internally supplied. The 24 VDC power supply shall be provided by the Seller. The 120 volt AC power shall be housed in the power supply control compartment and shall be grouped together in one location

and covered with a safety barrier and warning signs. A two pole, 120 Volt, circuit breaker shall be provided by the Seller. Its operating handle shall be accessible without removing the 120 VAC safety barrier.

14.4.3 A suitable EMI/RFI line filter shall be provided for 120 VAC line control power. The filter shall be properly sized to exceed the maximum voltage and current rating of the control circuit.

14.4.4 A high current relay or contactor shall be provided which will be used to turn the 120 VAC power to all the power supply control functions on and off, (**Standby relay**). The relay shall also turn on all regulator and SCR triggering circuitry. Extra terminals shall be provided for connection of BNL control circuitry. The relay shall be an Allen-Bradley type 700DC-P400Z24 or approved equal with a coil voltage of 24 VDC and 4 poles. The coil shall be controlled by the output module of a PLC and shall have a diode and an MOV connected across the coil to limit the back EMF to the PLC module. When the relay is de-energized (Auxiliary OFF command) all 120 VAC power shall be off except to the PLC and the PLC 24 VDC control power supply. An auxiliary contact from the standby relay shall be wired to an input module of the PLC for standby status verification.

14.4.5 The Seller shall provide a **master interlock relay** and it shall be connected to the PLC output module. The relay shall be an Allen-Bradley type 700DC-P400Z24 or approved equal with a coil voltage of 24 VDC and 4 poles. The coil shall have a diode and MOV connected across it to limit the reverse EMF the PLC output module will receive. The relay shall be located in the power supply control compartment. This relay will be used to trip the incoming 480 volt contactor which feeds the rectifier transformers. An auxiliary contact from the master interlock relay shall be wired to an input of the PLC for ready status verification.

14.4.6 Over temperature protection of rectifier cells will be required. The over temperature detection devices shall be thermostat type switches (or equal) with contacts that are electrically isolated from the heat-sink, and must be capable of meeting the high potential test in section 15. The thermostats shall be automatic reset type with normally closed contacts suitable for operation on a 24 volt DC system. The trip point of the thermostat is to be set to protect the rectifier cells from exceeding the manufacturer's recommended maximum safe operating case temperature for the maximum junction temperature given in section 14.3.6. All the over temperature devices shall be wired individually to the PLC input module for interlock control and alarm monitoring.

14.4.7 Each phase of the AC input lines to each rectifier bridge shall be fused. Current limiting fuses shall be selected to limit the peak let-through current to less than sixty percent (**60%**) of the rectifier manufacturer's maximum specified peak one cycle surge rating (I_{tsm}). Fuses shall be located in each AC input line of each rectifier bridge. A fuse monitoring system shall be provided. The fuse monitoring system shall provide fuse status information to the computer controller for interlock control and alarm indication. The fuse monitoring system contacts shall be normally closed and shall open when a main fuse fails. The contacts shall be suitable for 24 VDC operation. The fuse

monitoring system must meet the high potential test in section 15.

14.4.8 Water flow switches shall be installed on the return leg of every parallel water path for loss of cooling water protection. A pressure differential switch shall be installed in each power supply to protect against loss of pressure. Shut-off valves shall be placed on every parallel water path to aid in back flushing the water paths. The water flow switches and the differential pressure switch shall be wired to the computer controller for interlock control and alarm indication.

14.4.9 The Seller shall provide AC over and under voltage relays and a phase sequence relay in the incoming 480 volt line.

14.4.10 Three phase AC over-current relays shall be provided by the Seller to sense AC over current in primary input of power supply. The seller supplied current transformers shall be mounted in the power supply enclosure near the seller supplied contactor. The over current devices shall provide interlock contacts **wired directly** in series with the master interlock relay contacts. The AC over current relays shall also provide status information to the computer controller for other interlock control and alarm indication. The over-current relays shall be a CO2 type and have adjustable instantaneous and timed trip settings. The status and alarm contacts shall be suitable for 24 volt DC operation.

