Title: SNS Accumulator Ring Main Dipole Power Supply

QA Category: A2

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REVISION RECORD

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This specification consists of 27 pages
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 an SCR controlled rectifier power supply. The power supply will be built in two sections: (1) Outdoor rectifier / phase shifting transformers; (2) An indoor Rectifier Module consisting of rectifier bridges, firing circuitry, passive filter, controls, regulators, monitoring and annunciating, etc. The Vendor shall be responsible for delivering a complete turn key system including, high power rectifier modules, outdoor pad mounted phase shifting transformers, regulating electronics, local annunciation, remote controls and annunciating compatible in form and function with the SNS standard power supply interface unit, and high power switch gear. Oak Ridge National Laboratory (ORNL) will supply the transformer pads, cabling (AC and DC), cable tray, and water-cooling system and will install the power supply at their facility. This power supply will energize a string of 33 room temperature magnets and must operate continuously for long periods of time in an unmanned area. All components used in the power supply system must be selected to exhibit a high level of reliability and shall be thoroughly protected and interlocked.

1.2 The rectifier module shall be an SCR controlled, three phase, full wave, full control, twelve (12) pulse, continuous duty, AC to DC converter. The module shall be comprised of two (2) each, 3-phase full wave SCR bridges with the bridge outputs connected in series. There shall be free wheeling diode (FWD) placed across the module’s output terminals. The rectifier module shall be used to convert ORNL supplied, three phase, 60 Hz power into 400 VDC, 5000 amp, 2 MW, highly regulated, fully controllable power for the Spallation Neutron Source (SNS) Accumulator Ring main dipole magnet string. Neither output of the rectifier module will be grounded and due to the balanced nature of the load the output terminals will assume symmetrical values with respect to ground. Ground potential will be midway between the output terminal voltages. The SNS main dipole string consists of 33 magnets which constitute a large inductive / resistive load. The power supply shall be enclosed in an all-metal enclosure and shall be water-cooled. The main rectifier transformers and ac switchgear will be external to the rectifier module and will be supplied by the Vendor. Extreme care must be taken to produce a symmetrical balanced design to take full advantage of the ripple reduction and phase cancellation inherent in a twelve-pulse topology.

1.3 The rectifier / phase shifting transformers shall be supplied and guaranteed by the Vendor even if a secondary Vendor produces the transformers. It shall be the Vendor’s responsibility to size the transformer to produce the rated DC output current and voltage on a continuous basis within the specified temperature limits. The KVA, Voltage, and current ratings of the transformer depend to some extent on the Rectifier Module design and therefore these quantities listed in the attached Transformer Data Sheet section of this document are for reference only and must be confirmed by the Vendor. The transformers shall be of the liquid immersed, inert gas sealed, oil air/future forced air (OA/FFA) cooled type. The transformers shall be suitable for outdoor operation. The transformers shall be built and braced for rectifier service with ratings and configurations as shown on the attached Data Sheet, which shall be considered part of this specification. The transformer shall give full rated performance with an input voltage of 13.8 kV, +10%, -5%, without exceeding the specified temperature rise. The OA and FA ratings are given in the Transformer Data Sheet.

1.4 The Vendor shall supply all labor, materials and equipment necessary to design, manufacture and test the power supplies described in this specification. The Vendor shall also provide all labor and resources to produce detailed up to date documentation of the power supply as built. It shall be the responsibility of the Vendor to ensure that the powers supply the requirements of this specification in a highly reliable and conservative fashion. The equipment shall be designed to have an expected service life of greater than twenty years.

1.5 The design of this power supply be conservative, using standard commercially available component parts and techniques that insure high reliability and minimum maintenance. A very high priority shall be given to issues of mean time to repair such as modularity, layout of critical components and ease of serviceability. The detailed parameters for this power supply are given in the Specification Data Sheet which is 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 form a part of this specification and are to be used as standards in the design and manufacture of the rectifier module. Unless otherwise specified, the issue date or revision level shall be that in effect on the date of the Invitation to Quotation. Exceptions to these standards shall be approved in writing by BNL.

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2.2 All equipment supplied under this specification shall be in strict accordance with the latest standards, publications and definitions of the IEEE, ANSI, NEMA and NEC where applicable. The power supplies shall be manufactured in accordance with the best of existing techniques and recognized engineering practices. In all cases reference shall be made to recommended procedures of standards of the above organizations. Where this specification differs from the above standards and procedures, this specification shall apply, (see 3.1.3).
3.0  General Requirements

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

3.1  Parts, Materials and Processes

3.1.1  Materials that may be defined as hazardous in accordance with Title 29, Code of Federal Regulations, Section 1910.1200 shall not be used. More specifically, asbestos or asbestos-type insulation, insulating or dielectric fluids containing PCB's, etc., shall not be used. Where a choice of materials is available, eg. cables, support hardware, etc., preference shall be given to material or equipment exhibiting a higher level of fire retardancy, low oxygen content, etc.

3.1.2  The specifications for the various portions of the work describe certain special materials, processes and products of manufacture that will be required unless BNL Division of Contracts and Procurement specifically approves equal construction in writing. Should the Vendor propose to furnish other "equal" materials, processes, or products either in substitution for, or as an alternate to the specifications, Brookhaven can approve such substitution only if described in full detail. The Cognizant Engineer's 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 Vendor from his 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 Vendor's proposal and the standards or Brookhaven's requirements shall be resolved by the Cognizant Engineer's determination. Vendors 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 Vendor will be held responsible for the design, construction and testing of the power supply. However, the Vendor will not be held responsible for the installation and system testing of the unit at ORNL.

3.2  Submittals by Vendor

3.2.1  The Vendor shall submit a proposal that gives a PARAGRAPH by PARAGRAPH response as to how he intends to comply with this specification. Any exceptions that the Vendor may take to the specification shall be clearly noted in the proposal, in a section labeled "Exceptions to the Specification." The Vendor shall specifically state in the proposal that he is in full compliance with all aspects of these specifications that are not noted in the “Exceptions to the Specification” section.

3.2.2  The Vendor shall fill out the attached form entitled "Vendor Data Sheet" and return it with his proposal.

3.2.3  The Vendor’s proposal shall include a list of power supplies with similar ratings and construction that the Vendor has produced and shipped. The list shall include the performance data for these power supplies, the purchaser's name and shipping date.

3.2.4  The Vendor shall describe in his proposal the testing capabilities of his facility and the electrical capacity of the test site. The Vendor will be required, as an option, to perform a long-term full load test of this power supply. This test may be performed at an independent test facility. The cost for this full load test and the location and capabilities of the test facility selected shall be clearly stated in the Vendor's proposal. (see section 6.4)

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

3.2.6  Four (4) weeks prior to first article testing, the Vendor shall submit for BNL's review and approval, a
copy of the final test procedure.

3.2.7 The Vendor shall specify in detail the guarantee period and its provisions in his proposal.

3.3 Documentation

3.3.1 Paper Drawings - Upon delivery of the equipment, five (5) sets of final as built, signed prints shall be supplied by the Seller. These prints shall be made to the highest professional drafting standards. These prints shall include schematics of all circuits, and all assemblies, down to the card level. Each component shall be identified by it’s reference number, as well as it’s commercial part number. No markings shall be obliterated.

3.3.2 Electronic Drawings - All drawings supplied in paragraph 3.2.1 shall be supplied in electronic form. AutoCAD format is acceptable. Any other format must be approved by BNL.

3.3.3 Paper Manuals - Five (5) sets of bound design and operations manuals shall be shipped with the equipment. They shall include final parts lists, recommended spare parts lists, technical descriptions of the power supply operation and maintenance recommendations, detailed circuit descriptions, description of critical adjustments and potentiometer settings, and data sheets on gauges, meters, fuses, semiconductors, relays, valves, and other pertinent components.

3.3.4 Electronic Manuals - The manuals supplied in paragraph 3.2.3 shall be supplied in electronic form. Microsoft Word for Windows format is acceptable. Any other format must be approved by BNL.

3.3.5 Software Documentation - If software is used to program any device, such as microcontrollers, programmable gate arrays, PLCs, or any other device, the source code for that software shall be delivered in paper and electronic forms.

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

3.4 Design Reviews

3.4.1 Prior to awarding a contract under this specification a pre-award meeting shall be held at the Vendor's facility. At this time a preliminary review of the submitted design will be held and the capability of the Vendor to produce these rectifiers in a timely manner will be evaluated.

3.4.2 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 Vendor'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 fully documented by the Vendor and submitted to BNL for approval. After written approval of the FDR by BNL the Vendor shall promptly begin the production of the power supply.
4.0 Performance and Design Characteristics

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

4.1 Controlled Rectifier Modules

4.1.1 The thyristor module shall be supplied completely assembled in an all metal enclosure together with the passive filter system, protection, control and monitoring circuitry. A simplified schematic diagram is shown in Fig. 1.

4.1.2 The rectifier module to be supplied shall be dual, series connected (SCR bridge A & B), three phase, full wave, full control, SCR bridges with two separate three (3) phase AC inputs. The two AC inputs, produced by the Vendor Supply outdoor rectifier / phase shifting transformer, will be phase shifted 30 electrical degrees from each other. The DC output of the two bridges shall be connected in series to produce a 12-pulse output. In all cases the construction of the rectifier module shall exemplify symmetrical, balanced construction so that stray inductances and stray capacitances (i.e. series and shunt reactances) are equal in the three phases with respect to each SCR as well as between bridges and ground.

