# NSTX SWITCHING POWER AMPLIFIER (SPA)

NSTX-SPEC-5-84

REVISION 6

October 14, 2009

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RECORD OF CHANGES

| Rev. # | Date | Changes |
|---|---|---|
| 1 | 12/10/03 | Misc. comments |
| 2 | 02/19/04 | Included Addendum containing implementation details agreed to during bid negotiation phase |
| 3 | 03/01/04 | Para 3.1.3.1 Pulse duration & period typo corrected. Addendum A9: cap value change |
| 4 | 04/06/09 | Misc. changes |
| 5 | 08/25/09 | Incorporated PPPL changes on SPA |
| 6 | 10/14/09 | Updated required changes on SPA for procurement |

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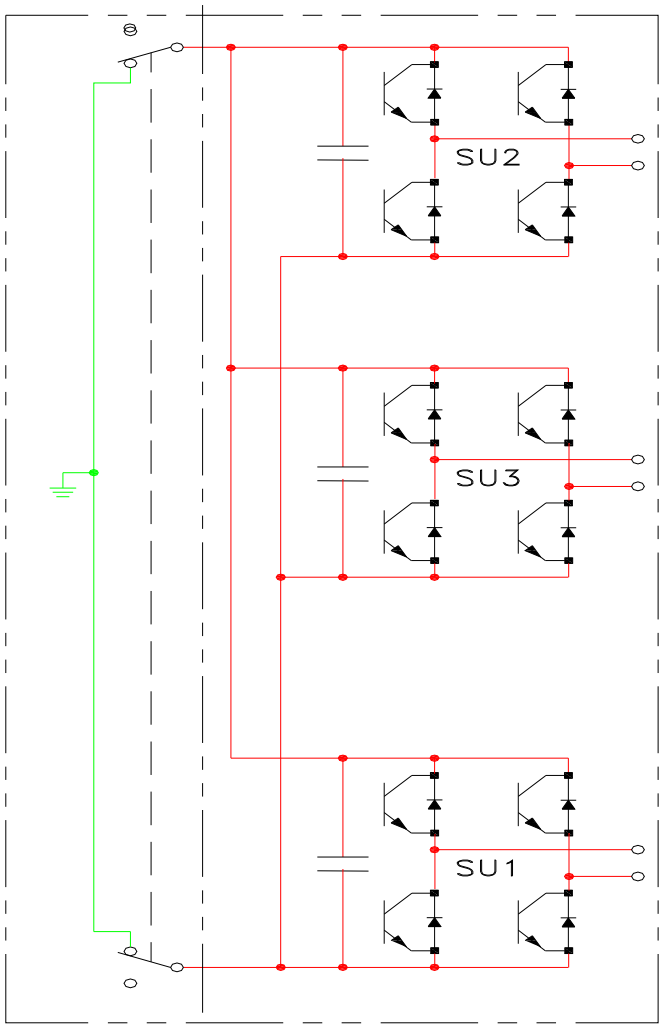
## 1. SCOPE

This specification is for an additional bipolar switching power amplifier (SPA) and input filter capacitor to be used in a closed-loop feedback system in the National Spherical Torus Experiment (NSTX) plasma physics research device located at the Princeton University Plasma Physics Lab (PPPL). The unit shall have identical performance characteristics to that of the existing SPA in PPPL furnished by IE Power (Sub-contract# S-04384-G) with the parts like H-Brides and control cards interchangeable with those in the existing unit. The new unit is required to operate synchronously with the existing SPA in PPPL. The SPA will be powered by a single 6-pulse thyristor rectifier DC source power supply provided by PPPL.

The SPA Unit shall consist of three independently controlled sub-unit SPA's which can be configured for operation as three independent units or as a single unit. In all cases the SPA will be fed from the same single DC source power supply.

Each SPA sub-unit shall consist of an H-bridge PWM inverter capable of 4-quadrant operation (+/-voltage and +/- current to load). See the following figure.