14.4.11 The power supply shall have a DC over current sensing device that has an adjustable trip setting from 10 percent to 110 percent of rated DC output current. The over current device shall use the power supply's internal DC transducer, DCCT. The DC over current device shall be mounted in the control compartment of the power supply. The DC over current device shall be **wired directly** in series with the master interlock relay coil so that , an over current condition shall open the master interlock relay contacts. The DC over current device shall also provide status information to the computer controller for other interlock control and alarm indication. The status and alarm contacts shall be suitable for 24 VDC operation.

14.4.12 Door interlock micro-switches shall be mounted on all hinged doors of the power supply that lead to high power AC and DC circuitry. The switches used shall be similar to the Micro-Switch type V-3. The door switches shall be wired directly in series with the master interlock relay contacts. The door interlock micro-switches shall provide status information to the computer controller.

14.4.13 A cubicle over temperature interlock shall be provided by the Seller. The device shall be adjustable, between 100° F and 200° F, and shall provide contacts for the computer controller.

14.4.14 All doors shall have provisions for applying a captive Kirk key interlock or other suitable protection devices.

14.4.15 Control circuits shall be designed in a fail-safe manner so that loss of power does not result in a hazardous operating condition. Protective interlock circuits and power supply controls shall be designed so that reactivation of the interlock circuit (i.e., completing the circuit) will not result in an automatic restoration of power to the equipment.

14.4.16 The Seller shall provide DC over-voltage protection and interlocking circuitry which shall be capable of protecting the power supply from over-voltage conditions, at the DC terminals. This protection shall be so designed that it can be activated by internal sensing within the power supply. The over-voltage protection equipment shall also provide a detection circuit that will be wired directly to the master interlock relay contacts. Status information shall also be provided to the computer controller.

14.4.17 The interlock circuitry as well as the buffering/isolating scheme supplied by the Seller shall be approved by BNL prior to commencement of fabrication.

14.4.18 All faults and statuses shall be isolated and buffered and brought out to the computer controller. Electrical isolation shall be accomplished by opto-couplers or relay contacts. All controls shall operate remotely via the computer controller. For local operation, a "Local / Remote" toggle switch and, "Off", "Standby", and "On", push buttons shall be provided on the units front panel. These controls shall be wired to the computer controller.

14.4.19 All protection and monitoring devices and circuits shall be properly isolated from the main power circuitry up to the high potential voltages as per section 15.

14.4.20 There shall be local "Off," "Standby," "On," and "Fault" indication.

14.4.21 The power supply shall contain a ground fault detection system to monitor the DC output of the power supply and the load.

14.4.22 Provisions shall be made for two external BNL interlocks. One interlock shall be for load fault and the other for system security. Interlocks shall be wired directly in series with the master interlock relay through an appropriate terminal board. Status of either of the remote interlocks shall be monitored by computer controller and annunciated.

14.4.23 The status of the power supply and interlocks shall be locally annunciated and shall be brought to the computer controller. The following is a list of some of the interlocks which shall be required in the base proposal. The exact number of status read-backs and alarms required to adequately protect the power supply cannot be finalized until the Sellers design is complete. This list will be finalized at the FDR.

14.4.23.1 On

14.4.23.2 Off

- 14.4.23.3 Standby
- 14.4.23.4 Fault Summary
- 14.4.23.5 Input AC Over-current
- 14.4.23.6 Output Over-current
- 14.4.23.7 Local/Remote
- 14.4.23.8 Water Under flow
- 14.4.23.9 Door interlocks
- 14.4.23.10 Two (2) external (load or customer) interlocks
- 14.4.23.11 Input AC Under-voltage, loss of phase, or wrong phase sequence
- 14.4.23.12 Water differential pressure
- 14.4.23.13 Ground Fault
- 14.4.23.14 Fan Fault or cubicle over-temperature

14.5 PS control functions:

14.5.1 OFF - de-energizes internal power and opens the main contactor. The OFF command is a normally open contact.

14.5.2 STANDBY- energizes the internal power and all control and regulation circuits are prepared towards a READY state. Whenever a STANDBY command is given a reset command is also given. This RESET signal shall clear all latched fault conditions after the faults have cleared. Standby also brings the power supply from the ON state back to the STANDBY/READY mode. The STANDBY command control switch is a normally open contact. The STANDBY contact is momentarily closed to energize the internal control power or reset the power supply faults.