4.1.3 One of the most exacting requirements of the rectifier module is to provide balanced 12-pulse DC output voltage that is as close to the theoretical ideal as possible. Typically, the amounts of subharmonic output components of voltage ripple should be less than three percent (3 %) of the fundamental. This is measured as a ratio of each component peak to peak to the fundamental peak-to-peak value. Therefore, reactance unbalance in both the transformers and rectifier modules, and SCR timing errors and delays must be minimized. The timing errors refer to both trigger circuitry errors as well as inherent device errors (e.g., excessive SCR T-ON or T-OFF variations).

4.1.4 The surge ratings of the individual SCRs used and the (internal) construction of the rectifier module and transformer shall be such that the power supply can handle the full expected fault current of the system until the external protective devices can safely shut the system down without damage. The fault current time period will be for ten (10) power line cycles at 60 Hz. or less.

4.1.5 The power supply will be controlled and protected by a medium voltage circuit breaker connected to the primary side of the rectifier transformers. The Vendor is required to supply those sensors needed to activate protection circuitry and support the application of externally generated signals needed for the protection of the module.

4.2 Transformers

4.2.1 The transformer impedance, based on the nominal convection cooled (OA) KVA rating, shall not differ from the value as specified on the transformer data sheet by more than +/- 5% of nominal.

4.2.2 The voltage ratio, phase shift and phase balance in each transformer shall be maintained from no load to full load conditions within close limits, as specified in the data sheets.

4.2.3 The transformers shall be designed to avoid all mechanical resonances at frequencies less than 150 Hz.

4.2.4 The transformers shall have an extended delta primary and a wye secondary. The transformers shall have secondary taps as defined in the data sheet. The taps shall be changed by means of an external manual tap-changing switch. All taps shall be rated for full rated secondary current. Alternate schemes such as Delta primary and Zig-Zag secondary or configurations with primary taps may be proposed and will be evaluated by BNL.

4.2.5 Transformers that differ only in the direction of their phase rotation shall be of identical construction. The phase rotation shall be selectable by connection of the winding terminals accessible from the service ports.
or top cover, both lead and lag configuration shall be possible within the same units.

4.2.6 The observed average winding temperature rise, by resistance measurements, shall not exceed 55 degrees C at full rated KVA. The hot spot winding temperature rise shall not exceed 80 degrees C for a 30 degree C average ambient temperature (40 degree C peak) over a 24 hour period without fans. The temperature rise of the insulating liquid shall not exceed 55 degrees C when measured near the top of the main tank.

4.2.7 The Vendor shall take into account the additional transformer losses caused by the harmonic load currents generated by the rectifier module. The Vendor shall use the theoretical harmonic content of the line current for each transformer, in percent of the fundamental as defined in the ANSI/IEEE Standard 519, for purposes of heat load design and calculation.

4.2.8 The transformers shall be designed and braced to withstand the available short circuit currents as specified in the transformer data sheets.

4.2.9 The core shall be of non-aging high permeability silicon steel in thin laminations, properly annealed after cutting and with smooth edges. Both sides of each sheet shall have a baked on heat resistant insulation. All materials used shall be chemically non-interactive with the selected transformer insulating fluid. The core shall be carefully assembled and rigidly clamped in all directions to insure adequate mechanical strength and to reduce vibration to a minimum under all operating conditions.

4.2.10 The core shall be solidly grounded at one location only. The core ground strap shall be conveniently located for ease of inspection and testing through an inspection port.

4.2.11 All windings shall be made of high-grade electrical copper with a conductivity of 101% IACS as per ASTM standards. There shall be no bolted, soldered, or welded connections or splices in any of the windings except tap connections. The primary and secondary windings shall be cylindrical and concentric with anchoring clamps suitable for rectifier duty. They shall be sized and clamped to handle the rms operating, inrush and peak let-through currents.

4.2.12 The windings shall have high dielectric and mechanical strength and shall be arranged to permit free circulation of the insulating fluid. They shall be adequately braced to prevent distortion due to any operating or fault condition. The coils shall be constructed, shaped and braced to allow for expansion and contraction due to temperature changes while avoiding abrasion of the insulating materials. Proper internal barriers shall be provided and the end coil insulation shall have additional protection against high voltage stress breakdown.

4.2.13 The transformer shall be constructed with electrostatic shields properly isolated and grounded via a visible ground strap.

4.2.14 All taps shall be rated for the maximum operating current capacity of the transformer.

4.2.15 The windings shall withstand induced and dielectric test voltages in accordance with ANSI C57 and as required in this specification.

4.2.16 The transformers shall have the primary, secondary and neutral leads brought out from the tank through bushings rated for full current and the appropriate voltages. The high voltage bushings shall have a BIL rating of 110 KV and the low voltage bushings shall have a BIL rating of 60kv. The high voltage bushings shall be tested at 34 kV rms as per ANSI C57. All bushings shall be ceramic, homogeneous and free from cavities or other flaws affecting their mechanical strength or dielectric qualities. All bushings shall be impervious to moisture and shall be oil tight.

4.2.16 The secondary and neutral bushings shall be located at the top of the transformer. The primary bushings shall be separately enclosed in suitable outdoor enclosures. The primary cable entry shall be either through the top or the bottom of the bushing enclosure via metal conduit. The doors of the enclosure shall be interlocked with micro-switches; the contacts of which shall be wired to the Main Terminal Box in a suitable conduit. Two sets of form C contacts shall be provided per door suitable for operation on a 24 volt DC system. The enclosure doors shall be electrically bonded to the tank.
4.2.17 All tanks shall be designed for outdoor service. All exterior surfaces shall be free of scale, rust and grease. The tank shall be painted with two coats of rust proof primer and two coats of exterior semi-gloss enamel, color "pale yellow beige" as per Federal standard No.595B, color No.37886.

4.2.18 The tank shall have adequate radiators mounted on it to maintain the proper cooling for the transformer. The seller shall specify the type and number of forced air cooling fans that can be mounted on the radiators (FFA). These will not be part of the order, however the seller shall make provisions for their mounting.

4.2.19 All tanks shall be made of steel and shall be oil tight and shall be constructed for Inert Gas Pressure Operation with a removable top cover. All gaskets shall be made of material, which will not deteriorate under normal service conditions. All hardware shall be stainless steel, including but not limited to bolts, nuts, washers, etc.

4.2.20 Suitable hatches shall be provided to facilitate servicing.

4.2.21 The tank shall be provided with a pressure relief diaphragm or valve of adequate size to protect the tank against an explosion due to arcing below the surface of the oil. The relief device shall be designed to minimize the discharge of oil and the entrance of air and water after it has opened. It shall be equipped with alarm contacts suitable for operation on 24-volt DC circuits. The alarm contact leads shall be run via a suitable conduit to the main watertight terminal box mounted on the tank.

4.2.22 The tank shall be able to withstand an internal vacuum of 1 torr without deforming. The transformer shall operate pressurized with an inert gas (N2) to a pressure of several pounds per square inch. The pressurized transformer shall not exhibit any leaks, especially around the sealed top of the unit, fittings, valves, and other tank penetrations.

4.2.23 The vendor shall provide the following valves especially designed for use with the selected insulating fluid and which shall hold hot fluids without leaking.

   4.2.23.1 Valve for draining and sampling the liquid in the extreme bottom of the tank.
   4.2.23.2 Lower filter press connection and complete drain.
   4.2.23.3 Upper filter press connection.
   4.2.23.4 Liquid inlet and outlet shutoff valve.
   4.2.23.5 Valve for draining the radiators.
   4.2.23.6 Gas pressurization regulator valve, regulator range of 1 to 10 psi.

4.2.24 The transformers shall be provided with a magnetic type fluid level gauge equipped with adjustable low level alarm contacts (form C) suitable for operation on a 24 volt DC system. The alarm contact leads shall be run to the main terminal box in a suitable conduit. The gauge shall have a dark face dial with light markings and a light colored indicating hand. The diameter of the dial (inside bezel) shall be 3-1/4 inch, +/-1/4 inch. The dial markings shall show the 25 degrees C level and the minimum and maximum levels. The words "liquid Level" shall be on the dial or on a easily visible nameplate adjacent thereto. The 25 degrees C liquid level shall be shown on the tank by suitable permanent markings.

4.2.25 The transformer shall be provided with an indicating dial thermometer to indicate the oil temperature. It shall be equipped with adjustable alarm contacts (form C) suitable for operation on a 24 volt DC system. The alarm contact leads shall be run to the main terminal box in a suitable conduit. The thermomter shall have a dark face dial with light markings, a light colored indicating hand, and an orange-red maximum indicating hand, with provision for resetting. The diameter of the dial (inside bezel) shall be 4-1/2 inches, +/-1 inch. The dial markings shall cover a range of 0 to 120 degrees C. The words "liquid Temperature" shall be on the dial or on a suitable nameplate mounted adjacent to the indicator.

4.2.26 A winding temperature simulator device with a thermal element mounted in a well and responsive to the simulated winding hottest spot temperature of the transformer shall be provided. It shall be equipped with adjustable alarm contacts (form C) suitable for operation on a 24 volt DC system. The leads shall be run to the main terminal box in a suitable conduit. The instrument shall have a dark face dial with light markings, a light colored indicating hand, and an orange-red maximum indicating hand with provisions for resetting. The
diameter of the dial (inside bezel) shall be 4-1/2 inches, +/-1 inch. The dial markings shall cover a range of 0 to 180 degrees C. The words "Winding Temperature" shall be on the dial or on a suitable nameplate mounted adjacent to the indicator.

4.2.27 The transformer shall be provided with a pressure-vacuum gauge. The scale range for the pressure-vacuum gauge shall be between 10 psi positive and negative. The diameter of the dial (inside bezel) shall be 3-1/2 inches, +/-1/4 inch. The gauge shall have a dark-face dial with light-colored markings and a light-colored pointer.

