National Spherical Torus eXperiment Upgrade

National Spherical Tokamak Experiment-Upgrade

NSTX-Upgrade

SYSTEM REQUIREMENTS DOCUMENT

POWER SYSTEMS

NSTX-U-RQMT-SRD-006-01

March 24, 2018

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NSTX-U SYSTEM REQUIREMENTS DOCUMENT

Revision	Date	Description of Change
0	1/15/18	First Issue
1	3/24/2018	Modified signature block as per new QAPD and ENG-050
		Updated interface tables as per new Interface Spreadsheet
		Updated table 5.4-7, along with associated text, to have a specification on the allowed PF coil ripple current amplitude.
		Updated Table 5.4-1 with values for the external resistance on the PF-1b & PF-1c circuits.
		Updated 5.4-3 for the new PF-1a hipot requirement
		Updated all power supply current requirements to round to the nearest kA away from zero, in Tables 3.4.2-3 & 5.4-2.
		Small changes in the energy values in 3.4.2-3 based on the changes to the currents (rounding) and the additional external resistances for the -1b and -1c coils.
		Added 4.3k, 5.3n, and 6.3m requiring interlocks to prevent rectifier operation where people are potentially within the test cell.
		Added 4.3l, 5.3o, and 6.3n requiring interlocks to prevent rectifier operation test cell bus bar grounding switches are closed.

NSTX-U SYSTEM REQUIREMENTS DOCUMENT

References

[1] NSTX-U-RQMT-GRD-001, NSTX-U General Requirements Document
[2] NSTX-U Design Point Spreadsheet, https://sites.google.com/pppl.gov/systemengineering/home
[3] NSTX-U-RQMT-SRD-002-00, NSTX-U SRD - Heating and Current Drive Systems

1.0 Scope

a. This SRD provides requirements for the NSTX-U AC power distribution (WBS 1.5.1) & FCPC rectifiers & inverters (WBS 1.5.2).

b. The format of this document, including interfaces specifications, is provided in the General Requirements Document [1].

c. Numerical tables in this document are derived from, and can be found it, the Design Point Spreadsheet [2].

d. Legacy design requirements for the FCPC AC/DC converters (the TRANSREX rectifiers) and motor generator (MG) as systems are not included in this document. Rather, this document describes the required configuration, performance capabilities, and interfaces of those systems to support NSTX-U operations.

2.0 General Requirements

a. The baseline Power Systems shall be designed to produce a maximum of 50 pulses per 24 hour period

b. Routine NSTX-U operation shall be assumed to consist of 30 pulses per day, 5 days per week, 3 weeks per month, 9 months per year. Non-operating times are available for maintenance.

3.0 AC Power Systems

3.1 Functions

a. The function of the AC Power System is to provide the source of all electric power required for the NSTX-U facility. The AC Power System must establish the connection between the PPPL facility and the local utility network in a fashion which permits the pulsed loading required by the NSTX-U experiment while maintaining a power source of suitable quality for existing house loads.

The specific functions of the Experimental AC Power System include:

b. Delivery of power to D-Site 13.8kV S1 bus, from primary AC input terminals of XST-1 to S1 bus.

c. D-site MG equipment, including excitation and cycloconverter drive systems, from S1 bus to variable frequency busses SV1 and SV2.

d. AC distribution from SV1 and SV2 busses to converter transformer primary AC input terminals, including feeds to NB equipment.

e. AC distribution from secondary terminals of C-site transformer XQT-1 or XQT-2 to high-harmonic fast wave (HHFW) converter transformer primary AC input terminals.

The specific functions of the Auxiliary Systems AC Power System include:

f. Delivery of power to D-Site 13.8kV S2 bus, from primary AC input terminals of XST-2 to S2 bus.

g. All auxiliary system AC distribution at D-Site, from S2 bus to points of utilization at 13.8kV, 4.16kV, 480V, 208V, and 120VAC levels.

h. Standby power diesel generator and all associated equipment.

i. UPS systems and all associated equipment.

3.2 Materials and Design Requirements

a. None beyond proper electrical system design and implementation.

3.3: Configuration Requirements and Essential Features

a. All input power shall be derived from the 138kV service coming into the laboratory.

b. The electrical utility service to the Princeton Plasma Physics Laboratory (PPPL) site is a 138 kV transmission line thermally rated at 600 Amp steady state (equivalent to roughly 140 MVA). Present agreements with the local utility, Public Service Electric and Gas (PSE&G) permit PPPL to take a 120 MVA dynamic load without phase correction.

c. The limitation on pulsed loading of the utility service is determined by the regulatory requirements regarding the voltage variation experienced by other customers as a result of the pulsed load. The utility considers a +/-1% variation at the nearest point of connection to other customers to be acceptable.

d. PPPL's pulsing affects other PPPL loads which derive power from the 138kV system as well, some of which (such as computer systems) are voltage sensitive. For that reason the dynamic voltage variation at PPPL's 138 kV bus (on pulsing) shall be held to +/-3% or better. The composite loads imposed by NSTX-U and the remainder of PPPL need to be accommodated, as well as fault transients due to short circuits, load sheds etc.

e. The utility system per unit impedance data given in the Table 3.3-1 (100 MVA base apparent power, 138 kV base voltage) shall be utilized for voltage drop and short circuit calculations.

Table 3.3-1*: Utility system per-unit impedance data.*

Impedance	Resistance	Reactance
Positive sequence	.008704	.026112
Zero sequence	.060927	.182782

f. All auxiliary systems AC power is obtained from the S2 bus at D-site, which is powered by the C-site transformer XST-2.

g. Standard Auxiliary Power Systems services shall be as follows:

- Service voltages (3-phase) 13.8kV, 4.16kV, 480V, 208V
- Service voltages (single phase) 120V

h. A subset of the Auxiliary Power Systems loads require automatic transfer to the standby (diesel generator) power source in the event of a loss of site power from the 138kV service. These are listed in Table 3.3-12

Table 3.3-2*: NSTX-U Auxiliary systems transfer to standby generator during operations periods*

D- Site Cryosystems
D-Site Cooling Water Pumps
D- Site Lighting
D-Site HVAC
D-Site miscellaneous motor loads (MCC’s feeding test cell, etc.)

i. Critical control and diagnostic systems require for MG operations shall be backed up by uninterruptible power supplies (UPS).

3.4 Baseline Performance and Operational Requirements

3.4.1: AC Power Requirements

a. Table 3.4.1-1 describes the requirements for total (composite) input power, as measured at the 138kV utility interface with PPPL, for the maximum case.

b. Auxiliary power loads are conservatively estimated based on recent (2016) D-site operations (see section 3.4.3).

Table 3.4.1-1: *Composite AC Input Power Requirements*

Load	**S**	**p.f**	**P**	**Q**
	MVA	**---**	**MW**	**MVA R**
NSTX-U Experimental AC Power	17.4	0.86	14.9	9.0
NSTX-U Auxiliary System AC Power	6.3	0.8	5.0	3.8
NSTX-U D-site MG (between pulses @ 70Hz)	3.5	0.76	2.6	2.3
PPPL House Power (A,B,C,-sites)	3.4	0.80	2.7	2.0
Max base load	13.1	0.79	10.4	8.1
Max Pulsed load	17.4	0.86	14.9	9.0
Max load during pulses	30.5	0.83	25.3	17.0

c. Any combination of pulsed load and repetition period with $\int i^2(t)dt$ less than or equal to that described by the nominal loading scenario shall be possible, as long as the repetition period is not less the minimum NSTX-U repetition period and as long as the peak active and reactive power demands do not exceed the nominal maximum values given in Table AC-3.1-1.

d. Voltage variations and distortion at PPPL's 138 kV bus, under regular operating conditions shall conform to IEEE 519, "IEEE Guide for Harmonic Control and Reactive Compensation of Static Power Converters".

e. Voltage variations at PPPL's 138 kV bus, under unusual and fault conditions (such as load shed or short circuit) shall be limited to less than +/-10%.

f. Harmonic content of the line current at PPPL's 138 kV bus shall not exceed that of a 12 pulse rectifier, i.e.:

harmonic:	11th	13th	23rd	25th
rms % of fundamental:	9	7.5	4.5	4

g. Operation at full rating shall not be restricted to any particular time of day.

h. Experimental power loads from other machines at PPPL shall be assumed inactive or not coincident with NSTX-U. However, the auxiliary systems loads from other experiments at the laboratory shall be considered coincidental, including those due to D-site.