14.5.3 ON - the ON command energizes the system's contractors (main and step start) and output current is available upon receipt of reference. The ON command control switch is a normally open contact that is momentarily closed to turn on the power supply.

14.5.4 FAULT-there is a fault condition. If the power supply is ON it will trip to STANDBY and if it is in STANDBY it will remain in STANDBY until a RESET clears the fault.

14.5.5 READY-the power supply is in standby and all faults are clear.

15.0 Testing

The power supply shall be fully tested at the Seller's plant to insure complete compliance with this specification. All facilities shall be provided by the Seller at their

plant for a partial load test of the power supply. Three (3) weeks before these tests the Seller shall provide the final test procedure to BNL for approval. Included in this procedure shall be test data sheets and interlock check out lists. Final tests at the Sellers plant must be witnessed by Brookhaven prior to shipment, but final acceptance of the units shall be at Brookhaven.

15.1 Standard tests

15.1.1 The BNL Cognizant Engineer and /or their representative shall have access to the Seller's facility during fabrication and testing. The Seller shall provide the facilities and instrumentation at their plant to perform all necessary tests to ensure compliance with all parts of the specification. The Seller shall provide ten (10) working days notice in advance of the test date so that BNL can make the necessary travel arrangements.

15.1.2 The testing shall include but not be limited to the specific tests outlined below. The Seller shall supply a detailed test procedure for individual components, sub-assemblies, and the completed power supply to BNL at the final design review for approval.

15.1.3 A Heat run, as well as other performance tests shall be conducted on the completed assembled power supply at rated output current. The Seller shall install thermocouples on the rectifiers and other points designated by the BNL Cognizant Engineer. The power circuits shall be operated continuously under a load acceptable to Brookhaven for a period of 24 hours. Short periods of downtime to make measurements or adjustments will be accepted but the total of all such downtime shall not exceed one (1) hour.

15.1.4 A hydrostatic pressure test shall be performed on the power supply at a pressure of 250 psi for one half hour.

15.1.5 The water flow in each parallel path and the total flow of water at a known differential pressure shall be measured. The temperature differential of the water paths shall also be recorded.

15.1.6 All interlock protection and status indication circuits of the full system shall be checked for proper operation. Actual fault conditions shall be induced where possible and control and annunciation shall be checked up to the computer interface.

15.1.7 ON, OFF, and Emergency OFF switching transients across the output of the high power semiconductor components shall be measured and recorded.

15.1.8 The time delay and jitter of the Seller high level rectifier triggering circuitry shall be measured.

15.1.9 The power supply output ripple, as well as the line and load regulation, shall be checked at 50% and 100% of the output rated load current.

15.1.10 The output current transient response time shall be measured.

15.2 High Potential Testing

These tests are to be conducted for a minimum of one (1) minute at 60 HZ between the designated points and the power supply ground or frame. Actual leakage currents are to be monitored and recorded.

15.2.1 All control circuits shall pass a hi-pot test to frame (ground) of 600 V ac rms. The control circuits shall be connected to ground during high potential testing of the power circuitry.

15.2.2 AC terminals - 2500 V, rms.

15.2.3 DC terminals - 2500 V, rms.

15.2.4 A high potential test shall be performed on the inductor. The test shall be at 60Hz for one minute between each set of coils and between the coils and the core. These tests shall be performed at 2,500 Vrms.

SELLER DATA SHEET

The formation requested on this sheet shall be supplied with all proposals for the LEBT Magnetic Lens power supply.

I Power Supply Documentation

preliminary drawings
block diagram
preliminary production schedule

II Power semiconductors

Bridges

type, mfg.....

PFV/ PIV Rating.....

Current Rating.....

Expected Tj max

FWD

type, mfg.....

number

PIV Rating.....

Current Rating.....

III. Transducer

DCCT type, mfg.....

DC Accuracy.....