4.2.28 The tank shall be provided with two (2) NEMA standard stainless steel ground pads located diagonally opposite each other at the base of the tank for BNL's use. These pads shall be drilled and tapped to accept NEMA 2 lugs.

4.2.29 All tanks shall be equipped with lifting eyes and skid rails suitable for frequent lifting and handling of the transformers by overhead crane and forklift.

4.2.30 Data sheets describing all gauges, meters and protective devices shall be included in the design manual, see section 3.8.3.

4.2.31 The transformer shall use silicone insulating fluid.

4.2.32 A data sheet describing the insulating fluid shall be included in the design manual, see section 3.8.3.

4.2.33 All accessories that require wiring shall be provided with a suitable galvanized steel conduit run to a watertight hinged terminal box. This box shall be mounted on the tank and shall house a terminal board to provide connections to controls, alarms and auxiliary power cables. The terminal box shall be watertight for outdoor use and provided with conduit entrance fittings for use by BNL. There shall be 10 spare terminals provided for later use by BNL. An electrical drawing shall be supplied showing how all the components are wired and how they can be interconnected to BNL's circuitry.

4.2.34 The vendor shall supply a stainless steel type "C" nameplate for each transformer giving all standard information, including the following:

4.2.34.1 Manufacturer's name and address.
4.2.34.2 Manufacturer's part number.
4.2.34.3 BNL's part number.
4.2.34.4 Type, serial number and date of manufacture.
4.2.34.5 Input voltage and current rating (OA).
4.2.34.6 Output voltage and current rating for each tap (OA).
4.2.34.7 KVA ratings.
4.2.34.8 Percent Impedance.
4.2.34.9 Total weight with and without oil, tank weight.
4.2.34.10 A phase shift diagram.
4.2.34.11 Outline diagram including wiring and terminal designation in their relative location.
4.2.34.12 Allowable temperature rise.
4.2.34.13 x/r ratio at rated load and 40 degrees C ambient.
4.2.34.14 Insulating fluid volume and type.
4.2.34.15 Maximum tank pressure.
4.2.34.16 The change in liquid level per 10 degrees C change in temperature.

4.2.35 A transformer / winding data sheet shall be provided in the design manual.
5.0 Control and Instrumentation Interface

5.1 Control States

5.1.1 OFF - When AC power is applied to the power supply, it shall automatically go into this OFF state.
   a) AC power is connected to the power supply.
   b) The main contactor is open, preventing AC power from being applied to the power stages of the unit (rectifiers, SCRs, transformer inputs). No power is delivered to the load.
   c) The fans are off.
   d) Internal control power, sufficient for the unit to respond to other commands and indicate state is available.
   e) The OFF indicator is illuminated, and the OFF state is indicated as a status readback to the PSI.

5.1.2 STANDBY
   a) AC power is connected to the power supply.
   b) The main contactor is open, preventing AC power from being applied to the power stages of the unit (rectifiers, SCRs, transformer inputs). No power is delivered to the load.
   c) The fans are on.
   d) Internal control power is applied to all circuit boards, including regulators and control circuitry.
   e) The STANDBY indicator is illuminated, and the STANDBY state is indicated as a status readback to the PSI.

5.1.3 ON
   a) AC power is connected to the power supply.
   b) The main contactor is closed, applying AC power to the power stages of the unit (rectifiers, SCRs, transformer inputs). The load is powered.
   c) The fans are on.
   d) Internal control power is applied to all circuit boards, including regulators and control circuitry.
   e) The ON indicator is illuminated, and the ON state is indicated as a status readback to the PSI.

5.1.4 FAULT
   a) AC power is connected to the power supply.
   b) The main contactor is open, preventing AC power from being applied to the power stages of the unit (rectifiers, SCRs, transformer inputs). No power is delivered to the load.
   c) The fans are on.
   d) Internal control power is applied to all circuit boards, including regulators and control circuitry.
   e) The STANDBY and FAULT indicators are illuminated, and the STANDBY state is indicated. The SUMMARY FAULT and individual faults are sent as status readbacks to the PSI.
   f) Fault events are latched in this state.

5.1.5 State Transitions - State transitions shall be as shown in Figure 5-1.
5.2 Operating Modes

5.2.1 The power supply shall operate in either Local or Remote mode as controlled by a front panel switch. 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 provided interface card. Remote mode status will be reported to the computer controller as true.

5.3 Local Instrumentation

5.3.1 There shall be front panel metering as described below. All monitoring will be fully functional in both Local and Remote modes.

5.3.1.1 An 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.

5.3.1.2 An 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 CTs. The seller shall supply the necessary current transformers.

5.3.1.3 A DC voltmeter operated from a buffered output of DC potential transformer (DCPT) connected across the power supply output terminals. The DCPT shall have an accuracy of +/- 1 %. The DCPT shall be similar to the Liaisons Electroniques Module LV series. An isolated and buffered output shall be provided for local voltage monitoring.

5.3.1.4 A DC ammeter that shall operate from a buffered output of the DC current transducer (DCCT) used for regulation. The output current measurement shall have a stability of five (5) times better then the value specified for output current.

5.3.2 There shall be front panel BNC connectors as monitors as described below:
5.3.2.1 Output Current - A buffered monitor of the output current, with a scale factor of 10V = Full Scale Current, a bandwidth of 1KHz, an accuracy equal to that of the power supply, and capacity to drive 10KΩ.

5.3.2.2 Output Voltage - A buffered monitor of the output voltage, with a scale factor of 10V = Full Scale Current, a bandwidth of 10KHz, an accuracy of 1%, and capacity to drive 10KΩ.

5.3.3 There shall be front panel LED indicators as described below:

5.3.3.1 State indicators (in the stated colors): ON (green), STANDBY (yellow), OFF (red), and FAULT (white).

5.3.1.2 Fault indicators: Each fault will be indicated with a red LED.

5.3.1.3 Interlock indicators: Each interlock will be indicated with a red LED.

5.3.4 There shall be front panel test points to assist in limit setting. These tests points shall be located near the corresponding limit adjustment (as described in 5.4.1.3). They shall include both the voltage and the voltage reference point (typically ground). Mechanically, they will selected to accept standard voltage meter probes, and spaced for those probes. Electrically, they shall be buffered and protected against short circuits.

5.3.3.1 Voltage Limit - The scale factor is 10 V per full scale output voltage. The power supply shall limit it's output voltage to no more than this value, regardless of either local or remote settings.

5.3.3.2 Current Limit - The scale factor is 10 V per full scale output voltage. The power supply shall limit it's output voltage to no more than this value, regardless of either local or remote settings.

5.3.3.3 Current Slew Rate Limit - The scale factor is 1 V per second of slew time to full scale. For example, 8.3 V would indicate a slew rate that would allow the output current to rise no faster than to go from zero current to full scale current in 8.3 seconds.

5.4 Local Controls

5.4.1 Active in Both Local and Remote Modes - The se controls are operated locally, but are fully functional in both Local and Remote Modes.

5.4.1.1 CRASH - A momentary switch, with a large red button, that when pressed, puts the power supply in the off mode regardless of current state, local inputs, or remote inputs.

5.4.1.2 LOCAL/REMOTE - This is a toggle action switch selects either the Local or Remote modes. The state of this switch is unaffected by power removal and re-application.

5.4.1.3 Limit Setpoints - These setpoints are to accessible from a front panel, but shall be recessed, and require a screwdriver to make adjustments.

5.4.2 Active in Local Mode Only - The se controls are operated locally, and are functional in Local Mode only.

5.4.2.1 Mode Switches - These three momentary pushbutton switches, labeled OFF, STANDBY/RESET, and ON, are used to control the state of the power supply locally, as described in the state diagram, Figure 5-1.

5.4.2.2 Local Reference - There will be two ways to provide a local reference, as selected by a front panel toggle switch. In one position, the reference is provided by a ten turn potentiometer. In the second position, it is provided by a signal applied to a front panel BNC. This front panel BNC will be terminated with 100KΩ such that if there is no input, the reference will be near zero.
This will act as the local current reference in the current mode, and the local voltage reference in the voltage mode.

5.4.2.3 Voltage/Current Mode - This selects whether the supply is operating in the current or voltage modes.

5.5 Remote Power Supply Interface

BNL will provide the seller with a Power Supply Interface (PSI) units and a Power Supply Controller (PSC), which together provides the control and monitoring function under accelerator operation. Acceptance tests shall be performed with the PSI/PSC system operating the power supply.

In the Local mode, the analog setpoint and all commands are to be ignored by the power supply, but analog readbacks and status bits must continue to be provided by the power supply.

5.5.1 Mechanical Requirements- The PSI is packaged in a standard 19" rack enclosure, 1.75' in height (1U), and 10" deep, max. The PSI shall be mechanically integrated into the power supply by the vendor.

5.5.2 Electrical Requirements- The PSI shall be electrically integrated into the power supply by the vendor, who shall also provide power to the PSI. The PSI will have a standard 115 VAC plug, and requires less than 30W of 115VAC, 60Hz power.

5.5.3 Signal Requirements - The PSI is connected to the power supply by two cables, one analog and one digital, as described below. The vendor shall supply these cables.