3.4.2 Experimental Power Component of Load

a. Experimental power shall be taken nominally through one of the two D-site Motor-Generator (MG) units. The only exceptions shall be the HHFW system, for which the sources are located at C-site, and the NBI auxiliaries (decel, arc, filament, and magnet supplies) which are fed by the S2 bus at D-site.

b. When the experimental power load is such that the total composite load required by NSTX-U can be supplied directly by the grid, the configuration of the AC systems shall permit operation directly from the grid without the use of the MG set. Therefore the AC input to the TF, OH, and PF converters, and the AC input to NBI equipment, shall each be separately connectable either to the MG set or to the grid.

c. Capability for testing of the experimental power equipment when supplied directly from the grid shall be possible within the limits of the grid.

d. Table Table 3.4.2-1 itemizes the experimental power loads

e. Table 3.4.2-2 sums the experimental power loads, under worst case simultaneous loading.

Table 3.4.2-1*: List of experimental power loads*[1]

Demand List	Delivered Power	Eff	S	pf	P	Q	Source
	[MW]		[MVA]	---	[MW]	[MVAR]	---
MG (between pulses @ 70 Hz)	---	---	3.5	0.8	2.7	2.3	S1
TF	---	---	131.4	---	104.9	79.2	MG/S1
OH	---	---	145.9	---	139.6	42.2	MG/S1
PF	---	---	213.0	---	22.5	211.8	MG/S1
HHFW (per source)	2	0.5	4.6	0.9	4.0	2.3	Q6
NBI Accel (per source)	1.67	0.277	6.9	0.9	6.0	3.3	MG/S1
NBI Decel, Arc, Filament, Mag	---	---	0.6	0.8	0.48	0.36	S2

[1] SPA power supplies and EC-PI [3] are negligible on the scale of this table.

Table 3.4.2-2: *Worst case sum of experimental loads*

Max Load, LPPI	#	Delivered Power	S	P	Q	Source
	---	[MW]	[MVA]	[MW]	[MVAR]	---
MG (between pulses @ 70 Hz)	1	---	3.5	2.7	2.3	S1
TF	1	---	131.4	104.9	79.2	MG/S1
OH	1	---	145.9	139.6	42.2	MG/S1
PF		---	213.0	22.5	211.8	MG/S1
HHFW	3	6	13.8	12.0	6.8	Q6
NBI Accel	6	10.02	41.1	36.2	19.5	MG/S1
NBI Decel, Arc, Filament, Mag	6	---	3.6	2.9	2.2	S2
MG (TF+OH+PF+NBI Accel)		---	314.1	280.7	140.9	---
Grid (HHFW, NBI Aux)		---	17.4	14.9	9.0	---

e. PF loads are based on simultaneous operation of all PF coil circuits at their maximum current ratings. Actual load scenarios are much less.

f. For the case when operation is entirely from the grid, peak S1 bus power shall be limited to 120MVA and 50 MVAR.

g. MG loads are based on operation via the MG set with PF loads and NBI taken via MG.

h. Grid pulsed loads consist of the HHFW and NBI auxiliaries.

i. Any combination of pulsed load and repetition period with $\int i^2(t)dt$ less than or equal to that described by the nominal loading scenario shall be possible, as long as the repetition period is not less than the minimum NSTX-U repetition period and as long as the peak active and reactive power demands do not exceed the nominal maximum values given in Table 3.4.2-1.

j. Conservative estimate of the total energy required from the MG set for the neutral beams, TF coils and PF coils, based on magnetic energy due to the self-inductance of all coils at their maximum current ratings, and the dissipated energy due to all coils and bus work at their maximum current and ESW ratings, is given in Table 3.4.2-3.

Table 3.4.2-3: *Experimental power energy consumption. Inductances are the low frequency limits.*

Circuit	Max Current	Net Circuit Inductances	Mag Energy	Dissipation	Total Energy
	[kA]	[mH]	[MJ]	[MJ]	[MJ]
OH	24.0	37.90	10.92	88.3	99.2
PF1aU	20.0	2.12	0.42	7.0	7.4
PF1aL	20.0	2.12	0.42	7.0	7.4
PF1bU	21.0	0.72	0.16	5.0	5.2
PF1bL	21.0	0.72	0.16	5.0	5.2
PF1cU	20.0	0.73	0.15	4.8	4.9
PF1cL	20.0	0.73	0.15	4.8	4.9
PF2U	15.0	2.25	0.25	5.2	5.4
PF2L	15.0	2.25	0.25	5.2	5.4
PF3U	12.0	5.43	0.39	9.4	9.7
PF3L	12.0	5.43	0.39	9.4	9.7
PF4	16.0	5.40	0.69	26.5	27.2
PF5	24.0	12.67	3.65	114.8	118.4
Sum of PFs ->					211.0
PF/OH Sum ->	-	-	-	-	521.2
TF	130.0	4.04	34.10	524.4	558.5
TF+OH ->					657.7
RWM (each)	3.3	0.07	6.10E-04	1.2	-
RWM Sum ->	-	-	3.66E-03	7.4	7.4
NBI					180.5
Total: TF+PF+OH+ RWM+NBI ->					1056.6

3.4.3 Auxiliary Systems Component of Load

a. Load estimates based on demand data from July 2016 are summarized in Table 3.4.3-1. Actual loads for NSTX-U may vary depending on operational scenarios.

Table 3.4.3-1: *Auxiliary Power Loads*

Description	MVA	p.f.	MW	MVAR
D-site Auxiliary Power (S2 bus) Demand	6.31	0.8	5.048	3.8

3.5 Upgrade Performance and Operational Requirements

a. Future upgrades associated with additional non-axisymmetric coil power supplies may increase the aggregate power requirements.
b. Future upgrades associated with additional heating systems (ECH) may increase the aggregate power requirements.

3.6 Interfaces

Table 3.6-1*: Interfaces for the 13.8 kV Experimental Power Systems (WBS 1.5.1.1)*

Interfacing WBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.5.2.2	OH Power Systems Converters	Electrical Power	Primary of 13.8 kV FCPC transformers	Provide power to TF rectifiers from either S1 or MG	Electrical Schematic
1.5.2.3	PF Power Systems Converters	Electrical Power	Primary of 13.8 kV FCPC transformers	Provide power to TF rectifiers from either S1 or MG	Electrical Schematic
1.6.1.1	Control I/O systems	Electrical Signal	Digital I/O from CAMAC System	Information on the Motor Generator passed to the Plant Control and Monitoring Systems (EPICS)	CWD
1.2.4.6	Neutral Beam Power System	Electrical Power	Selector switches within the neutral beam switchgear.	13.8 kV power provided by the MG or directly from the grid for Accel power	Electrical Drawings
1.5.2.1	TF Power Systems Converters	Electrical Power	At FCPC 13.8 kV transformer primary	Either the fixed or variable frequency bus provides primary power to the AC/DC converters	Electrical Schematic
1.5.2.4.1	SPA DC Link	Electrical Power	At FCPC 13.8 kV transformer	Either the fixed or variable frequency bus provides primary	Electrical Schematic

			primary	power to the AC/DC converters	

Table 3.6-1*: Interfaces for the D-Site Auxiliary Power (WBS 1.5.1.2)*

Interfacing WBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.2.4.6	Neutral Beam Power System	Electrical Power	Various Places	Power for beam auxiliaries (decel, arc, filament, magnet, pumps, cryo, control)	Electrical Schematic for Directly Wired Components
1.8.1	Project D-Site Locations	Electrical Power	Mechanically, at locations of physical mounting of MCCs and electrical panels.	Provide power to the Test Cell	Electrical Schematic
1.3.2.1.1	Low-Pressure NTC Cooling Water Distribution	Electrical Power	various	Electrical power for low-pressure cooling water distribution	Electrical Schematic for Directly Wired Components
1.3.2.1.2	High-Pressure NTC Cooling Water Distribution	Electrical Power	various	Electrical power for the high-pressure cooling water distribution	CWD
1.3.2.1.3	OH Water Pre-Heater System	Electrical Power	various	Electrical power for the OH water pre-heater	Electrical Schematic for Directly Wired Components
1.3.2.2	FCPC Cooling Water System	Electrical Power	various	Electrical Power for the FCPC cooling water system	Electrical Schematic for Directly Wired Components
1.3.2.3	Deionized Make-Up System	Electrical Power	various	Electrical power for components of the deionized water make-up system	Electrical Schematic for Directly Wired Components
1.3.2.4	Water System PLC	Electrical Power	various	Electrical power for the water systems PLC	Electrical Schematic for Directly Wired Components
1.3.5.1.1	GDC + Filament Power Supplies	Electrical Power	various	Electrical power for glow discharge systems	Electrical Schematic for Directly Wired Components
1.7.3.1	Hardwired Interlock System	Electrical Power	various	Electrical power for the hardwired interlock system	Electrical Schematic for Directly Wired Components
1.7.3.2	NTC Ground Fault Monitor	Electrical Power	various	Electrical power for the NTC ground fault monitors	Electrical Schematic for Directly Wired Components