IV. Total weight of power supply.....

V. **Dimensions (H x W x L)**..... _____

VI. **Estimated heat rejected**

air..... _____

water..... _____

X. **Water Requirements**

general cooling water expected requirements

water flow (gpm)..... _____

quality of water..... _____

conductivity of water..... _____

metals exposed to water

XI **Expected Delivery Time ARO**..... _____

XIII **Exceptions to the Specification:**

LEBT MAGNETIC LENS POWER SUPPLY SPECIFICATION DATA SHEET

General Requirements

Output Current	3000A max pulsed 900A min pulsed
Pulse Repetition Frequency	10 Hz
Pulse Width	15 msec
Window for 1% Current @ 3000A	30A, 1 msec
Window for 1% Current @ 900A	9A, 1 msec
Window Timing Jitter	1 usec (0.1%)
Electrical Load	30 mOhm + 1.13 mH
Ambient Air Temperature.....	10 to 40 degrees C
Maximum Inlet Water Temperature.....	40 degrees C
Size of Unit	52" (W) 36" (D) 84" (H)

SIMULATIONS

By discharging a 20mF capacitor bank sitting at 785V into the load, the Window for 1%-Current @ 3000A requirement can easily be satisfied. A computer simulation for this case (ideal) is shown in Figures 1 and 2.

In Fig. 1, we see that the load current is a half sine pulse and the capacitor bank discharges from 785V to 0V but then charges back to -643V.

In Fig. 2, the top portion of the pulse fits nicely in a 20A 1-msec window since it only varies by 16A.