5.5.3.1 Analog Interface

a) Analog Output - There is one analog output from the PSI to the power supply. This shall be used for the current setpoint. This is unipolar (0V to 10V). It is designed to be received differentially, and will drive loads whose resistance is 10KΩ or greater.

b) Analog Inputs - There are four analog inputs to the PSI from the power supply. These shall be used for current setpoint, measured current, measured voltage, and measured current error. These are always bipolar (±10V). They are received differentially, with a load whose resistance is 5KΩ or greater.

c) Connectors - All connectors are nine pin standard D connectors, with gender as follows:

- On PSI: Male
- On PSI end of Cable: Female
- On Power Supply end of Cable: Female
- On Power Supply: Male

Connectors on both ends of the cable are to be supplied with strain relief back shells.

d) Pin Designations - The pin designations are given in Table 5-1, and the general arrangement is given in Figure 5-2.

e) Cable - An assembly of two separate cables, as seen in Figure 5-2, joins the connectors. One is a shielded twisted pair, and the other is a shielded twisted five conductor cable.
Figure 5-2. Analog Cable - General Arrangement

Table 5-1. Analog Cable Pin Designation

<table>
<thead>
<tr>
<th>Pin</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Current Error Analog Input</td>
</tr>
<tr>
<td>2</td>
<td>Measured Voltage Analog Input</td>
</tr>
<tr>
<td>3</td>
<td>Measured Current Analog Input</td>
</tr>
<tr>
<td>4</td>
<td>Current Setpoint Analog Input</td>
</tr>
<tr>
<td>5</td>
<td>Setpoint Analog Output</td>
</tr>
<tr>
<td>6</td>
<td>Input Shield</td>
</tr>
<tr>
<td>7</td>
<td>Input Return</td>
</tr>
<tr>
<td>8</td>
<td>Setpoint Shield</td>
</tr>
<tr>
<td>9</td>
<td>Setpoint Return</td>
</tr>
</tbody>
</table>
5.5.3.2 Digital Interface

a) **Digital Outputs** - There are sixteen digital outputs from the PSI to the power supply. They are designed to provide standard five volt TTL logic levels, and must be terminated by a 1KΩ resistor to digital ground in the power supply. All outputs are TRUE high (TTL logical 1), except for OFF, which is TRUE low (TTL logical 0). This will cause the power supply to shut off if the PSI loses power.

b) **Digital Inputs** - There are sixteen digital inputs to the PSI from the power supply. They accept standard five volt TTL logic levels, and each will be terminated in the PSI by a 1KΩ resistor to digital ground. All outputs are TRUE high (TTL logical 1).

c) **Connectors** - All connectors are 37 pin standard D connectors, with gender as follows:

- On PSI: Female
- On PSI end of Cable: Male
- On Power Supply end of Cable: Male
- On Power Supply: Female

Connectors on both ends of the cable are to be supplied with strain relief back shells.

d) **Pin Designations** - The pin designations are given in Table 5-2. The interpretation of these signals may change as a function of power supply type, but the designations as input or output will not.

e) **Cable** - A shielded twisted 37 conductor cable joins the connectors.

<table>
<thead>
<tr>
<th>Pin</th>
<th>Function</th>
<th>Pin</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>On Command</td>
<td>20</td>
<td>Off Command</td>
</tr>
<tr>
<td>2</td>
<td>Standby Command</td>
<td>21</td>
<td>Reset Command</td>
</tr>
<tr>
<td>3</td>
<td>Negative Polarity Command</td>
<td>22</td>
<td>Spare Command #1</td>
</tr>
<tr>
<td>4</td>
<td>Spare Command #2</td>
<td>23</td>
<td>Spare Command #3</td>
</tr>
<tr>
<td>5</td>
<td>Spare Command #4</td>
<td>24</td>
<td>Spare Command #5</td>
</tr>
<tr>
<td>6</td>
<td>Spare Command #6</td>
<td>25</td>
<td>Spare Command #7</td>
</tr>
<tr>
<td>7</td>
<td>Spare Command #8</td>
<td>26</td>
<td>Spare Command #9</td>
</tr>
<tr>
<td>8</td>
<td>Spare Command #10</td>
<td>27</td>
<td>Spare Command #11</td>
</tr>
<tr>
<td>9</td>
<td>Digital Ground</td>
<td>28</td>
<td>Digital Ground</td>
</tr>
<tr>
<td>10</td>
<td>Digital Ground</td>
<td>29</td>
<td>Digital Ground</td>
</tr>
<tr>
<td>11</td>
<td>Digital Ground</td>
<td>30</td>
<td>On Status</td>
</tr>
<tr>
<td>12</td>
<td>Off Status</td>
<td>31</td>
<td>Standby Status</td>
</tr>
<tr>
<td>13</td>
<td>Negative Status</td>
<td>32</td>
<td>Fault Summary</td>
</tr>
<tr>
<td>14</td>
<td>Overvoltage</td>
<td>33</td>
<td>Overcurrent</td>
</tr>
<tr>
<td>15</td>
<td>Out of Regulation</td>
<td>34</td>
<td>Fan Fault</td>
</tr>
<tr>
<td>16</td>
<td>Overtemp</td>
<td>35</td>
<td>Water Flow Fault</td>
</tr>
<tr>
<td>17</td>
<td>Water Mat Fault</td>
<td>36</td>
<td>Security Interlock</td>
</tr>
<tr>
<td>18</td>
<td>Ground Fault</td>
<td>37</td>
<td>Ripple Fault</td>
</tr>
<tr>
<td>19</td>
<td>Phase Fault</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.6  **External Interlocks**
The function of the external interlocks is to shut down the power supply in response to external events that could cause overload conditions to the power supply or it’s load. These include loss of magnet water flow, magnet over-temperature, and other external events.

5.6.1 Terminal Block

5.6.1.1 Physical Characteristics - An eight position terminal block with screw terminals will be provided for interface with the external interlocks. The terminal block shall be able to accommodate wires in the range of AWG #22 to AWG #16.

5.6.1.2 Pin Numbering - The pin numbering is shown in Table 5-3.

Table 5-3. Interlock / Fan Control Terminal Block Numbering

<table>
<thead>
<tr>
<th>Pin</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Magnet Overtemp</td>
</tr>
<tr>
<td>2</td>
<td>Magnet Overtemp</td>
</tr>
<tr>
<td>3</td>
<td>Spare External Interlock #1</td>
</tr>
<tr>
<td>4</td>
<td>Spare External Interlock #1</td>
</tr>
<tr>
<td>5</td>
<td>Magnet Water Flow</td>
</tr>
<tr>
<td>6</td>
<td>Magnet Water Flow</td>
</tr>
<tr>
<td>7</td>
<td>Spare External Interlock #2</td>
</tr>
<tr>
<td>8</td>
<td>Spare External Interlock #2</td>
</tr>
</tbody>
</table>

5.6.1.3 Shipping / Testing Jumpers - The power supply will be shipped with all interlock connections shorted with a jumper. These will be removed after installation.

5.6.2 Operational Details

5.6.2.1 Operation - The interlock inputs will be connected to a normally closed dry contact. When this contact opens, it will cause the power supply to go into the FAULT mode as described in the power supply specification.

5.6.2.2 Signal Levels - The contacts for these inputs are typically 1,000 feet away from the power supply. The voltage that appears on an open contact shall not be more than 30 Volts, but not less than 15 Volts. The current through a closed contact shall not be more than 100 mA, nor less than 10 mA.

5.7 Personnel Protection System (PPS) Interface

The function of the PPS interface to the power supplies is to have the ability to drop out (de-energize) the main contactor of the power supply in a fail-safe manner. Positive indication of this de-energized state is sent back to the PPS by means of auxiliary contacts from the power contactor.

5.7.1 Interface General Description

The elements of the PPS interface are shown in Figure 5-3.

The basic concept is to have a direct, fail-safe connection between external 24VDC control source and the coil of the main contactor. Removing the external control source prevents main power from reaching the converters.

In the case of high power SCR power supplies, it is advantageous to remove gating to the SCRs prior to opening the main contactor. This is the function of the Delay Relay. The MPS signal is derived from the PPS relay contact closure, so that system can be informed of the impending shut-down. If a topology other than thyristor phase control is used, the function of the delay relay may not be required.
5.7.2 PPS Interface Details

5.7.2.1 Connector - The PPS interface connector on the power supply is Amphenol P/N 97-4102A-18-19S. This is a box mounted receptacle with ten female crimp pins. The pin designations for this connector are shown in Table 3.

5.7.2.2 Test Plug - A test plug, to permit operation of the power supply without the PPS, shall consist of the mating connector to the PPS interface connector described in 5.6.2.1 with pins A and B shorted and pins C and D shorted, and a backshell to assist handling. One test plug assembly will be supplied with each power supply.

5.7.2.3 PPS Pin Designation - The pin designations are shown in Table 5-4.
5.8 Machine Protection System (MPS) Interface

The function of the MPS interface described in this section, is to indicate when the power supplies has power to its output leads. This will be derived from sensing the state of the power contactor.

5.8.1 Interface Details

The elements of the MPS interface are shown in Figure 5-4.

<table>
<thead>
<tr>
<th>Pin</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>+24 VDC</td>
</tr>
<tr>
<td>B</td>
<td>Contactor Coil: +24 VDC Side</td>
</tr>
<tr>
<td>C</td>
<td>Contactor Coil: +24 VDC Return Side</td>
</tr>
<tr>
<td>D</td>
<td>+24 VDC Return</td>
</tr>
<tr>
<td>E</td>
<td>Aux Contact 1 - Pin 1</td>
</tr>
<tr>
<td>F</td>
<td>Aux Contact 1 - Pin 2</td>
</tr>
<tr>
<td>G</td>
<td>Aux Contact 2 - Pin 1</td>
</tr>
<tr>
<td>H</td>
<td>Aux Contact 2 - Pin 2</td>
</tr>
<tr>
<td>J</td>
<td>Chassis Ground</td>
</tr>
<tr>
<td>K</td>
<td>Not Used</td>
</tr>
</tbody>
</table>

Figure 5-4  MPS Interface Elements

5.8.2 Connector

The MPS interface connector on the power supply is an Amphenol C 091 B 4 (four) pin series connector, with IEC contact arrangement 130-9 with female gold plated crimp contacts, in an outside bayonet panel mounted configuration. Acceptable part numbers are T 3327 550 and T 3327 050.