1.7.3.7	Radiation Area Monitors	Electrical Power	wall plug	Electrical power for radiation area monitors	N/A
1.4.1.1	Neutron measurements	Electrical Power	wall plug	Electrical power for neutron detectors	N/A
1.4.1.2	Magnetics	Electrical Power	wall plug	Electrical power for magnetic diagnostics	N/A
1.4.1.4	Plasma TV	Electrical Power	wall plug	Electrical power for the plasma TV systems	N/A
1.4.1.13.1	Filterscopes	Electrical Power	wall plug	Electrical power for the filterscope diagnostics	N/A
1.2.3	Electron Cyclotron Pre-Ionization (ECH)	Electrical Power	various	Electrical power for ECH pre-ionization system	Electrical Schematic for Directly Wired Components
1.3.5.2	Trimethylboron (TMB) System	Electrical Power	various	Electrical power for dTMB system	Electrical Schematic for Directly Wired Components
1.3.5.3	Li Evaporator (LITER)	Electrical Power	various	Electrical power for LITER system	Electrical Schematic for Directly Wired Components
1.3.5.4	Granule Injector	Electrical Power	various	Electrical power for the granule injector	Electrical Schematic for Directly Wired Components
1.8.1.4	Diagnostic DARM	Electrical Power	various	Electrical power for the panels & outlets in the DARM	Electrical Schematic for Directly Wired Components
1.3.4.5	Valve Driver and Interface Systems	Electrical Power	various	Power for the valve driver and interface systems	Electrical Schematic for Directly Wired Components
1.5.3.1	TF Convertor DC Systems	Electrical Power	various	Power for TF convertor DC system components such as current transducers	Electrical Schematic for Directly Wired Components
1.5.3.2	OH Convertor DC Systems	Electrical Power	various	Power for OH convertor DC system components such as current transducers	Electrical Schematic for Directly Wired Components
1.5.3.3	PF Convertor DC Systems	Electrical Power	various	Power for PF convertor DC system components such as current transducers	Electrical Schematic for Directly Wired Components
1.5.3.4	Switching Power Amplifier DC	Electrical Power	various	Power for SPA DC system components such as current	Electrical Schematic for

	Systems			transducers	Directly Wired Components
1.5.4.1	Hardwired Control System & PLC	Electrical Power	various	Power for the HSC and FCPC PLC	Electrical Schematic for Directly Wired Components
1.5.4.3	DCCT Signal Conditioner	Electrical Power	wall plug	Power for the HSCs	N/A
1.6.1.1	Control I/O systems	Electrical Power	various	Power for control I/O systems at D-site	Electrical Schematic for Directly Wired Components
1.6.1.2	Plant Control and Monitoring	Electrical Power	wall plug	Power for Plant Control and Monitoring (EPICS) system hardware at D-Site	N/A
1.6.1.3	Timing and Synchronization System	Electrical Power	wall plug	Power for clock system distribution at D-Site	N/A
1.6.1.5	Test cell audio/video	Electrical Power	wall plug	Power for NTC audio/video system	N/A
1.6.2.1	Data I/O systems	Electrical Power	various	Power for Data I/O systems	Electrical Schematic for Directly Wired Components
1.3.1.7	Interspace Vacuum Pumping System	Electrical Power	various	Electrical power for the interspace pumping system	Electrical Schematic for Directly Wired Components
1.4.1.3	Multi-pulse Thompson Scattering (MPTS)	Electrical Power	AC power outlets	AC Power for lasers, racks, and other equipment located in the laser/detector room	Electrical Schematic for Directly Wired Components
1.3.2.1.2	High-Pressure NTC Cooling Water Distribution	Electrical Power	various	Electrical power provided for the high-pressure pumps in the NSTX-U test cell	Electrical Schematic for Directly Wired Components
1.3.3.1.1	Helium Skid & Piping	Electrical Power	various	Electrical power provided for helium skid	Electrical Schematic for Directly Wired Components
1.3.3.2.2	Bakeout DC Power Supplies	Electrical Power	various	Electrical power for bakeout DC supplies	Electrical Schematic for Directly Wired Components
1.3.3.4	Bakeout PLC and Controls	Electrical Power	various	Electrical power for the bakeout PLC and related controls	Electrical Schematic for Directly Wired Components

1.3.3.3.1	MTWS Skid	Electrical Power	various	Electrical power for the medium temperature water skid	CWD
1.4.1.2.5	Digitizers and Integrators	Electrical Power	wall plug	Power for magnetics digitizers and integrators	N/A
1.4.1.5.1	Toroidal CHERS	Electrical Power	wall plug	Power for Toroidal CHERS diagnostics	N/A
1.4.1.5.2	Poloidal CHERS	Electrical Power	wall plug	Power for Poloidal CHERS diagnostics	N/A
1.4.1.6	FIDA	Electrical Power	wall plug	Power for various FIDA diagnostics	N/A
1.4.1.7	BES	Electrical Power	various	Power for various BES systems	Electrical Schematic for Directly Wired Components
1.4.1.8	MSE	Electrical Power	various	Power for various MSE systems	Electrical Schematic for Directly Wired Components
1.4.1.9.1	SSNPAs	Electrical Power	wall plug	Power for various SSNPAs	N/A
1.4.1.10	FIReTIP	Electrical Power	various	Power for FIReTIP	Electrical Schematic for Directly Wired Components
1.4.1.11	High-K Scattering	Electrical Power	various	Power for High-k scattering	Electrical Schematic for Directly Wired Components
1.4.1.12	Microwave Diagnostics	Electrical Power	various	Power for various microwave diagnostics	Electrical Schematic for Directly Wired Components
1.4.1.13	Visible Spectroscopy	Electrical Power	wall plug	Power for visible spectroscopy systems	N/A
1.4.1.14	Physics Imaging Systems	Electrical Power	wall plug	Power for various physics imaging systems	N/A
1.4.1.15	Vacuum Spectroscopy	Electrical Power	wall plug	Power for vacuum spectroscopy systems	N/A
1.4.1.16	SXR Spectroscopy	Electrical Power	wall plug	Power for SXR Spectroscopy systems	N/A
1.4.1.17	Langmuir Probes	Electrical Power	wall plug	Power for Langmuir probe electronics	N/A
1.4.1.18	Surface Measurements	Electrical Power	various	Power for surface measurement systems electronics	Electrical Schematic for Directly Wired

					Components
1.4.1.19	MAPP	Electrical Power	various	Power for MAPP	Electrical Schematic for Directly Wired Components
1.4.1.20	Bolometers & Vacuum Radiation Sensors	Electrical Power	various	Power for Bolometers and Vacuum Radiation Sensors	Electrical Schematic for Directly Wired Components
1.4.1.21	IR Cameras for Thermography	Electrical Power	wall plug	Power for IR cameras	N/A
1.7.3.4.1	Fiber Optic Strain, Temp., Disp. Meas.	Electrical Power	wall plug	Power for the instrumentation	N/A
1.7.3.4.3	Passive Plate and Vessel Accelerometers	Electrical Power	wall plug	Power for the instrumentation	N/A
1.7.3.4.4	Vessel Voltage Monitors	Electrical Power	various	Power for vessel voltage monitors	Electrical Schematic for Directly Wired Components
1.7.3.6.1	FPDP Data Stream	Electrical Power	wall plug	Power for the FPDP data stream at various locations	N/A
1.7.3.6.7	DCPS Realtime Linux Computers	Electrical Power	wall plug	Power for the DCPS realtime computer	N/A
1.7.3.6.4	DCPS Autotesters	Electrical Power	wall plug	power for the DCPS autotesters	N/A
1.7.3.6.5	DCPS Hardware Interface, Expansion Chassis & WDTs	Electrical Power	wall plug	Power for the DCPS hardware	N/A
1.7.3.6.8	Ip Calculator System	Electrical Power	wall plug	Power for the Ip Calculator	N/A
1.7.3.6.9	Shorted Turn Protection System	Electrical Power	wall plug	Power for shorted turn protection system	N/A
1.3.4.3.2	Massive gas injectors	Electrical Power	wall plug	Electrical power for MGI power supplies, controls	N/A
1.2.4.4	Neutral Beam Services	Electrical Power	various	Electrical power for various beamline services	Electrical Schematic for Directly Wired Components
1.2.4.5	Liquid Helium Refrigerator	Electrical Power	various	Electrical power for the cryogenic systems	Electrical Schematic for Directly Wired Components
1.2.4.7	Neutral Beam	Electrical	various	Electrical power for neutral	Electrical