## 2. APPLICABLE DOCUMENTS

| | |
|---|---|
| ANSI C34.2 | Practices and requirements for Semiconductor Power Rectifiers |
| ANSI IEEE 18 | Shunt Power Capacitors |
| ANSI/IEEE 4 | Techniques for Dielectric Tests |
| ANSI/EIA RS-197-A | Power Filter Inductors for Electronic Equipment |
| ANSI/NEMA ICS 1 | Industrial Control and Systems General Requirements |
| ANSI C2 | National Electrical Safety Code |
| ANSI/NFPA | National Electrical Code No. 70 |
| ANSI/IPC-A-610 | Acceptability of Electronic Assemblies – Class 2 |
| NEMA PV-3 | Safety Code for Semiconductor Power Converters |

## 3. REQUIREMENTS

Requirements for the SPA are delineated in the following paragraphs. Seller may elect to take exception to any of the requirements in order to achieve a more cost effective or technically superior solution. Solutions which adapt an existing product to the requirements of this application are strongly encouraged. However, any exceptions shall be clearly delineated in the Technical Proposal.

### 3.1. PERFORMANCE REQUIREMENTS

#### 3.1.1. Input DC

PPPL will provide a 6-pulse thyristor rectifier DC source power supply with a variable (thyristor phase controlled) output (see para 3.1.2). The connection between the DC source and the SPA will consist of a cable run of approximately 300 feet (per pole) of 500MCM cable in series with a 330uH inductor.

3.1.1.1 Seller shall provide FOUR Motor operated double pole double throw Disconnect Switches of bolted pressure type– one switch in the DC input from PPPL to the SPA and three switches (one in each of the three outputs of the SPA). Each switch shall be housed in NEMA12 enclosure. The switches shall be rated to carry at least 600 amps continuous, and to withstand a short circuit current of 30.5k and the peak operating currents under all conditions. All the switches shall be provided with kirk key interlocks; the keys of which shall be captured unless the load is shorted and grounded. A second kirk key in each switch is required to open the door of the switch. PPPL will install the three output switches and provide the necessary cabling. All the switches shall be provided with four

auxiliary switches of four normally open and four normally closed contacts for each of the three positions.

3.1.1.2 A 40 milliohm power resistor in a separate enclosure shall be provided at the top of the disconnect switch for the DC Input to the SPA. This resistor shall be connected in series with the DC link power supply feeding the SPA and shall be rated to carry the load.

3.1.1.2 Output ratings of the DC power supply provided by PPPL.

The output ratings of the DC source power supply (provided by PPPL) are as follows.

| | |
|---|---|
| DC Voltage: | 0-1kV DC (adjustable via phase control) |
| Peak of Rectified AC Voltage: | sqrt(2)*750=1060V peak |
| Maximum Continuous Output: | 800 Amps |
| Maximum Pulsed Output: | 5kA-6 sec once every 300 seconds |
| Short Circuit Current: | 30.5kA peak |

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3.1.2. Load Circuit

There are three independent load circuits. Each load circuit consists of a cable run of approximately 300 feet (per pole) of 500MCM cable in series with a load.

Characteristics of load circuit (nominal as well as maximum range of impedances) including cable run are as follows:

| | |
|---|---|
| Resistance: | R = 20 mohms ( *Range: 15 to 25 mohms)* |
| Inductance: | L = 50 uH. ( *Range: 40 to 100 microhenries)* |

In all cases one SPA sub-unit will be connected to one load circuit.

When configured for independent operation, each sub-unit shall follow its own reference input signal and shall be electrically separate from the other sub-units.

When configured for parallel operation, all three sub-units shall be electrically paralleled via bus links internal to the SPA enclosure and shall follow a common reference signal.

3.1.2.1. Pulse Output

Output of SPA will be pulsed. Each sub-unit shall be capable of delivering a current pulse to the load as follows.

Equivalent Square Wave Current: 3.33 kA +/- 0.5%

Pulse output : DC to 100Hz

Pulse Duration: 6 seconds maximum

Pulse Rate : Once every 300.0 seconds minimum

If the Seller's standard accuracy tolerances vary from those above, Seller may propose exceptions for PPPL consideration.

3.1.2.2. Harmonics

*Switching frequency of the SPA shall be 7.5 kHz. IGBT devices shall be sufficient in rating and in number such that nominal temperature rise due to all losses is within manufacturers recommended limits for all modes and levels of operation described herein.* Seller shall describe proposed PWM switching method, and estimate of harmonic content in the Technical Proposal, assuming operation at the full DC source input voltage (1kV).

Supplier shall provide filtering of the output, to prevent electromagnetic interference on control and diagnostics circuits.

3.1.2.3.Control

Each SPA sub-unit, or the three paralleled subunits, shall be capable of three modes of control, namely 1) closed loop current control 2) closed loop voltage control and 3) open loop voltage control. In the closed loop current control mode, the current (higher of the two redundant current transducers built-in to the SPA) is controlled to the reference. In the closed loop voltage control mode, the input reference shall be feedback controlled against the output voltage of the SPA as measured by voltage transducers built-in to the SPA. In the open loop voltage control mode, the input reference shall correspond to the fraction of maximum positive or negative voltage, independent of the DC source input voltage. It is emphasized that the application demands that the delay time between a change in the input reference and the change in the SPA voltage be absolutely minimized. Seller shall describe proposed feedback control methods along with performance characteristics (accuracy, response, etc.) in the Technical Proposal.

## 3.2. EQUIPMENT REQUIREMENTS

### 3.2.1. Location

The SPA will be located indoors, in a general access area and in close proximity to other power supplies. The indoor facility is heated and ventilated but lacks air conditioning. The maximum ambient temperature is 35$^{o}$C..

### 3.2.2. Cooling

If cooling water is required, PPPL will supply same with an inlet temperature of $20^{o}$ C maximum @ 90 psig. Vendor shall specify flow requirements with Technical Proposal.

3.2.3. Reconfiguration

Suitable bus links and switches shall be provided to configure the control and power circuits in the single SPA or combined SPA mode. Transfer from one mode to the other should require no longer than 4 hours when performed by two qualified technicians.

3.2.4. Controls

All controls shall be derived from a separate 120V AC, 20 Amps, 60Hz single phase power feed from PPPL. Each sub-unit shall have a circuit breaker of suitable ratings which can also be used as a switch to remove control power from the sub-unit.

3.2.4.1. Local/Remote Control Selection

The SPA will normally be monitored and controlled remotely. However, a local control capability shall be provided for test and maintenance for which a Local/Remote keyed switch shall be provided. A local stop button shall be provided to trip the SPA. Provision shall be made for local/remote control selection locally at the SPA cabinet, in addition to the selection of remote control mode (closed loop current control, closed loop voltage control, or open loop voltage control). Seller shall describe the local control capability in the Technical Proposal.

3.2.4.2.Internal Fault Sensing and Interlocks

The SPA shall be equipped with suitable sensing of faults such as over-current, over-temperature, etc., as required to ensure safe and reliable operation of the equipment. In addition, interlocks shall prevent mis-operation of the equipment when a fault condition exists and/or when the configuration of the equipment is not in the proper state for operation. The over-current protection shall be manually adjustable and shall be designed such that no single point failure will defeat the protection. This requires that separate power supplies be provided for each output current DCCT. Latched indicators shall be provided that indicate the cause of any fault. Seller shall describe the internal fault sensing and interlocks in the Technical Proposal.

3.2.4.3. Remote Control

3.2.4.3.1. Supervisory Input Signals to SPA

PPPL will provide PERMISSIVE 24V dc signal to SPA if all the external interlocks are satisfied. When the PERMISSIVE signal is present, the SPA sub-units shall transition to a READY state (e.g. dump switches on capacitor banks, etc., shall be lifted).

PPPL will provide ENABLE contact closure signals to the SPA sub-units which shall enable the firing of the gate pulses to the power electronics in the Remote Mode. Gate pulses shall only be issued when the ENABLE signal is present and the Mode is Remote.

All digital inputs, if any, shall be optically coupled at the SPA.

3.2.4.3.2. Supervisory Output Signals from SPA

Each SPA sub-unit shall provide a READY contact closure when it is in a READY state, i.e. ready for capacitor bank charging.

Each SPA sub-unit shall provide a FAULT NOT contact closure when it is in a fault-free state. The contact shall open and remain latched in the open state. .

All control outputs shall be isolated contact closures or isolated solid state switches capable of passing up to 1 Amp and withstanding at least 125 V DC and 120V AC in the open state.

3.2.4.3.3. Analog Input Signals to SPA

PPPL will provide three (3) +/- 10V reference signals one to each of the three SPA sub-units. Each sub-unit shall receive the reference input differentially in either a differential or instrumentation amplifier having a bandwidth of at least one half of the switching frequency. The reference signals shall only be used in the Remote Mode.

Each reference signal shall be interpreted as a reference input command to the sub-units as follows:

| | |
|---|---|
| Closed Loop Current control mode: | +/- I where I = 3.33kA in the single SPA mode or 10kA in the combined SPA mode |
| Closed Loop Voltage control mode: | +/-V where V= 1kV |
| Open Loop Voltage control mode: | +/-f where f= fraction of PWM duty cycle |

Selection of control mode shall be local at the SPA via a keyed switch.

3.2.4.3.4. Analog / Digital Output Signals from SPA

The following analog output signals shall be made available:

Redundant Current output from each SPA sub-unit (total 6 signals): 5V=3.33kA

Output Voltage from each SPA sub-unit (total 3 signals) : 5V=1000V

Bank Charging currents for each sub-unit and the total Charging Current (total of 4 signals) : 5V=400A

Input Voltage to the SPA: 5V=1200V

Capacitor bank voltages at each sub-unit: 5V=1200V

Seller shall describe the method of current measurement, including accuracy, filtering, etc., in the Technical Proposal.

Each analog output shall be connected to the terminal board via twisted pair shielded cable with the shield being connected to the rack near the source.

Each output shall be scaled for +/-5V = +/-full scale and shall be capable of at least 10% over ranging.

All the internal fault signals within the SPA by providing a tap off from the fault indicting LEDs internal to the SPA.

3.2.4.3.5. Local Controls, Displays Monitoring Points and Inputs
The following Controls, Displays and Monitoring Points shall be accessible at each SPA sub-unit without removal on any doors or enclosures that protect the high energy section of the sub-unit.

3.2.4.3.5.1. Controls
Each SPA sub-unit shall have key controlled switch to select either the Local or Remote Control.

Each SPA sub-unit shall have a 3 position key controlled switch to select the Control Mode; Current, Voltage, or Open Loop.

Each SPA sub-unit shall have a manual Enable switch which shall be active only in the Local Mode.

Each SPA sub-unit shall have a momentary switch which shall allow the resetting of latched statuses once the cause of the latched status has been corrected.

Each SPA sub-unit shall have Primary Power breaker to turn on and off as well as protect the sub-units control power.

3.2.4.3.5.2. Displays
At a minimum each SPA sub-unit shall have the following LED displays:
The seller shall provide addition indicators are required.

No Fault
Power Supply Ready

Sub-unit Rack Over Temperature
Sub-unit Door(s) Not Closed
Water Flow Too Low (If water cooled)
Fuse Blown
IGBT Module #X Fault (One display for each IGBT module)
Output Over Voltage
Output Over Current
Control Power Fault

Each SPA sub-unit shall also have an analog meter displaying the capacitor voltage for that sub-unit.

3.2.4.3.5.3. Monitoring Points

Each SPA sub-unit shall have BNC monitoring points for the Output Current and the Output Voltages. Each output shall have a +/- 10 Voltage range.

3.2.4.3.5.4. Inputs

Each SPA sub-unit shall have a BNC Reference Input which shall be active only in the Local Mode. The range and function shall be the same as that specified in the paragraph Analog Input Signals to SPA.

3.2.4.4. Isolation

All control circuits shall be isolated from the power circuits and from any other source of high voltage, in a dedicated, grounded, accessible, and totally enclosed enclosure that will form part of the equipment. This control enclosure shall be on one side of the SPA enclosure. The equipment shall withstand 3kV. Isolation between the Power and control part of equipment and with PPPL control circuits that will be interfacing with the SPA. There shall not be any galvanic connection between live power components and the control components shall be housed in a grounded enclosure. The Power Semi-conductor devices shall be isolated from the gate drivers fiber-optically. Any isolated (at 3kV level) copper control cables shall be run in grounded metallic conduits from the Control part to the Power part of the enclosure. The design shall be such that it should be possible to access and work in the control cubicle while the SPA is energized and operating.

3.2.5. Protection

*3.2.5.1 Suitably rated fuses shall be provided on the input side of each H-bridge.*

3.2.5.2 Each SPA sub-unit shall be self-protecting under abnormal and normal operating conditions including the following:

a) Load is open-circuited

b) Output is suddenly shorted

c) Cooling water flow is disrupted or the water temperature exceeds a pre-set value.

d) Enclosure air temperature exceeds the design value.

3.2.5.3 All fault interlocks and indicators shall be latching, fail-safe. The SPA sub-unit shall not turn back on after a fault is cleared until reset. The seller shall provide two levels of protective trips – one level to switch off the IGBTs and the other level to, additionally, discharge the SPA cap bank and suppress & bypass the PPPL thyristor rectifier.

3.2.5.4 Also Self-protection for the SPA should follow the guidelines set forth in ANSI/IEEE Standard 444.

3.2.6. Capacitors

Seller shall provide a minimum of 24000uF capacitors (non-electrolytic) for each sub-unit. Seller shall provide a detailed explanation as to how the link capacitance value is determined. Seller may recommend a capacitance value higher than above as part of the Technical Proposal. Non PCB, input filter capacitors, with spill containment as applicable, shall be provided. Capacitor shorting resistor(s) and switch(es) as well as the necessary controls shall be provided such that the capacitor shall be automatically discharged on removal of PERMISSIVE command from PPPL supervisory control system.

Steps shall be taken to prevent oscillations when step inputs are applied. The capacitors shall:

a) Have permanent, parallel-connected, redundant bleeder resistors sized per NEC Article 460-6
b) Have fuses as necessary, sized to prevent nuisance blowing during power supply turn-on and operation, but also sized to prevent damage to the bank should a capacitor short-circuit. Visual indication of an open fuse shall be provided.
c) Be accessible for maintenance and shall be labeled for connection of grounding hooks.
*d) The PPPL input DC may be tripped, shorted and grounded several times a day. The SPA shall be capable of withstanding same without taking credit for the 40mOhm resistor in series with the circuit.*
e) Capacitor shorting resistor(s) and switch(es) as well as the necessary controls shall be provided such that the capacitor shall be automatically discharged on removal of PERMISSIVE command from PPPL supervisory control system and/ or when the fuse for the H bridge is blown. Following the discharge of the cap bank, operation of the system shall be inhibited by a timer or other interlock which prevents repetitive charge/discharging beyond the dissipation capacity of the discharge resistors.

3.2.7. Insulation

The SPA shall be insulated to ground, between sub-units, and from power to control circuits based on 1kV operation and hipot for 5 minutes at 2*1+1=3kVDC. Nema PV-3, Safety Code for Semiconductor Power Converters shall apply for electrical creepage and clearance.

3.2.8. Enclosure

SPA shall be supplied in a free-standing drip-proof metallic enclosure suitable for installation in a general access area. Provision shall be made for transport via forklift and lifting via lifting lugs located on the top of the cabinet. Enclosure shall meet NEMA 12 ratings for dust and moisture. Overall size of the SPA shall not exceed 6 feet wide x 6 feet deep x 8 feet tall. Seller shall indicate actual cabinet dimensions and weight in the Technical Proposal. Enclosure shall be designed to segregate the control and instrumentation cable termination area from the power area via metallic barriers.

3.2.9. Finish

Cabinet shall be cleaned, primed and painted inside and out following good industrial practices. Seller shall indicate interior and exterior finish details (color, etc.) in the Technical Proposal.

3.2.10. Construction

SPA should be modular and utilize identical modules and components where possible. Modules shall be equipped with lifting devices and guides to facilitate removal and replacement.

All bolted power connections shall be silver plated and use a minimum of two (2) bolts with Belleville or lock washers.

3.2.11. Nameplate

Nameplates shall be in accordance with ANSI C34.2, modified to take into account the pulsed operating ratings (as well as thermal ratings).

3.2.12. Grounding and Bonding

Enclosure shall be so constructed as to constitute a single contiguous conductive shell, allowing for electrical contact between panels and frame via bolts and fasteners as applicable. Provision shall be made for connection of PPPL 4/0 ground cable.

3.2.13. Identification and Marking

Internal components shall be provided with identification and name tags for easy trouble shooting. These name tags shall be identified in the Seller’s drawings.

3.2.14. Cabling Interface

3.2.14.1. Power Cable

Cut-outs shall be provided at the top and bottom of the enclosure for power cable entry. Bolted cover plates shall be provided in each cut-out with bushings for cable entry. Seller shall also provide copper pads to connect the power cables using NEMA standard 2 hole lugs. All power cable joints as well as the copper pads to receive cables shall be silver plated. PPPL will install two incoming 500MCM cables from the DC source via the bottom cut-out and six 500MCM output cables via the top cut-out. All power cabling shall use two hole lugs per ANSI standards.

3.2.14.2. Control Cable

SPA shall provide terminal blocks to receive AWG#20 control cables. Cut-outs shall be provided at the top of the enclosure for control cable entry. Bolted cover plates shall be provided in each cut-out with bushings for cable entry.

All analog signals (inputs and outputs) shall be configured as twisted shielded pairs, with all three leads (twisted pair and shield) be connected to the terminal board.

3.2.14.3 Life of devices in SPA

The SPA shall be designed for reliable operation for at least 100,000 pulses at maximum ratings described herein.

## 4. TESTING

4.1.1. Seller shall supply with the Technical Proposal a list and brief description of all dielectric, interlock, control, and dummy load tests that will be performed to establish compliance with this specification, including both in-process and final acceptance tests. Seller is encouraged to include and perform tests that are routine and standard in the normal production of the subject equipment, to the extent applicable to the requirements and functions delineated herein. Additional test procedures and/or modified versions of existing procedures shall be developed as necessary to demonstrate conformance with the specific requirements delineated herein.

4.1.2. Hipot testing shall be included as one of the planned tests. Hipot tests (3kV DC, 5 minute to ground) shall be performed on the completed SPA system one sub-unit at a time (total 3 tests), with the other two sub-units grounded, and all control circuits grounded.

4.1.3. All tests shall be conducted using written procedures with acceptance criteria. A subset of the test procedures, primarily those that are unique to the subject application, shall be subject to PPPL review and approval. The testing plan and the list of procedures subject to PPPL review and approval shall be agreed to prior to contract.

4.1.4. PPPL reserves the right to witness factory tests. PPPL witness points shall be established prior to contract. A minimum of one week notice shall be given for tests to be witnessed by PPPL.

4.1.5. Documentation of all test results, including actual values, shall be included in a final documentation report. One copy of this report is to be supplied as part of the shipping release documentation and two are to be delivered with the SPA.

4.1.6 Acceptance Tests

The following tests shall, as a minimum, be performed at Seller's facility prior to PPPL's agreement to release equipment for delivery.

- control functionality and interlock checks
- hipot tests
- full power (rated current and voltage) control step response tests
- harmonic measurement at full power (rated current and voltage)
- full load heat run (rated current and voltage pulses for rated duration and repetition period) until thermal equilibrium is reached

Specific methodology of tests and pass/fail criteria shall be established at or prior to the design review.

5. QUALITY ASSURANCE

5.1.1. Inspection/Surveillance/Audit by Princeton

Representatives of PPPL shall have the right to visit the Seller's premises during the performance of this procurement as stated in the General Provisions of this subcontract. The Seller shall make available records and documentation necessary for this function. PPPL recognizes the Seller's right to withhold information concerning proprietary processes.

5.1.2. Changes to Princeton Approved Documents

Revisions or changes by the Seller to documents approved by PPPL shall be reviewed and approved by PPPL prior to use.

5.1.3. Subcontractor's Responsibility for Conformance

Neither PPPL's review and/or approval of Seller's documents nor PPPL's inspection of Seller's items or services shall relieve the Seller of responsibility for full compliance with requirements of the purchase order/contract. The Subcontractor is responsible for assuring that all requirements and restrictions are imposed on any subtier suppliers.

5.1.4. Submittal of Quality Assurance Manual

As part of the proposal, the Seller shall submit a copy of its Quality Assurance Program Manual, describing the Seller's quality capability and general approach to quality assurance. The manual is subject to Princeton's review and acceptance prior to contract award.

5.1.5. Control of Special Processes

Subcontractor shall use trained and qualified personnel and qualified written procedures in accordance with specified requirements for the performance of certain special processes, including but not limited to, soldering, electronic assembly, brazing, welding, plating, heat treatment, nondestructive examination, etc.

5.1.6. Design Reviews and Notification of Princeton for Design Reviews

A design review shall be conducted prior to release for fabrication. The scope of the review shall depend on the extent to which the subject equipment is a departure from Seller’s standard practice and product line. Design review scope and requirements shall be established prior to contract award.

After award of contract, any changes in the design shall be documented and the changes shall be submitted to PPPL for approval prior to implementation.

5.1.7. Progress Reports

The Seller shall furnish biweekly progress reports for the duration of the job. The report shall include any schedule updates.

5.1.8. Submittal of As Built Configuration

The Subcontractor shall submit a list of drawings, if more than one, and the actual as-built drawings of each delivered item. Each drawing shall be reproducible, black on white, hardcopy. Additionally, one electronic copy shall be provided in AutoCAD format that can be used with version 2000. Electronic copies of schematics may be provided it PDF format.

5.1.9. Handling, Packaging, Shipping, and Storage

Seller shall control items during handling and shipping and while in storage, including Princeton furnished items, and shall assure that materials and items are adequately protected from damage or deterioration, with special attention to packaging for shipment.

5.1.10. Princeton Receiving/Inspection

Princeton will perform Receiving Inspection on items supplied by the Seller. Discrepant items will be rejected and returned to the Seller or reworked by Princeton. Costs caused by rejects will be charged to the Seller.

5.1.11. Material Requirements

Material(s) and/or product(s), including those components, parts, and materials that are permanently installed into systems, sub-systems, and/or assemblies, etc. furnished under this purchase order/subcontract shall be new and unused. Parts and components that have been rebuilt, refurbished, or modified are specifically prohibited unless approved by PPPL in writing.

Subcontractors (Suppliers) found to be supplying any of the following will be reported to the Office of the Inspector General, U.S. Department of Energy:

- Re-manufactured, rebuilt, or used parts represented as new.
- Counterfeit parts (fraudulently labeled or marked with another Seller's name).
- Misrepresented parts.

5.1.12. Nonconformances & Corrective Actions And Notification to Princeton

Nonconforming items or services shall be positively identified, and, where possible, segregated to prevent use. The Subcontractor shall document each nonconformance. The written approval of Princeton is required prior to the use of the nonconforming item or service. The Subcontractor's system shall provide not only for timely resolution of nonconformances but also for analysis of nonconformances to determine root causes and to implement appropriate and effective corrective actions.

5.1.13. Repairs

No repairs shall be performed without written notification to and concurrence by Princeton.

5.1.14. Release for Shipment Form

Prior to any shipment of items, Seller shall obtain a signed "Product Quality Certification and Shipping Release" form from PPPL's Quality Assurance Representative. PPPL reserves the right to refuse to accept shipment unless accompanied by a signed "Shipping Release Form" (See Attachment 1). A full documentation package shall accompany the request for release for shipment.

5.1.15. Certificate of Compliance

Seller shall submit a C of C stating that the work performed conforms in every respect to the physical configuration and functional inspection/test requirements.

The Seller's Quality Assurance Manager shall sign the C of C. This shall be furnished with the shipping release request.

5.1.16. Test and Measuring Equipment

Inspections and tests shall be performed using properly calibrated measuring and test equipment. Calibration standards shall be traceable to the National Institute for Standards and Technology (NIST) or equivalent.

5.1.17. Submittal of Completed Process History (Documentation Package)

The Seller shall provide three complete Documentation Packages, one with the request for Shipping Release and two with the completed item. At a minimum, the documentation package shall include:

Certificate of Compliance

Test and Inspection Reports required by Section 4

As-Built Configuration Drawings & Files

*5.1.18 Seller shall provide warranty for the period (whichever expires earlier) as follows:*

1. *Eighteen months from date of shipment*
2. *Twelve months from date of operation.*

5.1.19 Spare Parts

The seller shall submit a list of suggested spare parts (board or module level) and provide cost for each.

## 6. SCHEDULE

Seller shall include design, fabrication, test and delivery schedule with quotation.

## 7. SHIPPING AND HANDLING

SPA to be shipped FOB Destination freight prepaid and included.
Ship to:

US Department of Energy, C/O
Princeton Plasma Physics Laboratory
US Route 1 North,
Princeton University, Forrestal Campus
Receiving 3, Princeton, NJ 08543

## 8. WARRANTY

Seller is to state their warranty at the time of quotation.

## 9. DELIVERABLES

### 9.1. At time of Quotation

#### 9.1.1. Technical Proposal

Technical proposal shall be submitted with quotation. The following information shall be included, along with any other supporting information to establish that proposed design will conform to requirements of this specification.

- *Simplified circuit schematic*
- *Recommended DC Link capacitance value*
- *Control block diagram and description of PWM and scheme*
- *Description of voltage and current feedback control schemes, along with predicted performance*
- *Description of open loop voltage control scheme, including delay time between change in input reference to change in output voltage.*
- *Description of basic power electronic device (e.g., IGBT) to be supplied along with justification for same (voltage and current vs. duty, expected junction heating under pulsed load)*
- *Estimate of harmonic content in load current*
- *Water cooling requirements as applicable*
- *Description of local control capability, interlocks, and fault detection*
- *Method of current measurement, including accuracy, filtering, etc*
- *Sketch of Cabinet layout demonstrating that Power & Control circuits and devices are separated by grounded metallic barriers.*
- *Cabinet dimensions and weight*
- *Interior and exterior finish details (color, etc.)*
- *In-process dielectric, interlock, control, and dummy load tests that will be performed*

- *Acceptance Tests – Objectives & Summary*
- *Exceptions to this specification, along with justification of same*

9.1.2. QA Manual

9.1.3. Provisions of standard warranty

9.1.4. Schedule

9.2. At Design Review

- *Schematic diagrams*
- *Performance calculations (junction temperature, harmonics, fault conditions, control loop response, etc.)*
- *Outline Drawing showing PPPL interface details*
- *Bills of Material*
- *Test Plan with procedures*

9.3. With the request for release for shipment:

Test results as required per paragraph 4.1.5

9.4. With Delivery

9.4.1. Operating Manual (3 hard copies plus electronic files as available)

9.4.2. As-built Drawings (3 sets hard copy plus CAD files as available)

9.4.3. Recommended list of spare parts with price

9.4.4. Test and Inspection Records (2 Copies)

9.4.5. Product Quality Certification and Shipping Release

9.4.6. Certificate of Compliance signed by Seller's Quality Assurance Manager

PRINCETON UNIVERSITY
PLASMA PHYSICS LABORATORY—PPPL

**PRODUCT QUALITY CERTIFICATION AND SHIPPING RELEASE**

| PROJECT | ITEM DESCRIPTION | | | | SHIPMENT NUMBER |
|---|---|---|---|---|---|
| PPPL SUBCONTRACT/ ORDER NO. | REV. | ITEM NO. | SUPPLIER REFERENCE NO. | REV. | QUANTITY SHIPPED |

SUPPLIER'S CERTIFICATION

This is to certify that the products and services identified herein have been produced under a controlled quality assurance program and are in conformance with the procurement requirements including applicable codes, standards and specifications as identified in the above-referenced documents unless noted below. Any supporting documentation will be retained in accordance with the procurement requirements.

SIGNED: _____ DATE: _____

TITLE: _____ COMPANY: _____

PPPL (AUTHORIZED REPRESENTATIVE) SHIPPING RELEASE

This is to certify that evidence supporting the above Supplier's Certification statement has been audited and no product/service nonconformances from procurement requirements have been found unless noted below. This product/service is hereby released for shipment.

This section serves as the Quality Assurance release for the above described product for shipment. It does not constitute an acceptance thereof and does not relieve the Vendor, Manufacturer or Contractor of any and all responsibility or obligation imposed by the purchase contract. It does not waive any rights the Purchaser may have under the purchase contract, including the Purchaser's right to reject the above described material upon discovery of any deviations from requirements of the purchase contract, drawings and specifications.

NONCONFORMANCES FROM PROCUREMENT QUALITY REQUIREMENTS:

REMARKS/PRODUCT SERIAL NUMBERS:

| BY PPPL QA REPRESENTATIVE (OR DESIGNEE) | DATE |
|---|---|