5.8.3 Signal Levels

A TTL level HIGH signal capable of driving an HPCL2612 optocoupler (10 mA) is the input to the
5.3 Final Acceptance

For purpose of warranty under an order for these transformers, final inspection (acceptance) is defined as the successful completion of acceptance tests at BNL to substantiate the compliance of the modules with this specification. Final Acceptance will be completed within twelve (12) months after receipt of the units at BNL. 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 transformers produced and delivered to BNL.

Final Acceptance testing at BNL shall include any or all of the following tests:

a. Hi-pot testing
b. Full power heat run
c. Interlock and protection circuits
d. Any other standard tests deemed necessary by the BNL cognizant engineer to confirm conformance to the specification.

6.0 Preparation for Delivery

All units and parts of the equipment shall be properly packaged and delivered in an undamaged condition to BNL. All transformers shall be shipped with insulating fluid and shall be pressurized with an inert gas. The seller shall ship all transformers via air ride trucks. Devices shall be installed on the transformers during shipment which will record any unusual mechanical shocks or tipping.

7.0 Notes

7.1 Definitions

7.1.1 BNL - BNL shall mean the Associated Universities, 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.

7.1.2 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.

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

7.1.4 ANSI - American National Standards Institute.

7.1.5 ASTM - American Society for Testing Materials.

7.1.6 IACS - International Annealed Copper Standard.

7.1.7 IEEE - Institute of Electrical and Electronics Engineers.

7.1.8 NEMA - National Electrical Manufacturers Association.

7.1.9 NEC - National Electrical Code.

7.1.10 FFA - Future Forced Air.

7.1.11 OA - Oil to Air.

7.1.12 FA - Forced Air.

4.3 Power Semiconductor Ratings

4.3.1 The peak inverse voltage (PIV) and peak forward voltage (PFV) rating of all power semiconductors, SCRs and free wheeling diodes (FWD), shall be rated for three (3) times their peak circuit operating voltage or greater.

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

4.3.3 The SCRs shall be protected against high di/dt stress and dv/dt breakover. 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 overvoltage 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 selenium surge suppressors on the high power circuits. In these cases, fuse status monitoring shall be provided to the PLC (see 4.6.6) for interlock control and status.

4.3.4 The continuous current rating of all silicon rectifiers and SCRs shall be at least two (2) times greater than the maximum RMS current the device will conduct during operation of the rectifier module.

4.3.5 The number of SCRs used in the bridges shall be limited to one (1) SCR per leg; series
or parallel SCRs will not be permitted.

4.3.6 The size of the individual SCRs used shall be 67mm or greater. The Brown-Boveri Co. type 2102, the Marconi Electronic Devices, Inc. type DCR1675 and DCR1474 series, the Powerex Inc. TA20 and TD20 series, and the Siemens Corp. type BST U68 series, are some of the acceptable devices. The Vendor shall provide in his proposal data sheets that indicate the type of device and ratings chosen.

4.3.7 The SCRs and FWDs shall be water cooled. The units shall be mounted and clamped on water cooled heatsinks 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. Individual cooled SCR heatsinks shall have an over temperature protection scheme, such as thermostat type switch, mounted close to the SCR which shall be set to trip before the SCR junction temperature reaches 100°C. The output of these switches shall be connected to the PLC (see 4.6.6). The Vendor may elect to support over temperature protection using an alternate procedure. The Vendor shall provide calculations showing the expected temperature rise with his proposed cooling and protection scheme. The over temperature monitoring circuitry must meet the high potential test in section 6.6.

4.3.8 FWDs shall be installed across the rectifier module’s output terminals before the DCCT. They shall be rated to handle the full rated DC current of the system on a continuous basis. If it is required to used parallel units, current equalization or balance circuitry must be provided.

4.3.9 The SCRs and FWDs shall be mounted with consideration for replacement and maintenance accessibility, the Vendors preliminary drawings shall show their position in the rectifier modules.

4.4 SCR Bridge Triggering

4.4.1 The Vendor shall supply the high level, hard-fired gate triggering circuitry for all SCR triggering. The high level triggering must be capable of turning on all the SCRs within the recommended manufacturer device ratings and also meet the balancing specifications of section 8.0.

4.4.2 Brookhaven will supply the low level input pulse to the Vendors low level gate triggering circuitry. Optical isolation will be required between the Vendors low level gate trigger circuit and high level trigger pulse circuitry. The use of fiber optic links between the Vendor's high and low level circuitry is the preferred method to achieve this isolation. The Vendor shall provide the fiber optic receivers, transmitters and fiber optic cables. The Brookhaven input to the Vendor’s low level triggering circuitry shall be located in the customer control compartment.

4.4.3 The Brookhaven low level trigger pulse capability is 5 volts and 40 milliamperes. The rise time (10 to 90 percent) is less than 0.5 microseconds. The range of the SCR triggering will be greater than 160 electrical degrees to reliably trigger the SCRs from full rectify to full invert. The length of the signal is 120 degrees.
4.4.4 The Vendors SCR drive circuits shall have high drive power capability (i.e. hard drive) to reduce jitter variations and total turn on time. Reverse gate bias circuitry is desirable for reliable operation while forward bias or stray positive gate bias should be avoided to prevent a reduction of blocking capability. The Brookhaven supplied low level input pulse shall be amplified to hard fire each SCR device. The Vendors provided high level trigger system shall be capable of supporting the above parameters on each SCR. The power source for the gate drive circuits may be derived from the SCR anode power or supplied from an external control power source via properly rated isolation transformers.

4.4.5 The Vendor supplied high level gate trigger circuitry shall exhibit minimum delay from the Brookhaven input low level pulse to the final output gate pulse(s). The total delay (including dead time and rise time) shall be less than \textbf{1.0 microsecond}. The time jitter of the high level gate pulses shall be less than \textbf{+/-0.5 microseconds}. The gate trigger hard drive circuitry shall be mounted close to the individual SCRs to prevent delays and to reduce the possibility of false triggering due to noise pickup in long cable runs.

4.4.6 The Vendor shall use construction and wiring techniques designed to minimize noise pickup in the triggering circuitry. This shall include the use of twisted shielded cable, proper grounding techniques, and electrostatic / electromagnetic shielding of sensitive components. All printed circuit board designs shall have large traces, ground planes, and large area pads to accommodate the high gate / cathode currents. The design shall include an adequate number of test points to facilitate troubleshooting and set up.

4.4.7 The low level triggering system will be supplied by Brookhaven for testing of the module, the design data for the firing system will be finalized after the award of the rectifier module contract.

4.4.8 The Vendors trigger circuitry will be reviewed and approved at the time of the FDR meeting. Details of the circuit design will be required two (2) weeks prior to the FDR meeting, see section 3.3.

4.5 LRC Output Filter

4.5.1 The rectifier module shall contain a high current low pass filter to attenuate the output voltage ripple. This shall be a passive, damped, filter composed of a four terminal, coupled, series choke, a shunt capacitance, and a shunt resistive / capacitive (RC) damping section. The resistor shall be chosen to approximately damp the LC filter close to critical damping. The DC blocking capacitor shall have at least 5 times the basic filter capacitance value. One leg of the choke shall be installed in each of the output DC buses (see figure 1.).

4.5.2 The peak to peak output voltage ripple shall not exceed 0.66% of the rated DC output voltage for all voltage tap settings (at the worst point between 10% and 100% of output voltage) when fed from the transformer described in section 4.2. See the specification Data Sheet (section 8.0) for complete details.
4.5.3 The passive LC RC damped filter shall attenuate all the frequency components of the rectifier power supply output voltage above the specified cutoff frequency at the specified rate.

4.5.4 The transient response of the filter's output voltage to a step change in input voltage or a step change in load shall have an overshoot which shall not exceed 30% peak above the final output voltage and shall not be oscillatory beyond the first oscillation period.

4.5.5 The filter inductor (coupled, two legs) shall be braced for short circuit fault current. The windings and bus terminals shall be copper with class H insulation. The inductor shall be water cooled with a temperature rise of 30 degrees C max. Over temperature interlock protection shall be provided and shall be wired to the rectifier module's PLC (see 4.6.6) control system for interlock control and alarm indication. The over temperature contacts shall be normally closed and shall open for over temperature state, the contacts shall be suitable for 24 volt DC operation. The filter inductor system shall be capable of meeting the high potential test defined in section 6.6. The final inductance shall be constant to within +/- 10 % of the nominal value over a frequency range of from 0 to 10 kHz and over the full output current range.

4.5.6 All capacitors used in the filter circuit shall be fused, either individually or in groups, so that their rms current is not exceeded. Fuse failure interlock protection shall be provided and shall be wired to the rectifier module's PLC control system for interlock control and alarm indication. The fuse failure contacts shall be normally closed and shall open for fuse failure. The contacts shall be suitable for 24 volt DC operation. Fuse ratings shall take into account capacitor charging and discharging currents in addition to currents caused by voltage ripple.

4.5.7 The filter capacitors shall be rated to handle all applied voltages and shall be protected from the application of reverse voltage. Bleeder resistors shall be installed across each capacitor to ensure proper discharge of the capacitors when the rectifier module is turned off. The discharge time constant is listed in the specification data sheet. The capacitors shall be capable of meeting the high potential test defined in section 6.6.

4.6 Protection Devices and Control Circuits

4.6.1 The following devices or systems, (sections 4.6.2 through 4.6.15), shall be incorporated in the rectifier module and shall be used to interlock the module to internal and external control devices. All of the interlocks and controls of each module shall be connected to a programmable logic controller in the module control compartment. Some interlock and control devices shall be wired directly to terminal strips and to external protection circuits (BNL supplied medium voltage switchgear) as well as to the programmable logic controller. These interlock circuits are defined under each device section. All control, interlock devices and circuits must meet the high potential tests of section 6.6.