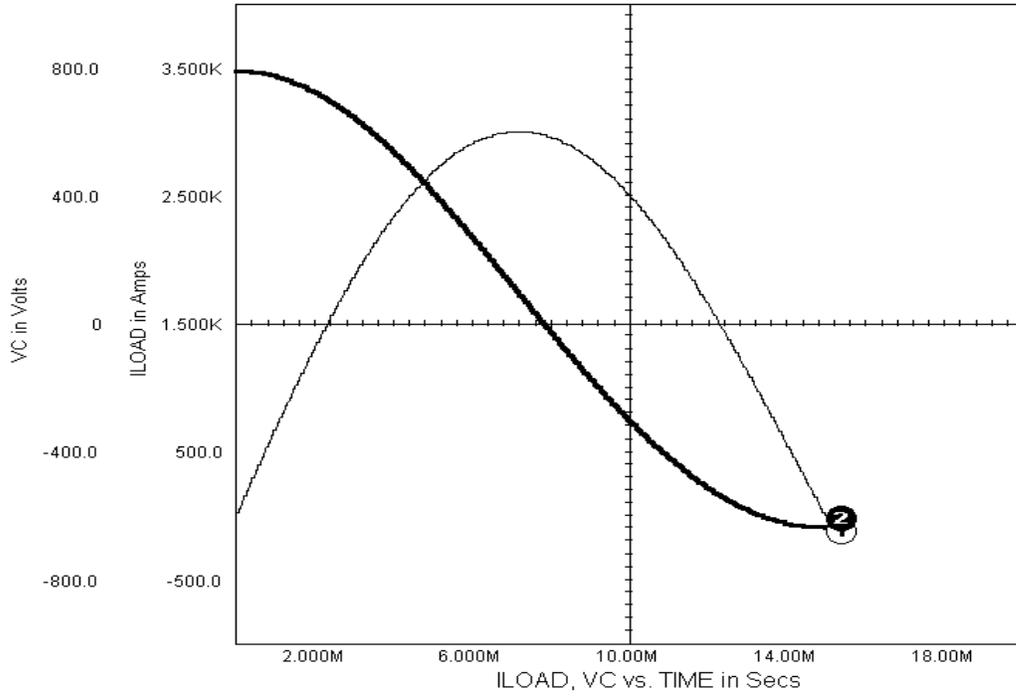


Fig. 1

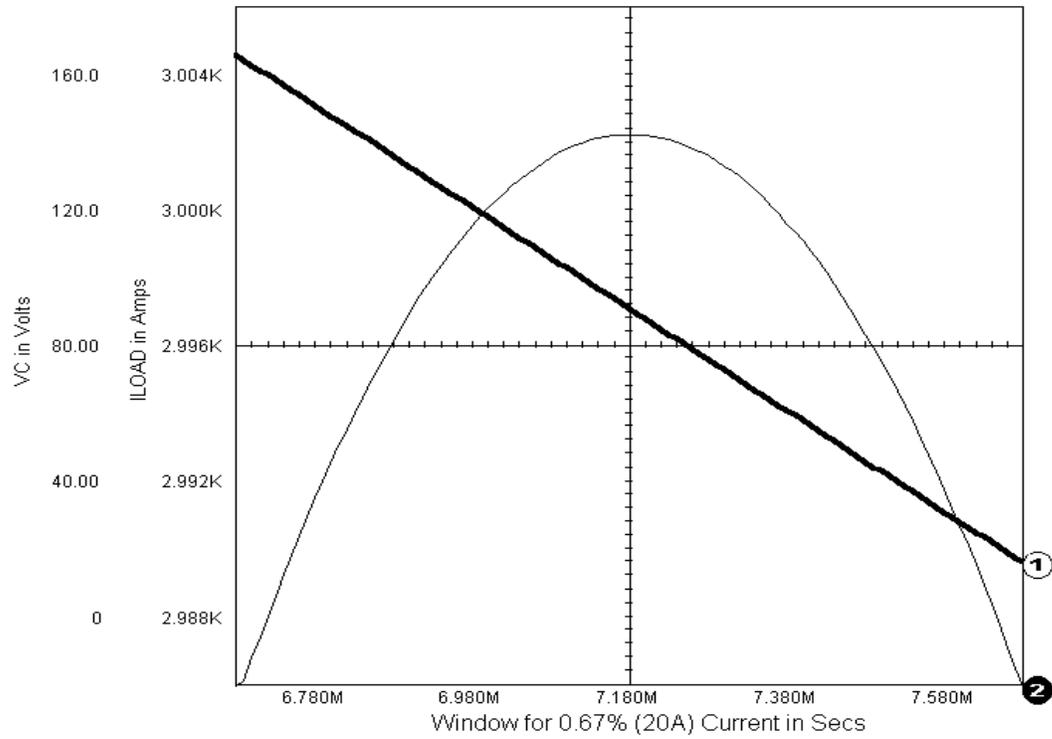


Fig. 2

Implementation Guide

As long as the specifications for the General Requirements are met, any suitable proposal will be considered.

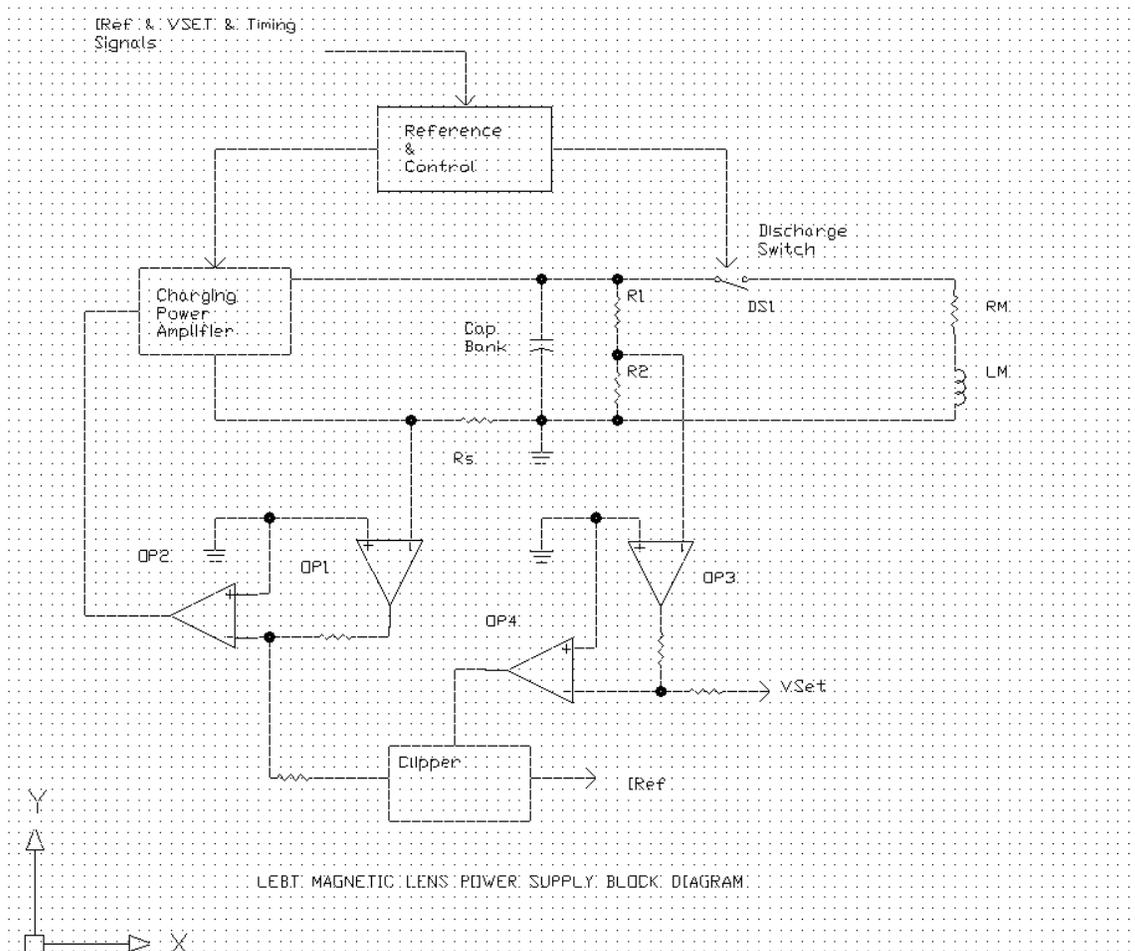
As a design guide, a practical implementation with a switching power supply is outlined in the following Application Note. In this case, the charging power amplifier has the following requirement:

Switching Power Supply Specifications

Input Voltage	460 Vrms 3 phase, +10%, -5%, 60 Hz
Output Voltage	+/- 800 V
Output Current	0 to 160 A max. DC/Pulsed
Pulse Repetition Frequency	10 Hz
Regulation mode	Current plus Voltage See Application Note.
Voltage Regulation	0.1% (DC to 10 Hz)
Output Voltage Ripple	< 0.1%, (0.8 V _{pp} , 20 Hz to 10 kHz) < 1%, (8 V _{pp} , 10 kHz to 1 MHz)

APPLICATION NOTE

A practical implementation of the Magnetic Lens power supply is shown below:



Basically the **charging power supply** charges the **Cap Bank** with a constant current set by I_{Ref} until the target voltage set by V_{Set} is met, and holds the voltage across the capacitors constant.

Upon receiving a discharge command, the output of the charging power supply goes **high impedance**, and the **discharge switch** DS1 turns on to dump Cap Bank current into the magnet. DS1 turns off when the discharge portion of the magnet current reaches zero.

Upon receiving a charge command, the charging cycle of the Cap Bank repeats.

The key feature of this implementation is the application of **current** and **voltage** feedback loops. The **clipping circuit** guarantees a smooth transition between the operation of the two loops.

Since VSet is adjusted to the target voltage, when charging starts, the output from OP4 goes to the rail because of the large voltage error.

The clipping circuit in the Clipper block has its limit set by IRef. Now that the output voltage from the Clipper is IRef, the current loop, consisting of OP1 and OP2, charges the Cap Bank with a constant current set by this reference.

As the charging of the Cap Bank continues, its voltage rises. When this voltage rises close to 98% (or some other design value) of the target voltage value, the voltage error at the output of OP4 starts to drop.

When the output of OP4 drops to a value equal or smaller than IRef, the Clipper lets the output of OP4 through. As a result, the voltage loop, now consist of OP3, OP4, and OP2, takes over and charges the Cap Bank to VSet.