	Control Systems	Power		beam control systems	Schematic for Directly Wired Components
1.2.4.8	Armor Protection Systems	Electrical Power	various	Electrical power for armor protection systems	Electrical Schematic for Directly Wired Components
1.7.3.5.1	PDP Timer	Electrical Power	Wall plug	Power for PDP Timer	N/A
1.4.1.2.4	Diamagnetic Loop System	Electrical Power	Wall plug	Power for the electronics in the diamagnetic loop system	N/A
1.8.1.1.6	NTC Fire Protection	Electrical Power	various	Fire protection systems relies on D-site power	Electrical Schematic for Directly Wired Components
1.8.1.1.3	ODH Monitor	Electrical Power	various (TBD)	AC power provided to oxygen monitor system	Schematic (TBD)
1.8.1.1.4	NTC Walls	Structural	At NTC wall	Components of the test cell power distribution are supported by the test cell wall	N/A
1.5.2.4.1	SPA DC Link	Electrical Signal	At panel or bus	Auxiliary power for DC link rectifier	Electrical Schematic
1.5.2.1	TF Power Systems Converters	Electrical Signal	At panel or bus	Auxiliary power for TF rectifiers	Electrical Schematic
1.5.2.2	OH Power Systems Converters	Electrical Signal	At panel or bus	Auxiliary power for OH rectifiers	Electrical Schematic
1.5.2.3	PF Power Systems Converters	Electrical Signal	At panel or bus	Auxiliary power for PF rectifiers	Electrical Schematic
1.5.2.4.2	SPAs Inverters	Electrical Signal	At panel or bus	Auxiliary power for SPA Inverters	Electrical Schematic

4.0 TF AC/DC Converters and DC Systems

4.1 Functions

a. The PF/OH Power Conversion System shall provide a variable current in the PF and OH magnet circuits during an NSTX-U discharge based on a reference firing angle signal provided in real time.

4.2 Materials and Design Requirements

a. None beyond standard high-voltage and power circuit design

4.3: Configuration Requirements and Essential Features

a. The TF Power Conversion System shall include all equipment necessary to power the TF coils. This shall include all equipment from the AC input power interface through to the DC bus connections to the magnets, including converter transformers, thyristor converters, DC cable, DC bus, disconnect switches and bus links, and all associated monitoring, control, and protection equipment.

b. Bus links or other means shall be provided in order that the current in the TF magnets can be driven in either direction. The polarity reversal procedure shall require 4 hours or less/

c. No-load disconnect switches shall be provided to isolate the TF Power Conversion System from the connections to the TF magnets. In addition, no-load grounding switches shall be provided to ground the terminals of the connections to the TF magnets. These switches shall be interlocked with test cell access control.

d. The TF power system shall be capable of accepting a reference firing angle from the realtime data stream and producing the appropriate voltage from that firing angle.

e. The TF Power Conversion System shall include protection to avoid the delivery of current which would overheat the TF magnets, assuming that their coolant conditions are nominal.

f. Redundant measurements of TF current shall be provided.

g. The TF power system shall be grounded via high resistance connections at the (+) and (-) coil terminals. A ground fault protection system shall be used in conjunction with the grounding scheme to detect grounds within the TF circuit and terminate the discharge upon excessive ground current.

h. The TF power system equipment and bus system external to the test cell shall be totally enclosed so that access can be maintained around the operating equipment without danger to the personnel.

i. Branch currents, line-to-ground voltages, ground currents, and other rectifier signals shall be digitized for post-shot inspection.

j. For each parallel branch in the TF circuit, each active rectifier shall be in series with a permanently bypassed rectifier.

k. TF rectifiers shall be interfaced to the Hardwired Interlock System (HIS) in a fashion to prevent operations when when the test cell is potentially occupied.

l. TF rectifiers shall be interlocked to prevent operations when test cell ground switches are closed.

4.4 Baseline Performance and Operational Requirements

a. Two basic waveform sets shall be considered for the TF coil. The “Long Pulse Partial Inductive” (LPPI) is described in the GRD, and provides the long flat-top scenario. The “Short Pulse Full Inductive (SPFI)” case provides a simpler waveform, in support of shorter plasma discharges. Current and voltage cases for these two scenarios are provided in Figures 4.4-1 and 4.4-2

Figure 4.4-1: Current in the TF coil

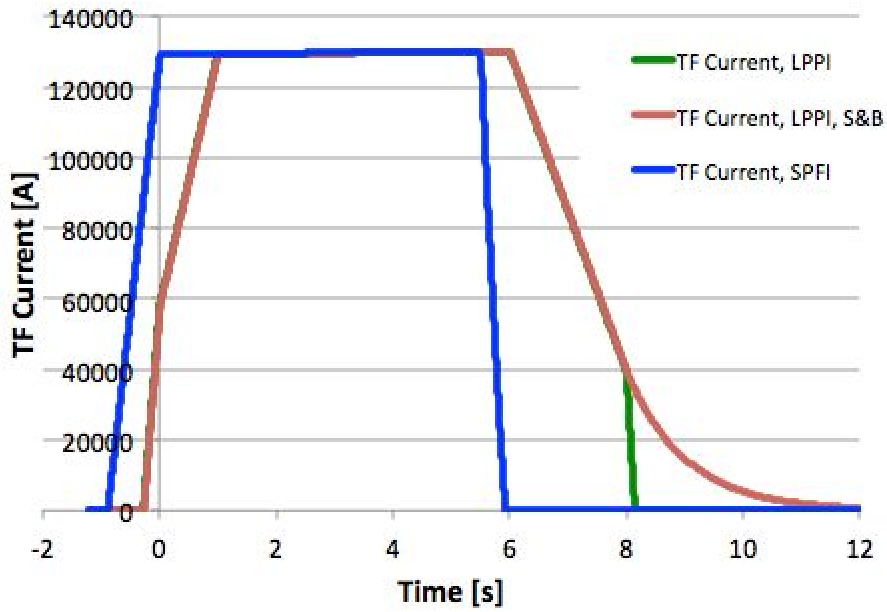
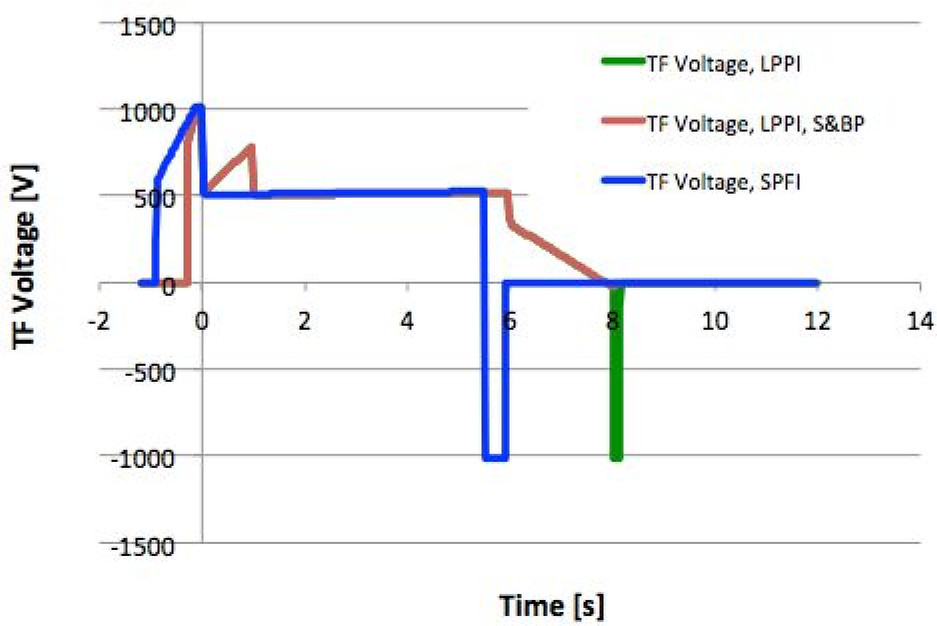


Figure 4.4-2: TF power supply voltage



b. The current values of the LPPI and SPFI waveforms are provided in Tables 4.4-1 and 4.4-2

Table 4.4-1: *Waveform for the LPPI TF waveform*

Time [s]	Bt [T]
-0.28	0
0.00	0.45
1.00	1.00
6.00	1.00
8.00	0.30
8.18	0

Table 4.4-2: *Waveform for the SPFI TF waveform*

Time [s]	Bt [T]
-0.89	0
0.00	1.00
5.50	1.00
5.96	0

c. Basic requirements are summarized in Table 4.4-3.

Table 4.4-3: *Basic Requirements for the TF coils and Circuit*

Parameter	Units	Value
Major Radius	m	0.934
Toroidal Field during Ip Flat-top	Tesla	1.00
TF Coil # of Turns	---	36
Maximum Temperature	C	92
TF Current Measurement Accuracy	%	0.2
TF Current Control Accuracy	%	0.5

The following are points of elaboration with regard to Table 4.4-3:

- Current measurement accuracy specification is defined as the absolute value of the difference between the measured value and the actual value as a percentage of the full scale value.
- The current control accuracy specification corresponds to steady state conditions and is defined as the difference between the measured DC current and the reference current as a percentage of the full scale current, excluding measurement errors.

d. Derived requirements for the TF coil and circuit are shown in table 4.4-4.

The following are points of elaboration with regard to Table 4.4-4:

- The Equivalent Square Wave (ESW) is the time duration of a constant current (equal to the current required to produce the required magnetic field) for which the $\int i^2(t)dt$ produces the maximum allowable coil temperature rise under adiabatic conditions. The current waveform in actual operation shall have an $\int i^2(t)dt$ which is less than or equal to that given by the ESW.
- The TF power supply system shall be capable of driving the coil current through the trajectories in Tables 3.4-1 and 3.4-2. The $\int i^2(t)dt$ of the resultant waveform shall be within the specified limit.
- In case of a fault the TF power supply shall shut down in such a way that the maximum $\int i^2(t)dt$ of the pre-fault and post-fault current waveform does not exceed the maximum value given Table 4.4-4.

***Table 4.4-4**: Derived Requirements for the TF coils and Circuit*

Parameter	Units	Value
current requirement	A	129778
ESW	s	6.50
Pulse $\int$ i^2dt	amp^2-sec	1.10E+11
Baseline Pulse Repetition Period	s	2400
Baseline Pulse Irms	kA	7
Upgrade Pulse Repetition Period	s	1200
Upgrade Pulse Irms	kA	10
# TF Series Power Supplies	---	1
# TF Parallel Power Supplies	---	8

***Table 4.4-5**: Electrical Parameters for the TF coil*

Parameter	Units	Value
TF Inner Leg Resistance @ Tinlet	Ω	1.168E-03
TF Outer Leg & Misc Resistance at 20C	Ω	1.580E-03
TF External Circuit Resistance	Ω	1.160E-03
TF Net Coil Resistance @ Tinlet	Ω	2.748E-03
TF Net Circuit Resistance @ Tinlet	Ω	5.484E-03
TF Net Circuit Resistance @ Tmax	Ω	6.347E-03
Coil Inductance	Henries	4.00E-03
External Inductance	Henries	3.56E-05
Net Inductance	Henries	4.04E-03

4.5 Upgrade Performance and Operational Requirements

a. The TF cabling may be upgraded to permit a 1200 second repetition rate in the future.

4.6 Interfaces

Table 4.6-1: *Interfaces for the TF AC/DC converter (WBS 1.5.2.1)*

Interfacing WBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.7.3.6.1	FPDP Data Stream	Fiber Optic	At fiber optic interface to the firing generator	Reference firing angles are provided to the TF rectifiers from the Realtime Data Stream	CWD
1.5.1.1	Fixed and Variable Frequency 13.8 kV Experimental Power	Electrical Power	At FCPC 13.8 kV transformer primary	Either the fixed or variable frequency bus provides primary power to the AC/DC converters	Electrical Schematic
1.6.1.1	Control I/O systems	Electrical Signal	At digitizer front panel or breakout panel	TF rectifier internal signals, ground currents, and line-to-ground voltages are digitized via the control I/O system.	CWD
1.3.2.2	FCPC Cooling Water System	Fluid	At the supply and return pipe fittings in the D-Site Pump Room	Provides cooling water to FCPC	P&ID
1.5.3.1	TF Convertor DC Systems	Electrical Power	at connection of cables to SDS switch terminals	Current from the power supplies passess to DC systems.	Electrical Schematic
1.5.1.2	D-Site Auxiliary Power	Electrical Signal	At panel or bus	Auxiliary power for TF rectifiers	Electrical Schematic
1.5.4.1	Hardwired Control System & PLC	Electrical Signal	Permissive inputs/outputs and L1 fault lines	Provides permissives and fault propagation for TF rectifiers	CWD

***Table 4.6-2**: Interfaces for the TF DC systems (WBS 1.5.3.1)*

Interfacing WBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.4	Bus Bar Systems and Bus Tower	Electrical Power	At the Power Cable Termination Structure	Current is delivered to the bus work, and therefore coils.	Electrical Schematic, Mechanical Drawing
1.7.3.6.5	DCPS Hardware Interface, Expansion Chassis & WDTs	Electrical Signal	At input to HSC	The signal from the TF current transducers in FCPC are provided DCPS hardware, which subsequently directs them to the Halmar signal conditioners	CWD
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At NTC floor, floor penetrations	Power cables from FCPC come through the NTC floor, are terminated in the power cable termination structure resides in enclosure in corner of NTC	N/A
0.1.1.6	Other D-Site Physical Infrastructure	Location	various	Cables associated with feeding the TF coil pass through numerous rooms between FCPC and the NTC	N/A
1.6.1.1	Control I/O systems	Electrical Signal	At digitizer inputs	Some signals from DC systems are directly digitized (ground fault currents, coil voltages)	CWD
1.5.4.3	DCCT Signal Conditioner	Electrical Signal	At terminal strip in the Junction Area racks	TF Branch current signals directed to DCCT Signal Conditioner inputs	CWD
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Power for TF convertor DC system components such as current transducers	Electrical Schematic for Directly Wired Components
1.5.2.1	TF Power Systems Converters	Electrical Power	at connection of cables to SDS switch terminals	Current from the power supplies passess to DC systems.	Electrical Schematic

5.0 OH and PF AC/DC Converters and DC Systems

5.1 Functions

a. The PF/OH Power Conversion System shall provide a variable current in the PF and OH magnet circuits during an NSTX-U discharge based on a reference firing angle signal provided in real time.

b. The OH power supply shall:

- precharge the OH coil
- produce sufficient loop voltage to initiate the plasma
- ramp up the plasma current
- hold the plasma current at the requested value
- ramp down the plasma current

c. The PF power supplies shall:

- Energize selected PF coils to provide fields that null the OH linkage flux.
- Energize simultaneously all PF coils to control the plasma equilibrium from plasma current ramp-up, through the plasma current flat-top, through plasma current ramp-down, and then return all coil currents to zero.

5.2 Materials and Design Requirements

a. See Section 1.

5.3: Configuration Requirements and Essential Features

a. The PF/OH Power Conversion System shall include all of the equipment necessary to power the PF and OH coils. This includes all equipment from the primary terminals of the converter transformers through to the DC bus connections to the magnets, consisting of phase controlled thyristor converters, disconnect switches and bus links, and all associated monitoring, and protection equipment.

b. The PF coils shall be connected in series groups in separate circuits with independent current control as indicated in Table 5.3-1.

Table 5.3-1: *Independent PF & OH Circuits*

PF Circuit	Coil Grouping	Unipolar/Bipolar
OH	OH	Bipolar
PF-1aU	PF1aU	Unipolar
PF-1aL	PF1aL	Unipolar
PF-1bU	PF1bU	Bipolar
PF-1bL	PF1bL	Bipolar
PF-1cU	PF1cU	Bipolar
PF-1cL	PF1cL	Bipolar
PF-2U	PF2a, PF2b, upper	Unipolar
PF-2L	PF2a, PF2b, lower	Unipolar
PF-3U	PF3a, PF3b, upper	Bipolar
PF-3L	PF3a, PF3b, lower	Bipolar
PF-4	PF4b,PF4c, upper & lower	Unipolar
PF-5	PF5a, PF5b, upper & lower	Unipolar

c. All series coil connections indicated in Table 5.3-1 shall result in current flow which is equal in magnitude, and in the same ϕ direction, in the series connected coils.

d. The circuits requiring bipolar operations are listed in Table 5.3-1. OH bipolarity is required to maximize the available flux for inductive current drive. PF3 bipolarity is required to facilitate the formation of a field null prior to plasma initiation. PF-1b and PF-1c bipolarity is required for control of the divertor magnetic geometry through the OH coil flux swing.

e. Bus links or other means shall be provided in order that the current in the OH & PF magnets can be driven in either direction. The polarity reversal procedure shall require 4 hours or less.

f. No-load disconnect switches shall be provided to isolate the OH and PF Power Systems from the connections to the magnets. In addition, no-load grounding switches shall be provided to ground the terminals of the connections to the OH and PF magnets.

g. Disconnect and grounding switches shall be interlocked with test cell access control.

h. Redundant measurements of each OH and PF current shall be provided.

i. Dummy load, and system of bus links permitting connection into PF/OH power system circuits, shall be provided. Load ampacity should permit a brief flat top at full baseline PF/OH current.

j. Each power supply in the OH and PF power system shall be grounded via high resistance connections at the (+) and (-) coil terminals. A ground fault protection system shall be used in conjunction with the grounding scheme to detect grounds within the circuits and terminate the discharge upon excessive ground current.

k. The OH and PF power system equipment and bus system external to the test cell shall be totally enclosed so that access can be maintained around the operating equipment without danger to the personnel.

l. Branch currents, ground currents, line-to-ground voltages, and other rectifier signals shall be digitized for post-shot inspection.

m. In-line spare rectifiers shall be provided for the OH and PF circuits to the extent that it is practical to do so.

n. OH and PF rectifiers shall be interfaced to the Hardwired Interlock System (HIS) in a fashion to prevent operations when when the test cell is potentially occupied.

o. OH and PF rectifiers shall be interlocked to prevent operations when test cell ground switches are closed.

5.4 Baseline Performance and Operational Requirements

Description of PF/OH Coils

a. The PF coil geometric requirements are described in the Magnets SRD.

b. Based on the coil grouping given in Table 5.3-1 & the coil geometry, the PF circuit inductances and resistances are given in Table 5.4-1. Full mutual inductance matrices are given the Design Point Spreadsheet [2].

Table 5.4-1: *Coil and external resistances and inductances*

	Self Inductance	External Circuit Inductance	Total Circuit Inductance	Coil Resistance	External Circuit Resistance	Total Circuit Resistance
	H	H	H	Ohms	Ohms	Ohms
OH	3.69E-02	1.00E-03	3.79E-02	9.95E-02	4.59E-03	1.04E-01
PF1aU	1.84E-03	2.72E-04	2.12E-03	5.93E-03	3.00E-03	8.93E-03
PF1aL	1.84E-03	2.72E-04	2.12E-03	5.93E-03	3.00E-03	8.93E-03
PF1bU	4.45E-04	2.72E-04	7.17E-04	9.19E-03	3.00E-03	1.22E-02
PF1bL	4.45E-04	2.72E-04	7.17E-04	9.19E-03	3.00E-03	1.22E-02
PF1cU	4.57E-04	2.72E-04	7.29E-04	4.49E-03	3.43E-03	7.92E-03
PF1cL	4.57E-04	2.72E-04	7.29E-04	4.49E-03	3.36E-03	7.85E-03
PF2U	1.98E-03	2.72E-04	2.25E-03	4.14E-03	3.53E-03	7.67E-03
PF2L	1.98E-03	2.72E-04	2.25E-03	4.14E-03	3.18E-03	7.32E-03
PF3U	5.16E-03	2.72E-04	5.43E-03	8.31E-03	3.61E-03	1.19E-02
PF3L	5.16E-03	2.72E-04	5.43E-03	8.31E-03	4.31E-03	1.26E-02
PF4	5.13E-03	2.72E-04	5.40E-03	1.13E-02	5.97E-03	1.73E-02
PF5	1.24E-02	2.72E-04	1.27E-02	1.75E-02	3.07E-03	2.06E-02

<u>Baseline Operation</u>

c. In order to satisfy NSTX-U plasma equilibria requirements the PF/OH circuit ampacities and capabilities shall at minimum match the parameters in Table 5.4-2. RMS currents are rounded up to the nearest kiloampere.

d. Voltage requirements for the PF coil shall be as Table 5.4-3.

***Table 5.4-2**: Ampacity requirements for the PF/OH Circuits*

	# of Parallel Supplies, Forward	# of Parallel Supplies, Series	Min. Current	Max. Current	ESW Current	ESW	Action	Baseline RMS Current, 2400 second period	Baseline RMS Current, 1200 second period
	---	---	kA	kA	kA	s	A^2s	kA	kA
OH	1	1	-24.0	24.0	24.0	1.47	8.49E+08	1.0	1.0
PF-1a	1	0	0.0	20.0	20.0	1.96	7.86E+08	1.0	1.0
PF-1b	1	1	-10.0	21.0	21.0	0.95	4.20E+08	1.0	1.0
PF-1c	1	1	-7.0	20.0	20.0	1.51	6.02E+08	1.0	1.0
PF-2	1	0	0.0	15.0	15.0	6.00	1.35E+09	1.0	2.0
PF-3	1	1	-16.0	12.0	16.0	6.13	1.57E+09	1.0	2.0
PF-4	1	0	0.0	16.0	16.0	6.00	1.54E+09	1.0	2.0
PF-5	1	0	0.0	24.0	24.0	6.00	3.46E+09	2.0	2.0

***Table 5.4-3**: Voltage and series power supply requirements*

	# Series Supplies, Forward	Terminal Voltage	Three-Wire Factor	High-Pot Requirement
	---	V	1 or 2	kV
PF-1a	2	2026	1	5.1
PF-1b	2	2026	2	9.1
PF-1c	2	2026	2	9.1
PF-2	2	2026	2	9.1
PF-3	2	2026	2	9.1
PF-4	2	2026	1	5.1
PF-5	3	3039	1	7.1

e. Baseline voltage and current waveforms for the OH coil are shown in Figs. 5.4-1 and 5.4-2.

f. Baseline requirements for the OH coil are provided in Table 5.4-4..

Table 5.4-4: *OH Coil Requirements*

Parameter	Units	Value
Initiation Loop Voltage	V	4.665
Initiation Duration	s	0.020
Ramp Up Flux Swing	Wb	0.700
Ramp Up Duration	s	1.000
Flat Top Flux Swing, LPPI	Wb	0.812
Flat Top Duration, LPPI	s	5.000
Flat Top Loop Voltage, LPPI	V	0.162
Maximum Temperature, LPPI	C	100
Flat Top Flux Swing, SPFI	Wb	1.285
Flat Top Duration, SPFI	s	2.500
Flat Top Loop Voltage, SPFI	V	0.514
Maximum Temperature, SPFI	C	99
OH Current Measurement Accuracy	%	0.5
OH Current Control Accuracy	%	0.5

Figure 5.4-1*: Current waveforms for the OH coil under the long pulse partial inductive (LPPI) and Short Pulse Full Inductive (SPFI) scenarios*

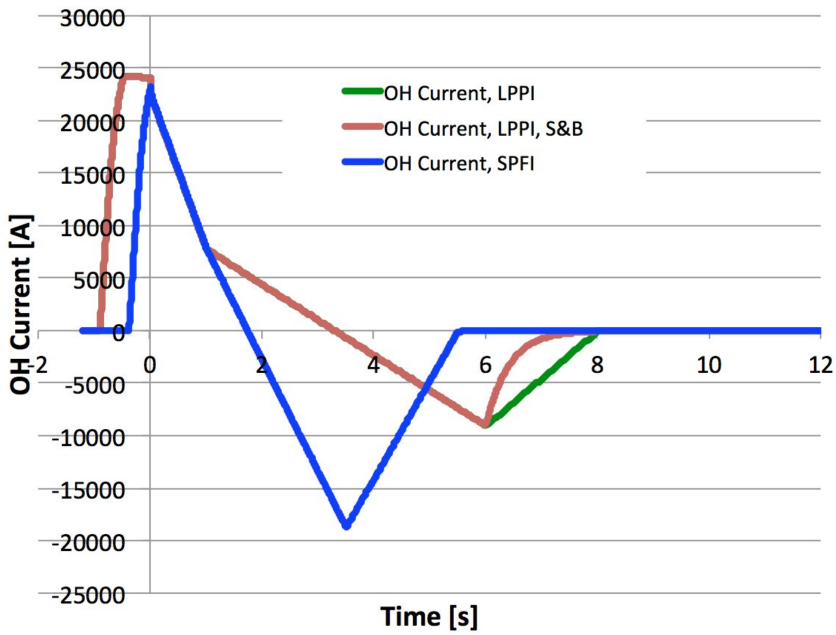
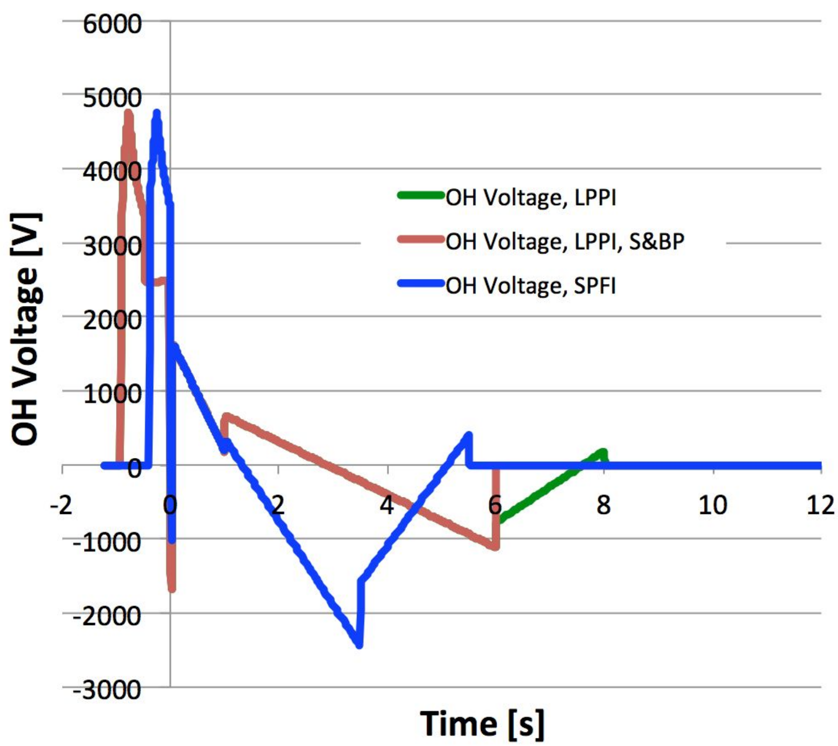


Figure 5.4-2*: Voltage waveforms for the OH coil under the long pulse partial inductive (LPPI) and Short Pulse Full Inductive (SPFI) scenarios*



f. Derived requirements on the OH coil and power supply are given in Table 5.4-5. RMS current levels are rounded up to the nearest kA.

***Table 5.4-5**: Derived requirements for the OH coil and power supply.*

Parameter	Units	Value
# of OH Coil Turns	---	888[2]
Baseline Pulse Repetition Period	s	2400
Upgrade Pulse Repetition Period	s	1200
Total Flux Swing, LPPI	Wb	1.61
ESW, LPPI	s	1.48
Pulse ∫ i^2dt, LPPI	amp^2-sec	8.51E+08
Baseline Pulse Irms, LPPI	kA	1.00
Upgrade Pulse Irms, LPPI	kA	1.00
Total Flux Swing, SPFI	Wb	2.08
ESW, SPFI	s	1.46
Pulse ∫ i^2dt, SPFI	amp^2-sec	8.39E+08
# OH Series Power Supplies	---	6
# OH Parallel Power Supplies	---	1
OH Current Measurement Accuracy	%	0.5
OH Current Control Accuracy	%	0.5

g. Electrical parameters of the OH coil are provided in Table 5.4-6.

[2] The final OH coil had 884 turns as fabricated. The number 888 is value based on the design point.

***Table 5.4-6**: Electrical parameters of the OH coil.*

Parameter	Units	Value
Coil Resistance (pre-pulse)	Ω	9.66E-02
Coil Resistance (end of pulse)	Ω	1.28E-01
External Circuit Resistance	Ω	4.59E-03
Net Resistance (pre-pulse)	Ω	1.66E-01
Net Resistance (end of pulse)	Ω	1.98E-01
Coil Inductance	Henries	4.31E-02
External Inductance	Henries	1.01E-03
Net Inductance	Henries	4.41E-02

h. PF current measurement, control accuracy, and ripple requirements are given in Table 5.4-7.

***Table 5.4-7**: PF Measurement and Control Accuracy Requirements*

Parameter	**Value**	**Units**
PF Current Measurement Accuracy	0.5	%
PF Current Control Accuracy	0.5	%
PF Current Ripple	0.5	%

- Current measurement accuracy specification is defined as the absolute value of the difference between the measured value and the actual value as a percentage of the full scale value (see Table 5.4-2).
- The current control accuracy specification corresponds to steady state conditions and is defined as the difference between the measured DC current and the reference current as a percentage of the full scale current (see Table 5.4-2), excluding measurement errors.
- The PF current ripple is defined as the peak-to-peak ripple amplitude at the 6 pulse thyristor frequency as a percentage of the full scale current (see Table 5.4-2).

5.5 Upgrade Performance and Operational Requirements

a. The PF-1a, PF-2, & PF-4 circuits may be converted to bipolar operation in the future.

5.6 Interfaces

***Table 5.6-1**: Interfaces for the OH AC/DC Converters s (WBS 1.5.2.2)*

Interfacing WBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.7.3.6.1	FPDP Data Stream	Fiber Optic	At fiber optic interface to the firing generator	Reference firing angles are provided to the OH rectifiers from the Realtime Data Stream	CWD
1.6.1.1	Control I/O systems	Electrical Signal	At digitizer connectors	OH rectifier internal signals, ground currents, and line-to-ground voltages are digitized via the control I/O system.	CWD or Schematic
1.3.2.2	FCPC Cooling Water System	Fluid	At the supply and return pipe fittings in the D-Site Pump Room	Provides cooling water to FCPC	P&ID
1.5.3.2	OH Convertor DC Systems	Electrical Power	at connection of cables to SDS switch terminals	Current from the power supplies passess to DC systems.	Electrical Schematic
1.5.1.1	Fixed and Variable Frequency 13.8 kV Experimental Power	Electrical Power	Primary of 13.8 kV FCPC transformers	Provide power to TF rectifiers from either S1 or MG	Electrical Schematic
1.5.1.2	D-Site Auxiliary Power	Electrical Signal	At panel or bus	Auxiliary power for OH rectifiers	Electrical Schematic
1.5.4.1	Hardwired Control System & PLC	Electrical Signal	Permissive inputs/outputs and L1 fault lines	Provides permissives and fault propagation for TF rectifiers	CWD

***Table 5.6-2**: Interfaces for the OH DC Systems (WBS 1.5.3.2)*

Interfacing WBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.4	Bus Bar Systems and Bus Tower	Electrical Power	At the Power Cable Termination Structure	Current is delivered to the bus work, and therefor coils.	Electrical Schematic, Mechanical Drawing
1.7.3.6.5	DCPS Hardware Interface, Expansion Chassis & WDTs	Electrical Signal	At input to HSC	The signal from the OH current transducers in FCPC are provided DCPS hardware, which subsequently directs them to the Halmar signal conditioners	CWD
1.8.1.1	NTC Penetrations	Wall/Floor Penetration	At NTC floor, floor penetrations	Power cables from FCPC come through the NTC floor, are terminated in the power cable termination structure which resides in enclosure in corner of NTC	N/A
0.1.1.6	Other D-Site Physical Infrastructure	Location	various	Cables associated with feeding the OH coil pass through numerous rooms between FCPC and the NTC	N/A
1.6.1.1	Control I/O systems	Electrical Signal	At digitizer inputs	Some signals from DC systems are directly digitized (ground fault currents, coil voltages)	CWD
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Power for OH convertor DC system components such as current transducers	Electrical Schematic for Directly Wired Components
1.5.2.2	OH Power Systems Converters	Electrical Power	at connection of cables to SDS switch terminals	Current from the power supplies passess to DC systems.	Electrical Schematic

***Table 5.6-3**: Interfaces for the PF AC/DC Converters (WBS 1.5.2.3)*

Interfacing WBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.7.3.6.1	FPDP Data Stream	Fiber Optic	At fiber optic interface to the firing generator	Reference firing angles are provided to the PF rectifiers from the Realtime Data Stream	CWD
1.6.1.1	Control I/O systems	Electrical Signal	At digitizer connectors	PF rectifier internal signals, ground currents, and line-to-ground voltages are digitized via the control I/O system.	CWD
1.3.2.2	FCPC Cooling Water System	Fluid	At the supply and return pipe fittings in the D-Site Pump Room	Provides cooling water to FCPC	P&ID
1.5.3.3	PF Convertor DC Systems	Electrical Power	at connection of cables to SDS switch terminals	Current from the power supplies passess to DC systems.	Electrical Schematic
1.5.1.1	Fixed and Variable Frequency 13.8 kV Experimental Power	Electrical Power	Primary of 13.8 kV FCPC transformers	Provide power to TF rectifiers from either S1 or MG	Electrical Schematic
1.5.1.2	D-Site Auxiliary Power	Electrical Signal	At panel or bus	Auxiliary power for PF rectifiers	Electrical Schematic
1.5.4.1	Hardwired Control System & PLC	Electrical Signal	Permissive inputs/outputs and L1 fault lines	Provides permissives and fault propagation for TF rectifiers	CWD

***Table 5.6-4**: Interfaces for the PF DC Systems (WBS 1.5.3.3)*

Interfacing WBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.4	Bus Bar Systems and Bus Tower	Electrical Power	At the Power Cable Termination Structure	Current is delivered to the bus work, and therefor coils.	Electrical Schematic, Mechanical Drawing
1.7.3.6.5	DCPS Hardware Interface, Expansion Chassis & WDTs	Electrical Signal	At input to HSC	The signal from the PF current transducers in FCPC are provided DCPS hardware, which subsequently directs them to the Halmar signal conditioners	CWD
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At NTC floor, floor penetrations	Power cables from FCPC come through the NTC floor, are terminated in the power cable termination structure which resides in enclosure in corner of NTC	N/A
0.1.1.6	Other D-Site Physical Infrastructure	Location	various	Cables associated with feeding the PF coils pass through numerous rooms between FCPC and the NTC	N/A
1.6.1.1	Control I/O systems	Electrical Signal	At digitizer inputs	Some signals from DC systems are directly digitized (ground fault currents, coil voltages)	CWD
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Power for PF convertor DC system components such as current transducers	Electrical Schematic for Directly Wired Components
1.5.2.3	PF Power Systems Converters	Electrical Power	at connection of cables to SDS switch terminals	Current from the power supplies passess to DC systems.	Electrical Schematic

6.0 Switching Power Amplifiers

6.1 Functions

a. The function of the switching power amplifier (SPA) system is to power the EFC/RWM (error field correction / resistive wall mode) coils.

6.2 Materials and Design Requirements

a. See Section 1.

6.3: Configuration Requirements and Essential Features

a. The SPA system shall have at least six independently controllable power supplies.

b. DC charging power shall be provided by a spare TRANSREX section.

c. Disconnect switches shall be provided between the TRANSREX supply and the SPA, enabling the systems to be isolate from each other.

d. No-load disconnect switches shall be provided to isolate the SPA Power Systems from the connections to the RWM coil. In addition, no-load grounding switches shall be provided to ground the terminals of the connections to the RWM coils.

e. Disconnect and grounding switches shall be interlocked with test cell access control.

f. Redundant measurements of each power supply current shall be provided.

g. Each power supply in the SPA system shall be grounded via high resistance connections at the (+) and (-) coil terminals.

h. A ground fault protection system shall be provided, with capability to terminate the pulse if a ground is detected.

i. Overcurrent, overtime, and I^2t protection shall be provided

j. The SPA/RWM power system equipment and bus system external to the test cell shall be totally enclosed so that access can be maintained around the operating equipment without danger to the personnel.

k. The SPA current output shall be controlled from the plasma control system.

l. Sufficient SPA signals shall be digitized to aid in troubleshooting. These include but are not limited to the current reference for each supply or subunit, any enable/status bits, the voltage on the SPA capacitor banks and the bank charging current.

m. The SPA systems shall be interfaced to the Hardwired Interlock System (HIS) in a fashion to prevent operations when when the test cell is potentially occupied.

n. The SPA systems shall be interlocked to prevent operations when test cell ground switches are closed.

6.4 Baseline Performance and Operational Requirements

a. The SPAs shall produce a bipolar output current of at least +/- 3.33 kA, with output from DC to 100 Hz, into the load indicated in Table 6.4-1.

b. The SPAs shall be capable of producing this current rating for 6 seconds, every 300 seconds.

c. Parameters of a single RWM/EFC coil are provided in Table 6.4-1.

Table 6.4-1*: Parameters of an RWM/EFC coil*

Coil Resistance	Ohms	0.0006
External Resistance	Ohms	0.01819
Total Resistance	Ohms	0.01879
Coil Inductance	mH	0.016
External Inductance	mH	0.054
Total Inductance	mH	0.070

6.5 Upgrade Performance and Operational Requirements

a. There are no upgrades to the SPA power supply system presently envisioned.

6.6 Interfaces

***Table 6.6-1**: Interfaces for the Switching Power Amplifier DC Link (WBS 1.5.2.4.1).*

Interfacing WBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.6.1.1	Control I/O systems	Electrical Signal	At digitizer connectors	Various signals are digitized (voltage, current, control, etc.)	CWD or Schematic
1.7.3.1	Hardwired Interlock System	Electrical Signal	FCPC Control Boards	The HIS prevent rectifier DC link operation when the NTC and related areas are in an unsafe condition.	CWD
1.5.1.1	Fixed and Variable Frequency 13.8 kV Experimental Power	Electrical Power	At FCPC 13.8 kV transformer primary	Either the fixed or variable frequency bus provides primary power to the AC/DC converters	Electrical Schematic
1.3.2.2	FCPC Cooling Water System	Fluid	At the supply and return pipe fittings in the D-Site Pump Room	Provides cooling water to the SPA DC-link power supply	P&ID
1.5.2.4.2	SPAs Inverters	Electrical Power	At disconnect switch between DC link supply and the SPA capacitor bank	DC link charges the capacitor bank within the SPA	Electrical Schematic
1.7.3.6.1	FPDP Data Stream	Fiber Optic	At fiber optic interface to the firing generator	Reference firing angles are provided to the OH and PF rectifiers from the Realtime Data Stream	CWD
1.5.1.2	D-Site Auxiliary Power	Electrical Signal	At panel or bus	Auxiliary power for DC link rectifier	Electrical Schematic
1.5.4.1	Hardwired Control System & PLC	Electrical Signal	Permissive inputs/outputs and L1 fault lines	Provides permissives and fault propagation for TF rectifiers	CWD

***Table 6.6-2**: Interfaces for the Switching Power Amplifier Inverters (WBS 1.5.2.4.2).*

Interfacing WBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.7.3.6.1	FPDP Data Stream	Fiber Optic	At SPA reference input connector	Reference currents, in the form of an analog voltage, are provided by the Realtime Data Stream	CWD
1.3.2.2	FCPC Cooling Water System	Fluid	At the supply and return pipe fittings in the D-Site Pump Room	Provides cooling water to the SPAs	P&ID
1.5.3.4	Switching Power Amplifier DC Systems	Electrical Power	At outputs of the inverters	DC systems such as disconnect switches and power cabling used to connect the SPA outputs to the interface cabinet in the test cell	Electrical Schematic
1.6.1.1	Control I/O systems	Electrical Signal	At digitizer input	Data from SPA inverters digitized	CWD
1.5.2.4.1	SPA DC Link	Electrical Power	At disconnect switch between DC link supply and the SPA capacitor bank	DC link charges the capacitor bank within the SPA	Electrical Schematic
1.5.1.2	D-Site Auxiliary Power	Electrical Signal	At panel or bus	Auxiliary power for SPA Inverters	Electrical Schematic
1.5.4.4	Analog Coil Protection	Electrical Signal	Control input	Provides overcurrent and I^2t protection for SPA circuits	CWD

***Table 6.6-3**: Interfaces for the Switching Power Amplifier DC Systems (WBS 1.5.4.4).*

Interfacing WBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.4	Bus Bar Systems and Bus Tower	Electrical Power	At SPA interconnection box, in the test cell	Current is delivered to the bus work, and therefor coils.	Electrical Schematic, Mechanical Drawing
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At penetration surface	Power cables from the SPAs come through the test cell wall	N/A
0.1.1.6	Other D-Site Physical Infrastructure	Location	various	Cables associated with feeding the RWM coils pass through various areas between 2nd floor FCPC and the NTC	N/A
1.6.1.1	Control I/O systems	Electrical Signal	At digitizer inputs	Some signals from DC systems are directly digitized (coil voltages, coil currents)	CWD
1.5.2.4.2	SPAs Inverters	Electrical Power	At outputs of the inverters	DC systems such as disconnect switches and power cabling used to connect the SPA outputs to the interface cabinet in the test cell	Electrical Schematic
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Power for SPA DC system components such as current transducers	Electrical Schematic for Directly Wired Components