4.6.2 The control voltage for the rectifier module shall be 24 volts DC. The input voltage for the 24 volt DC power supply shall be 120 volts AC externally supplied. The 24 volt power supply shall be provided by the Vendor. The 120 volt AC power shall be housed in the module 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 Vendor. Its operating handle shall be accessible without removing the 120 volt AC safety barrier. Provisions for locking the circuit breaker open shall be provided.

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

4.6.4 A high current relay or contactor shall be provided which will be used to turn the 120 VAC power to all the rectifier module control functions on and off, (Standby relay). The relay shall also turn on all regulator and SCR triggering circuitry. Extra terminals (determined at FDR) shall be provided for connection of BNL’s 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 the 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.

4.6.5 The Vendor 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 module control compartment. This relay will be used to trip the incoming 13.8 kV circuit breaker 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.

4.6.7 Over temperature protection of rectifier cells will be required (see 4.3.7). The over temperature detection devices shall be thermostat type switches (or equal) with contacts that are electrically isolated from the heatsink, and must be capable of meeting the high potential test in section 6.6. 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 4.3.7. All the over temperature devices shall be wired individually to the PLC input module for interlock control and alarm monitoring.

4.6.8 Each phase of the AC input lines to each SCR 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 SCR manufacturer's maximum specified peak one cycle surge rating (Itsm). Fuses shall not be placed in line with each individual SCR. Fuses shall be located in each AC input line of each SCR bridge. Parallel fuses may be used for proper coordination. A fuse monitoring system shall be provided. The fuse monitoring system shall provide fuse status information to the PLC 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 volt DC operation. The fuse monitoring system must meet the high potential test in section 6.6. Care should be taken to balance the internal resistance of the fuses so as not to unbalance the incoming line voltages.
4.6.9  The Vendor shall provide a DC ripple detection circuit to monitor the output of the rectifier module for phase loss, system unbalance and misfiring SCRs. This interlock shall operate within five cycles of the 60 Hz line. The levels at which this monitor shall operate are specific to the Vendor’s design and will be quantified at the FDR. The ripple detection circuit shall provide status information to the PLC for interlock control and alarm indication. The ripple detection circuit contacts shall be normally closed and shall open when a fault condition is detected. The contacts shall be suitable for 24 volt DC operation. The ripple detection circuitry must meet the high potential test in section 6.6.

4.6.10 Six (6 ea.) AC overload relays shall be wired to the Vendor supplied AC CTs (see 4.7.3) installed in the rectifier units. 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 PLC for other interlock control and alarm indication. The overcurrent 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.

4.6.11 The rectifier module 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 module’s internal DC transducer, DCCT, see section 4.7.5. The DC over current device shall be mounted in the module control compartment of the rectifier module. 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 PLC for other interlock control and alarm indication. The status and alarm contacts shall be suitable for 24 volt DC operation.

4.6.12 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 module 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 PLC for interlock control and alarm indication.

4.6.13 Door interlock microswitches shall be mounted on all hinged doors of the thyristor module 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 microswitches shall provide status information to the (PLC) for other interlock control and alarm indication.

4.6.14 The Vendor shall provide DC overvoltage protection and interlocking circuitry which shall be capable of protecting the thyristor module from overvoltage conditions, at the DC terminals. This protection shall be so designed that it can be activated by internal sensing within the module. The overvoltage 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 PLC.
4.6.15 The Vendor shall provide a FWD assembly across the output terminals of the module, before the DCCT, to protect the module from transients caused by an interruption of the inductive load current. The FWD’s must be able to continuously carry the full load current. The FWD’s shall not be fused.

4.6.16 A cubicle over temperature interlock shall be provided by the Vendor. The device shall be adjustable, between 100° F and 200° F, and shall provide contacts for the PLC.

4.6.17 All doors shall have provisions for applying a captive Kirk lock (which will be provided by BNL) or other suitable protection devices.

4.6.18 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.

4.6.19 All faults and statuses shall be isolated and buffered and brought out to the programmable logic controller (PLC). Electrical isolation shall be accomplished by opto-couplers, relay contacts, or insulated switch contacts. All controls shall operate remotely via the PLC. 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 PLC.

4.6.20 All protection and monitoring devices and circuits shall be properly isolated from the main power circuitry up to the high potential voltages of 6.6.

4.6.21 There shall be local “Off,” “Standby,” “On,” “Fault”, and “Polarity” indicating LED’s on the power supply front panel. These shall be wire to the PLC.

4.6.22 The status of all interlocks shall be brought to the PLC. The following is a list of some of the interlocks which shall be required in the base proposal. The exact number of status readbacks and alarms required to adequately protect the module cannot be finalized until the Vendors design is complete. This list will be finalized at the Final Design Review.

4.6.22.1 Incoming line (transformer secondary) AC Overvoltage (T1 & T2)
4.6.22.2 Incoming line AC Overcurrent (T1 & T2), rectifier units A&B
4.6.22.3 Incoming Phase Imbalance, loss of phase, phase rotation, DC ripple
4.6.22.4 DC Over current
4.6.22.5 SCR Over temperature including location
4.6.22.6 SCR Failure
4.6.22.7 FWD Over temperature
4.6.22.8 Filter Choke Overtemperature
4.6.22.9 Filter Capacitor Failure - Capacitor Fuse Monitoring System
4.6.22.10 Cubicle over temperature
4.6.22.11 Water flow
4.6.22.12 Water differential pressure
4.6.22.13 Blown fuses-indication and location
4.6.22.14 Door interlocks
4.6.22.15 Ground Fault
4.6.22.16 Customer Interlock

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

4.6.24 All interlocks and alarm circuits must be capable of meeting the high potential tests outlined in Section 6.6.

4.6.25 The module control functions will be determined by the PLC program and the hardware configuration of the module. The control functions will be as follows:

4.6.25.1 Auxiliary OFF - all power off except power to the 24 volt power supply and power to the PLC.

4.6.25.2 STANDBY- energizes all low level control (see 4.6.4), interlock and regulating circuits (toward a ready state). Whenever a STANDBY command is given a reset command is also given. This RESET signal shall clear any fault condition that has previously occurred and no longer exists. The Vendor shall install a multi-contact “Reset” relay and wire it to the PLC.

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

4.6.25.4 READY - the module is in standby and all faults are clear (see 4.6.5).

4.6.25.5 ON - the ON command energizes the system’s main circuitbreaker and output current is available upon receipt of gate drive signals. The Vendor shall install a multi-contact “On” relay and wire it to the PLC and to the contactor terminals.

4.6.25.6 The rectifier module shall contain a ground detection system to monitor the DC output of the module and the load. The detection scheme shall be based on the current measurement system shown in figure # 1. A circuit unbalance will cause the virtual ground to move and a current will flow in the detection relay. The current detection relay shall have two set points which shall be adjustable (from 0 to 5 amps) and shall have auxiliary contacts interfacing to the PLC. One set point will be used as a warning alarm level and the second set will be used as a trip level.

4.6.26 Provisions shall be made for two external BNL interlocks. One interlock shall be wired to the PLC input and the other 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 and annunciated via the PLC.
4.7 Instrumentation

4.7.1 The following switchboard instruments and their appropriate selector switches shall be mounted on the front door of the thyristor module. The instruments shall be standard 4 ½ inch flush mounted and shall have an accuracy of +/- 3%. They shall be of the same manufacturer and shall be of the same series. The instruments shall be properly isolated for personnel safety, adequately protected against over voltage, and shielded individually against stray magnetic fields so that they remain within their design accuracy under all operating conditions.

4.7.2 The line to line AC input voltage of all three phases of bridge A and all three phases of bridge B. There shall be two meters and two selector switches to allow metering all six voltages.

4.7.3 The input line current of all six input phases shall be measured using Vendor supplied CT’s. There shall be one meter and a selector switch for bridge A and one meter and a selector switch for bridge B.

4.7.4 There shall be a DC voltmeter operated from an isolated DC potential transformer (DCPT) connected across the rectifier 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 LEM Module LV series. Two isolated and buffered front and rear panel outputs shall be provided for voltage monitoring. In addition an isolated buffered output shall be supplied to the BNL regulation circuitry. The bandwidth of the monitoring and regulation voltage signals provided to BNL shall be at least 10 kHz. A second DCPT shall monitor the output voltage of the filter. Isolated buffered outputs shall be provided by the Vendor for this DCPT identical to those described above.

4.7.5 There shall be a DC ammeter that shall operate from an isolated current transductor (DCCT). The output current measurement shall have an accuracy and stability of better than ±0.001%. A Hazemeyer type D.C.C.T. manufactured by Holec, a Danfysik Ultrastab series, or an approved equal, is to be used. Two isolated and buffered front and rear panel outputs shall be provided for local load current monitoring. In addition an isolated buffered output shall be supplied to the BNL regulation circuitry. The bandwidth of the monitoring and regulation current signals provided to BNL shall be at least 10 kHz. The DCCT shall be installed after the passive filter so that it measures the load current only.

4.8 General Requirements

The detailed electrical requirements and parameters are listed in the Specification Data Sheets (section 8) The Module shall also meet the general electrical specifications that are given in the following sections.

4.8.1 The rectifier module shall be constructed with a view towards safety. All high voltages (greater than 125 Vac) shall be barriered or compartmentalized. All high voltages shall be
labeled with BNL approved labels. Controls shall be physically separated from the high power circuits.

4.8.2 The frame of the module shall be grounded, but both output terminals must be able to float up to test potentials of 3000 volts rms with respect to ground.

4.8.3 The frame of the module shall have a ground pad which shall be welded to the main frame and equipped with a 3/8 inch tapped hole for an external ground connection.

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

4.8.5 The module's final DC output settling time to a positive or negative step change shall exhibit close to a critically damped response and shall not exceed the value specified in 4.5.

4.8.6 Any electrical cable and buswork used as a power feeder or jumper shall be of copper and of sufficient ratings and cross-section that the cables shall not experience a temperature rise of greater than 50 degree C at maximum load.

4.8.7 All low level control wiring shall be a 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.

4.8.8 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 Vendor shall include in his proposal a list of the insulating material that will be used.

4.8.9 Each phase of the AC input terminals shall be sized for 4,500 amperes or greater. The AC terminals shall be phased A-B-C for each input set (A & B), from left to right facing the AC compartment door and shall be clearly labeled.

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

4.8.11 The DC output bus compartment shall be located in the upper rear of the module. 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. Doors, as described above, or easily removable panels shall be provided to facilitate the operation of the dc reversing section (4.9).

5.0 Mechanical Considerations

5.1 The equipment shall be constructed in an all-metal cabinet which shall be in accordance with NEMA standards for Indoor Power Switchgear as per publication SG5, latest edition.
5.2 The equipment shall be partitioned into compartments. The purpose of these compartments is to insure that access to electrically dangerous potentials can be isolated and through a key coordinated locking arrangement exposure to electrical hazards can be prevented. This unit will be operated in conjunction with other power sources which will be galvanically connected to its output.

5.3 The module shall have a control compartment which shall be used to enclose all of the module controls, the programmable logic controller, 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 50 volts ac or 50 volts dc shall be barriered.

5.4 The cabinet shall have a customer control compartment suitable for mounting standard 19 inch rack mounted equipment. The compartment shall be a minimum of 29 inches deep and shall be the full height of the rectifier cabinet. The compartment shall have a front door.

5.5 Provisions shall be made for lifting the equipment by either overhead crane (e.g. lifting eyes) or 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.

5.6 The Vendor shall provide an estimated module size, weight, and preliminary layout drawing in his proposal. The maximum dimensions of the units shall be within the values given in the Specification Data Sheets.

5.7 All bolted busbar, 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.

5.8 All bolts in blind locations shall have captive hardware.

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

5.10 The accessories, materials and supplies used on these modules shall be of the highest quality or specification grade wherever possible. The Vendor shall list in his proposal the manufacture of fuses, relays, receptacles, terminal strips, wire, hardware, etc. Auxiliary relays shall be enclosed in dust proof cases and mounted in the module control compartment.

5.11 The finish of the cabinets shall consist of degreasing of the unit followed by a coat of rustproofing paint and two coats of synthetic resin enamel, color "pale yellow beige" as per Federal Standard No 595B, Color No 37886.

5.12 The noise level three feet away from the power supply from all sources within the cubicle including cooling fans, shall be less than 70 dB when the unit is on and operating.
5.13 The Vendor shall provide and affix a stainless steel or aluminum name plate on each unit that shall include the following information:

5.13.1 Manufacturer's Name and Address
5.13.2 Manufacturer's Type and Serial Number
5.13.3 BNL’s part number
5.13.4 Complete Input Ratings
5.13.5 Complete Output Ratings
5.13.6 Cooling Requirements
5.13.7 Gross Weight of the Unit
5.13.8 Date of Manufacture
5.13.9 Specification Number

6.0 Rectifier Module Testing

The module shall be fully tested at the Vendor's plant to insure complete compliance with this specification. All facilities shall be provided by the Vendor at his plant for a partial load test of the module. Three (3) weeks before these tests the Vendor 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 Vendors plant must be witnessed by Brookhaven prior to shipment, but final acceptance of the units shall be at Brookhaven.

6.1 The BNL Cognizant Engineer and /or his representative shall have access to the Vendor’s facility during fabrication and testing. The Vendor shall provide the facilities and instrumentation at his plant to perform all necessary tests to ensure compliance with all parts of the specification. The Vendor shall provide fifteen (15) working days notice in advance of the test date so that BNL can make the necessary travel arrangements.

6.2 The testing shall include but not be limited to the specific tests outlined below. The Vendor shall supply a detailed test procedure for individual components, sub-assemblies, and the completed thyristor module to BNL at the final design review for approval (see section 6.0 for final procedure requirements).

6.3 SCR Testing

6.3.1 All individual SCRs and other power semiconductor devices shall be tested to rated PFV and PIV and the forward and reverse leakage currents shall be recorded.

6.3.2 All individual SCRs shall be tested near their actual operating current values to determine whether triggering characteristics are within specified values. T-on, I-holding, anode voltage, anode current, gate voltage and gate current shall be recorded.

6.3.3 The thermal ratings shall be checked on each SCR based on the maximum operating current, when mounted in its final heatsink and with specified water flow and
temperature. The case temperature, current, forward drop and water flow shall be recorded, under stabilized conditions.

6.3.4 Units not within manufacturing ratings shall not be used in the final assembly. The Vendor shall provide copies of the manufacturers specification data sheets for each type of device used.

6.3.5 Records of all tests shall be kept by the Vendor for each item by device serial number in the form of traveler sheets. Copies of all traveler sheets shall be supplied to BNL.

6.4 Assembled Module

6.4.1 A Heat run, as well as other performance tests shall be conducted on the completed assembled module at rated output current. The Vendor shall install thermocouples on the SCRs 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.

6.4.2 A hydrostatic pressure test shall be performed on the module at a pressure of 250 psi for one half hour.

6.4.3 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.

6.4.4 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 PLC, I/O connections.

6.4.5 The fully assembled thyristor module shall be run lightly loaded (500 amps or greater) to full rated voltage.

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

6.4.7 The voltage balance between the positive output terminal and ground, and the negative output terminal and ground shall be measured over a wide frequency range (0 to 100 kHz). The balance shall remain within the specified values over this frequency range.

6.4.8 The time delay and jitter of the Vendor high level SCR triggering circuitry shall be measured.
6.5 LCRC Filter

6.5.1 There shall be a factory heat run on the inductor before installation in a power supply. The inductor shall be run at the rated module dc current and the temperature monitored and recorded. The test shall be ended when the temperature rise is less than 1°C in two hours. The minimum length of time for this test is four hours.

6.5.2 A turn-to-turn insulation test shall be performed at 400Hz or higher. This test shall apply or induce a voltage whose value is 1000 v rms on each set of terminals for a duration of 7200 cycles of the applied frequency.

6.5.3 The inductance and resistance of the choke shall be measured individually and as a coupled unit, in series.

6.5.4 During module testing the input voltage to the filter and the output voltage of the filter shall be recorded at several dc output currents, including the maximum rated current. The attenuation of the filter verses frequency shall be computed.

6.6 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 module ground or frame. Actual leakage currents are to be monitored and recorded.

6.6.1 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.

6.6.2 AC terminals - 3000V, rms.

6.6.3 DC terminals - 3000V, rms.

6.6.4 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 3,000 Vrms.

6.7 Acceptance

For purpose of warranty under an order for this rectifier module, final inspection (acceptance) is defined as the successful completion of acceptance tests at Brookhaven to substantiate the compliance of the modules with this specification. Final acceptance shall be completed within twelve (12) months after receipt of the units at Brookhaven. The Vendor will be notified of the test dates and may have a representative present to witness the tests. The Vendor will be held
responsible for the contracted performance of the modules produced and delivered to Brookhaven.

6.7.1 Final acceptance testing at Brookhaven may include all of the following:

6.7.1.1 Hi-pot testing
6.7.1.2 Full current heat run
6.7.1.3 Interlock, overload and protection circuits
6.7.1.4 Transient response time
6.7.1.5 P.S. controls
6.7.1.6 Output noise

4.0 Transformer TESTING

4.1 The BNL cognizant engineer and/or his representatives shall have access to the sellers facility during fabrication and testing. BNL reserves the right to witness any and all tests. The seller shall formulate an acceptance test procedure (ATP) and shall provide the facilities and instrumentation at his plant to perform all necessary tests to ensure compliance with all parts of this specification. The ATP shall include, but not be limited to, the specific tests outlined below. This ATP shall be agreed upon prior to commencement of fabrication of the transformers. BNL reserves the right to require additional or more extensive tests to be conducted in case of marginal design and performance. The seller shall provide fifteen (15) working days notice in advance of the test date(s) so that BNL can make the necessary travel arrangements.

4.2 First Article Test.

4.2.1 A heat run as defined in section 4.2.2 shall include the transformer base load plus the harmonic load current effect. The heat run test shall be performed on the first article transformer and shall be witnessed by BNL to insure compliance with the specification and the bid document. Upon successful completion of the first article acceptance test, BNL shall provide a written approval and a release for the remaining units. The remaining units shall then be tested in accordance with the tests in section 4.3. The seller shall provide a copy of the heat run test results to BNL.

4.2.2 The factory heat run shall be performed to determine that the transformer meets the specified temperature rise for both OA and FA loading conditions. Fans shall be temporarily mounted for the FA portion of the test. Based on the test results of the first article transformer BNL reserves the right to require that a heat run be performed on any or all of the subsequent units manufactured.

4.2.3 An impulse test on the line side terminals shall be conducted at the BIL crest value of 110kv.

4.3 Acceptance Tests For All Transformers.

4.3.1 The following tests shall be performed on the first article transformer and all
4.3.2 Each transformer shall be tested by the standard ANSI open circuit test to determine core losses and the standard ANSI short circuit test to determine copper losses.

4.3.3 Winding resistance shall be measured for all windings on the rated voltage tap position and recorded. The measurement accuracy shall be < 0.1%.

4.3.4 The impedance at rated current and frequency for each tap position shall be measured and recorded.

4.3.5 No load turns ratio test shall be performed on each phase and for all taps of each transformer and shall be recorded.

4.3.6 A phase relation test shall be performed to verify the phase shift (0.1%), voltage balance (0.1%) and phase angle balance (+/- 0.1%).

4.3.7 A high potential test shall be performed on each transformer. For those transformers subjected to a heat run, this test shall be performed immediately after the heat run. The test shall be performed at 60 Hz and the winding shall be subjected to the specified test voltage for one minute. The test voltage of $34 \text{ kV RMS}$ shall be applied between the primary winding and the secondary winding and the primary winding and the tank. The secondary winding to tank shall be tested at $2.5 \text{ kV RMS}$. All actual leakage currents shall be recorded at the end of one minute while the specified voltage is applied to the winding.

4.3.8 A turn to turn insulation test shall be performed at 400 Hz or higher frequency. This test shall directly apply or induce a voltage on the primary winding whose value is equal to twice rated value for the duration of 7200 cycles of the applied frequency.

4.3.9 Tank pressure withstand test shall be performed on each completed transformer. The test shall consist of pressurizing the tank to a pressure of +8 PSIG for eight (8) hours and recording the pressure loss readings. All seals and weld joints shall be tested using a soap water mixture during the pressure test.

4.3.10 All interlock protection and alarm indication circuits shall be checked for proper operation. Actual fault conditions shall be induced where possible.

4.4 The cognizant BNL engineer and/or his representative shall witness all of the above tests. Certified copies of all test data, for each unit, shall be supplied to the cognizant BNL engineer and shall also be included in each copy of the instruction manual.

7.0 Quality Assurance and the Responsibility of the Vendor

7.1 The Vendor shall furnish a manufacturing plan and acceptance test procedures for approval by Brookhaven. Approval by Brookhaven shall not release the Vendor from his
responsibility for conceptual design, manufacturing, or any other mistakes committed in the fabrication of the rectifier module.

7.2 All purchased articles from subcontractors or manufacturers released for inclusion in this power supply shall be clearly identified to indicate conformance to Vendor's receiving inspection.

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

7.4 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.

7.5 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. Copies of these travelers shall be supplied to Brookhaven.

7.6 Only calibrated test equipment shall be used. 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.

7.7 The Vendor 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.

7.8 All units and parts of this equipment shall be properly packaged and delivered in an 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.
8.0 Specification Data Sheets

The following sections contain data sheet sections, which are part of this specification. These include the transformer specification data sheet, specifying performance requirements, the Seller Data Sheet characterizing the configuration of the transformer to be supplied by the seller, and the Vendor Data Sheet, which each vendor will complete as part of their proposal. It is intended that upon the review of detailed designs and any modified Seller Data Sheet entries, the Seller Data Sheets shall become part of this specification.

8.1 POWER SUPPLY DATA SHEET

8.1.1 Input Voltage 3 phase ................................................................. 13.8 KVRms, +10%,-5%
8.1.2 Configuration ................................................................. 12 pulse-series connected bridges
8.1.3 Output Voltage ................................................................. 0 to 400 VDC
8.1.4 Maximum Time delay in SCR triggering circuitry ......................... 1 microsecond
8.1.5 Maximum time jitter in high level SCR triggers .................. +/- 0.5 microseconds
8.1.6 SCR hard fire pulse width: range ............................................... 120°, 160°
8.1.7 Balance of Inductance and Capacitance of each output terminal to ground ............. 1%
8.1.8 Output Current ................................................................. 5000 amps dc, max.
8.1.9 Passive Filter 3 dB point ............................................................... 100 Hz
8.1.10 Passive Filter Inductor Resistance ........................................... <1 mOhm
8.1.11 Passive Filter Rolloff ................................................................. 12 dB / Octave
8.1.12 Output Voltage Ripple (sum of all subharmonics) ...................... < 3 % of fundamental Total ................................................................. <0.66% of VDC rated 0 to 10 KHz
..................................................................................................................... < 0.1% of VDC rated 10 KHz to 1 MHz
8.1.13 Maximum Size (H x W x L ) .......................................................... 7’ x 6’ x 8’
8.1.14 Ambient Air Temperature ...................................................... 10 to 40 °C
8.1.15 Maximum Inlet Water Temperature .......................................... 40 °C
8.1.16 Maximum differential water pressure ........................................ 50 psi
8.1.17 Maximum Water Flow ............................................................... 25 GPM
8.18 Water Resistivity ................................................................. 2 Meg Ohm-CM
8.19 Maximum Humidity .............................................................. 99 %
8.20 Electrical Load ................................................................. 0.11 Hy, 0.06 Ohms
8.21 Maximum Floor Loading .................................................... 150 Lbs / ft
8.22 Filter Capacitor discharge Time Constant ....................... < 30 seconds
8.23 Input line CT ratio ............................................................ 5000/5

8.2 Transformer (2 each) Data Sheet

8.2.1 Rating, KVA. (OA / FFA) .............................................. 1250 / 1500 KVA
8.2.2 Winding configuration with electrostatic shield .......... Extended Delta-Wye
8.2.3 Relative Phase Shift .................................................... +/− 15 Elec. Deg.+/− 0.1%
8.24 Primary voltage, Volts (+10% max, -5% min) ............ 13.8KVrms, 60HZ, 3 Phase
8.25 Secondary voltage, Volts .................................................. 

Secondary tap voltages defined at 13.8KV primary.

Secondary Tap 1 (100%), volts ............................................. 170 Vrms
Secondary Tap 2 (65 %), volts ............................................. 110 Vrms

f. Secondary current, max, line amperes ......................... 4100 Amp
g. Transformer Impedance 65 % tap
   Max difference between matching transformers ........... 5.0% +/- 5.0%
h. Voltage Balance, no load (phase to phase) ............... 0.1%
   Max difference between matching transformers .......... 0.1%
i. Efficiency ................................................................. > 98%
j. Load Duty Factor ....................................................... Continuous
k. Available short circuit current (to primary terminals) .... 15 kAmp
l. Material, windings, bus bar, leads .......................... copper
m. Cooling ................................................................. OA/FFA
n. Insulating fluid (see 3.5.6) .......................................... Silicone
o. Ambient Air Temperature ........................................... -30 to +40 Degrees C.
p. Average Temperature Rise, Deg. C ......................... 55 Degrees C
q. Humidity          100%

r. Altitude          < 100 meters

s. High potential test voltage (hv terminal)    34 kV rms.
t. B.I.L. test voltage (hv terminal)    110 kV
fu. High potential test voltage (lv terminal)    2.5 kV

VENDOR DATA SHEET

The information requested on this sheet shall be supplied with all proposals for Specification Star Note 255.

I  Power Supply Documentation

preliminary drawings
block diagram
explanation of operation
preliminary production schedule

II  Rectifier Assembly

A.  Power semiconductors

Bridges

type, mfg.................................................................

number .................................................................

PFV / PIV Rating.....................................................

Current Rating....................................................

Cooling-gpm.........................................................

Expected Tjmax ..................................................

Over-Voltage Protection Devices..............................

FWD

type, mfg.................................................................

number .................................................................
PIV Rating .................................................................
Current Rating ............................................................
Cooling-gpm ..............................................................
Expected Tjmax ...........................................................

B. Transducers

CT (input ac line)
type, mfg ...............................................................
Accuracy ..............................................................

PT's
type, mfg ..............................................................
Accuracy ..............................................................

AC OC relays
type, mfg ..............................................................

DC OC relays
type, mfg ..............................................................

DC OV relays
type, mfg ..............................................................

C. Passive LCRC filter

Inductor

Inductance ..............................................................
Freq/Current dependence ............................................
Resistance ..............................................................
Current Rating ..........................................................  
Cooling (gpm) ............................................................
Coupling Coefficient ...................................................

Capacitors
Capacitance (each branch)….. ______________________

Manufacturer……………… ______________________

Voltage rating……………… _____________________
Fuses………………… _____________________
  size……………… _____________________
  mfg.……………… _____________________
  type……………… _____________________

Damping Resistor
  Resistance……………… _____________________

Wattage……………… _____________________

Cooling Requirements………____________________

Electrical Schematic
  Bode Plot

D. Triggering Circuit Requirements and Characteristics

  Expected Time delay………____________________

  Expected Jitter……………____________________

E. Total weight of Rectifier Module……………………

F. Est. Dimensions (H x W x L)………____________________

G. Estimated heat rejected
  air……………………………………………………

  water………………………………………………

H. Water Requirements
  general cooling water expected requirements

  water flow (gpm)………………____________________

  quality of water………………____________________

  conductivity of water…………____________________

  metals exposed to water …____________________

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III  Transformers

A  Primary Voltage

B  Secondary Voltage

C  Core Losses (110% /100% of rated V)

D  Copper Losses (OA/FFA KVA rating)

E  Total Losses

F  Transformer Efficiency

G  Impedance (100 % / 65 % tap)

H  X/R ratio

I  Operating flux (110%/100% voltage)

J  Dimensions Tank (HWL)

K  Weight of core

L  Weight of copper

M  Total weight of tanked unit-dry

N  Total weight of tanked unit wet(silicone Fluid)

O  Minimum allowable spacing between transformers

P  Gallons of fluid required (silicone)

Q  Winding Configuration

R  Tap Configuration

S  Submit a B-H Curve of the Transformer Steel

IV  Expected Delivery Time ARO

..............______________________
V Detailed list of Vendor's experience with similar modules, including ratings, equipment delivered, dates shipped, and appropriate references.

VI Exceptions to the Specification: