National Spherical Torus eXperiment Upgrade

PF-1b Power Loop and 13.8 kV Breaker Modifications

WBS 1.05.01.03 & WBS 1.09.04.03

NSTX-U Recovery Project FDR – March 17-19, 2020

John Dellas - Cognizant Engineer

Last edit: ?/?/??

Outline

1. Overview
2. Scope
3. Requirements and Interfaces
4. Analysis/Prototyping
5. Chit Closure
6. Procurement, Fabrication, Installation, and Test
7. Risk - Project Risks and Design FMECA
8. Quality, Environmental, Safety, and Health
9. Summary

Overview - WBS 1.05.01.02

(CDE-3B Scope)

WBS Title	PF-1b Power Loop	WBS #	1.05.01.03
Project Cog.	John Dellas	Assoc. Proj. Man.	Tom Jernigan
Design Scope	Design and implement power loops for the PF-1b coils, utilizing the existing FCPC infrastructure to the greatest extent possible.		
Technical Impact of Scope	Will enable PF-1b coils to be used during plasma operations, allowing extended divertor flexibility.		
Design Status	FDR completed on 9/20/2018: link chits: link calculations: link drawings: link SoW/Tech Spec: link		
Fabrication Status	Firing generators and communications electronics (FOMs) completed. Surge arrester boards fabrication underway.		
Installation Status	DC CTs installed. OH circuit reconfiguration completed.		

Overview - WBS 1.09.04.03

(CDE-3B Scope)

WBS Title	PSS Breakers	WBS #	1.09.04.03
Project Cog.	John Dellas	Assoc. Proj. Man.	Tom Jernigan
Design Scope	Install a single new 13.8 kV breaker with undervoltage trip mechanism; Refurbish existing 13.8 kV line-up while upgrading for undervoltage trip		
Technical Impact of Scope	Provides a fail-safe trip mechanism for PSS applications: power required to maintain breakers in closed position.		
Design Status	FDR completed on 7/12/2019: link chits: link calculations: N/A drawings: link SoW/Tech Spec: link		
Fabrication Status	Contract negotiations with the OEM underway.		
Installation Status	Not started		

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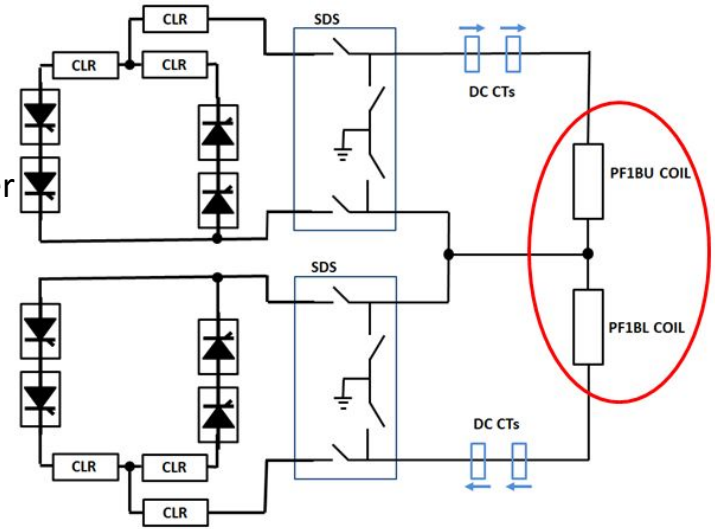
Power Loop - Converters - Scope

- Provide dedicated 2 kV, bi-polar power circuits for the new PF1B coils
- New circuit requires repurposing converters (from existing FCPC line-ups), cabling, disconnect and grounding switches (SDS), DC current transducers (DC CT's), and current limiting reactors (CLR's)
- Converters for PF1BU circuit requires new firing generators and PLC interface into control system.

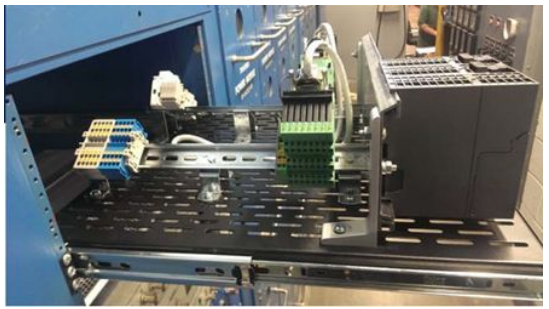
Transrex Power Converter



New PF1B Coil Set in Recovery Scope for Magnets

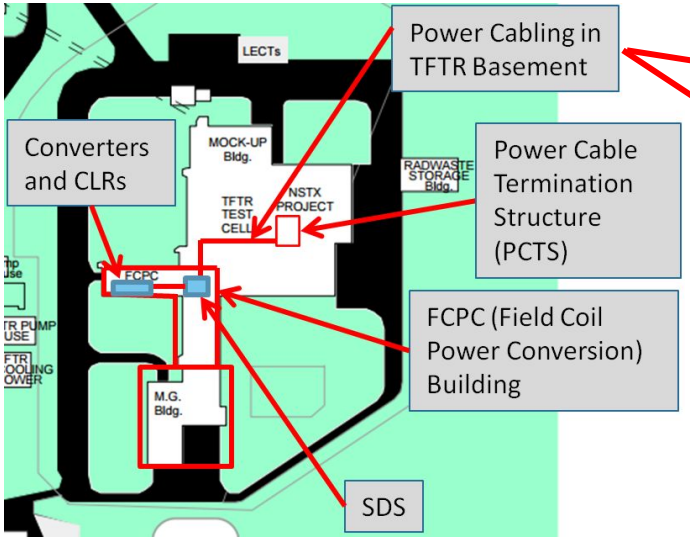
Firing Generator on control cubicle of power converter

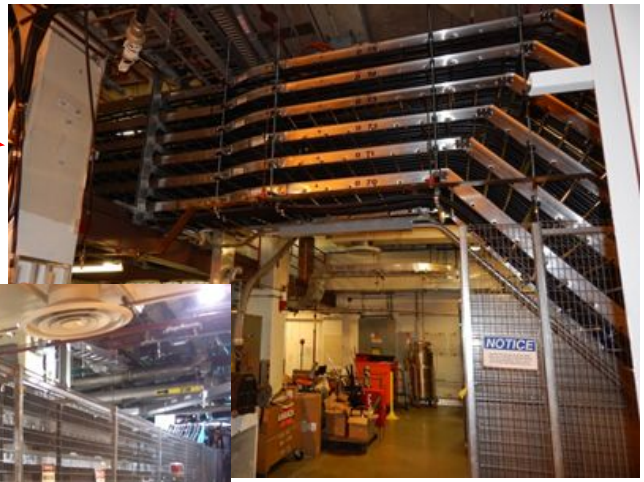
PLC Tray on withdrawable rack of power converter



Power Loop - Cabling - Scope

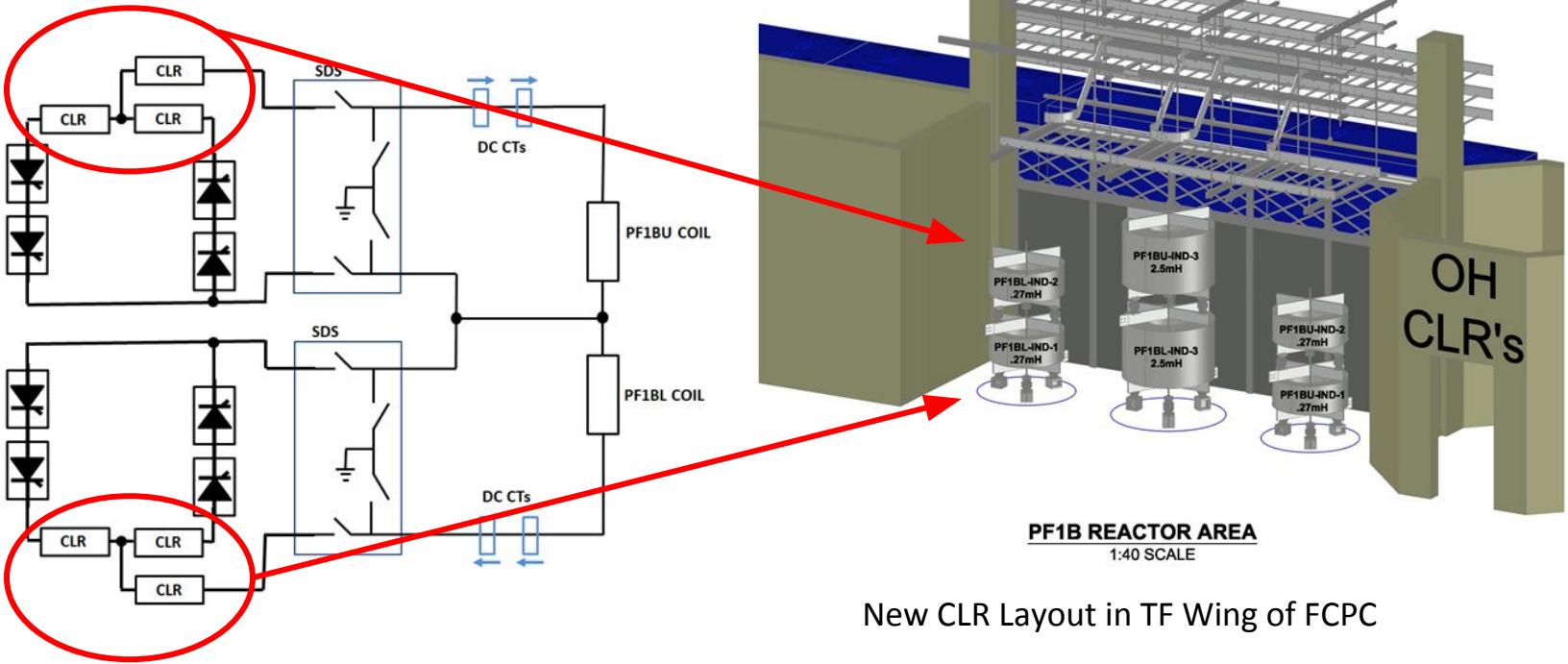
- Power cable and cable tray installation key element of work
  - Routing in FCPC between converters, CLR's and SDS
  - Routing from SDS to cable spread room to transition area
  - Routing from transition area to TFTR basement to MER PCTS





Power Loop - Current Limiting Reactors - Scope

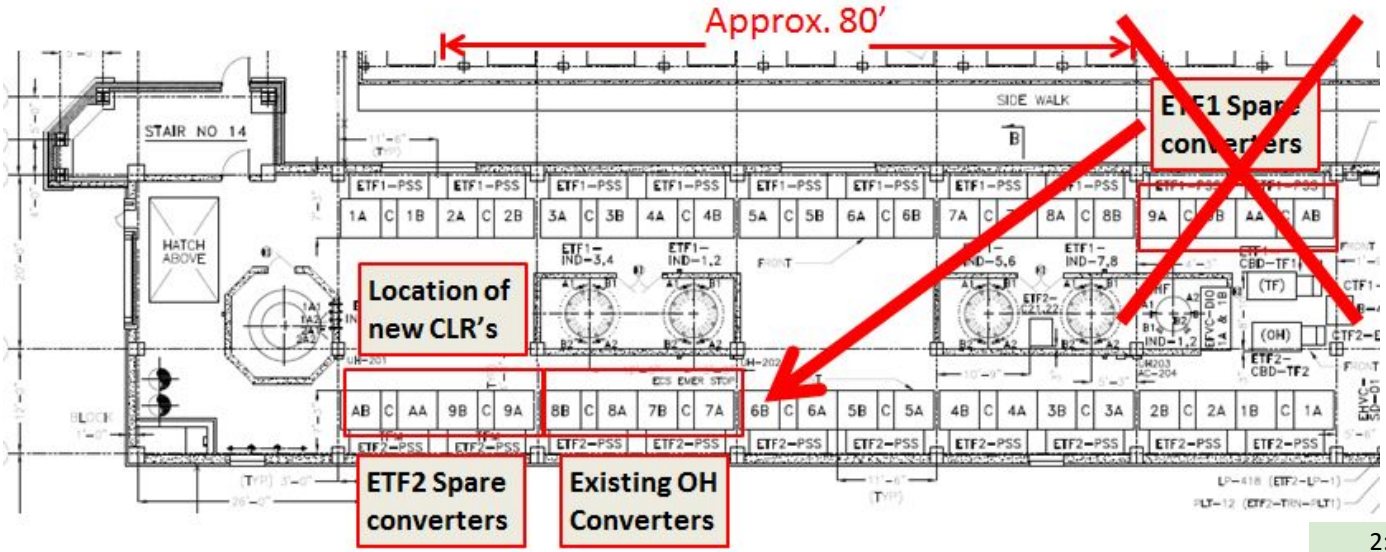
- Additional inductance (2.5 mH) needed to meet ripple limits as per latest requirements (link)
  - Supplements 256 µH CLR required for circuit protection
- Contract negotiations are underway with the selected vendor of the CLRs
- Design is as per industry standards (ANSI C57.16, Dry-Type, Air-Core, Series-Connected Reactors)



New CLR Layout in TF Wing of FCPC

Value Engineering Used in Defining the Scope

- Repurposing two OH Converters for PF1B circuit instead recommissioning legacy spares
  - Two new firing generators *not needed*
  - Outfitting for PLC interface *not needed* (I/O modules, communication modules)
  - *Reduction* in cabling/cable tray due to more optimum location of OH converters
    - Closer to CLR location
    - Availability of existing cable and tray on OH side of TF wing
  - OH interlock recovery project (DVVR chit) *not needed*



Breaker Replacement Overview

- Personnel Safety System turns off direct ionizing radiation hazards in the event of an e-stop or door violation or inconsistent state.
- 13.8 kV breakers are main interdiction devices
- Existing 13.8 kV breakers not fully fail-safe
- Work on these breakers will make them fail safe, is a critical aspect of the PSS program.
  - *See talk by J. Petrella for more details on PSS*

SV, S1 & S2 Breaker Scope

- Refurbishment of SV, S1B10 & S2B5 switchgear breakers plus replacement of S1B1 isolator. All with additional direct-acting Under Voltage Trip Devices added, in support of PSS.

Lineup/Bkr	1200A, 500MVA HK	1200A 750MVA VHK	3000A, 1000MVA VHK(X)	Replace (Rep)/ Refurbish(Ref)
ESV1	8	4		Ref
ESV2	11	1		Ref
Spares	3	1		Ref
S1B1 (Dummy)			1	Rep
S1B1 Spare			1	Rep
S1B10	1			Ref
S2B5	1			Ref
Total	24	6	2	

SV Lineup breaker (500MVA) withdrawn from cubicle

See talk by J. Petrella for more information on PSS

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Requirements Defined and Met - 1

PF1BU & PF1BL Circuit Performance Requirements

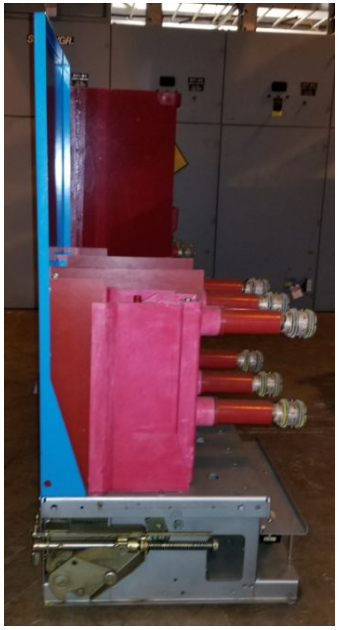
Performance Requirement	Value
Circuit Configuration	Bipolar, 3W
Min./Max. Current	-10 kA/21 kA
ESW	.95 secs
Action	4.20E+08 A^2-sec.
Terminal Voltage	2.026 kV
High-Pot Requirement	9.1 kV
Baseline RMS current	1.0 kA
Rep Rate	1200 secs.
PF Current Ripple	0.5%*

*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.

Requirements Defined in Power Systems SRD NSTX-U-RQMT-SRD-006.

Requirements Defined and Met - 2

- PSS Breaker Modifications
  - Refurbishment/Replacement of circuit breakers reusing existing cubicles
  - Breakers for interdiction identified in NSTX-U-RQMT-RD-024, Section 3.2, PSS-SIS Interlocked Systems
  - IEEE C37 Standards for HV Circuit Breakers and Switchgear
  - IEEE C37.59 Standard for Requirements for Conversion of Power Switchgear Equipment



Interfaces Defined in the SRD and Accommodated by Design

- Interfaces for the PF AC/DC Converters
  - Most are within Power Systems group (DC Systems, HCS, MG, AC Power)
  - Cooling Water System – Interface already in place (existing converters)
  - FPDP data stream – New FOMS transmitter board and output board to be installed in Junction Area + FO cables + code updates for addressing
  - Code mods to PSRTC, PCS, DCPS, EPICS, and MDSplus in CI&C scope

NSTX-U-RQMT-SRD-006

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

Details of Interfaces Defined in Interface Control Documents

System 1	System 2	ICD Link	Exposition
Power Systems	Magnets	link	Defines interface between the inner-PF coils and all Magnet systems and the Power Systems

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Calculations Used to Verify Design will Meet Requirements

Physical Quantity	Calculation #	Comment
Calculation of Power Cable Heating due to Pulse Load of PF1B	NSTX-U-CALC-53-07-00	Verifies acceptability of cable size for power circuit
Current Limiting Reactor Sizing Analysis and Calculation	NSTX-U-CALC-53-08-00	Determines inductance needed in external circuit to meet ripple requirement

Parts are generally COTS, technology is well tested through decades of experience in FCPC → Prototyping not needed.

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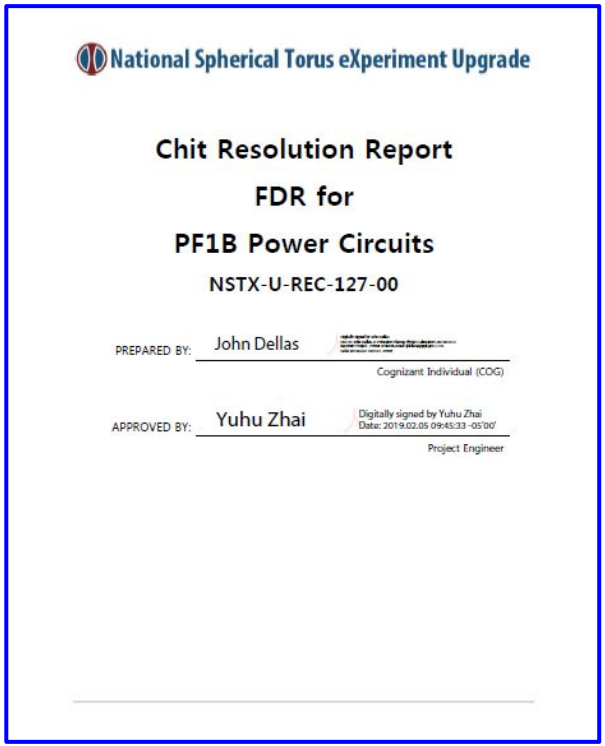
All Chits have been Closed

Chits closed at FDR

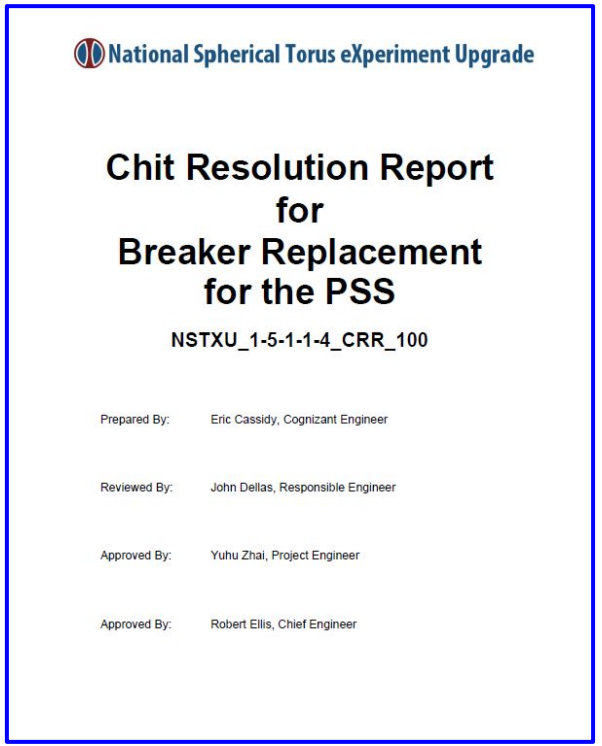

National Spherical Torus eXperiment Upgrade

Chit Resolution Report
FDR for
PF1B Power Circuits
NSTX-U-REC-127-00

PREPARED BY: John Dellas
Cognizant Individual (COG)

APPROVED BY: Yuhu Zhai
Digitally signed by Yuhu Zhai
Date: 2019.02.05 09:45:33 -05'00'
Project Engineer

Chit Resolution Report: link


National Spherical Torus eXperiment Upgrade

Chit Resolution Report
for
Breaker Replacement
for the PSS

NSTXU_1-5-1-1-4_CRR_100

Prepared By: Eric Cassidy, Cognizant Engineer

Reviewed By: John Dellas, Responsible Engineer

Approved By: Yuhu Zhai, Project Engineer

Approved By: Robert Ellis, Chief Engineer

Chit Resolution Report: link

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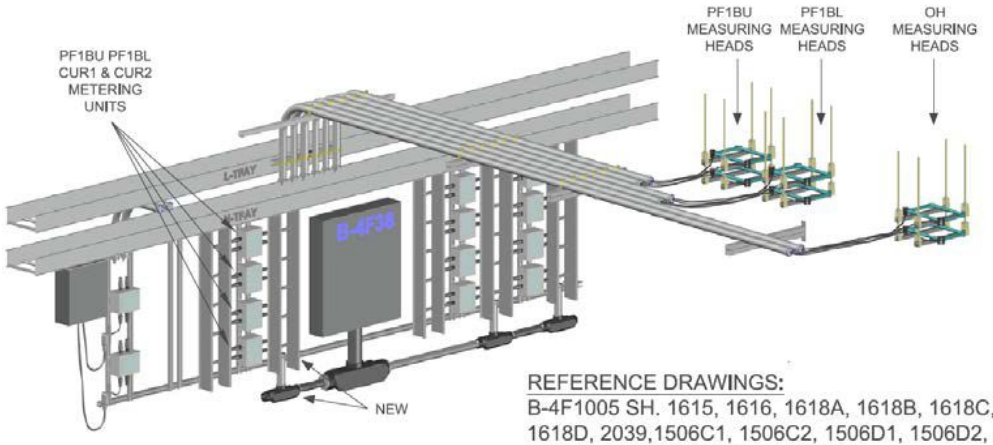
PF1B Power Loop Installation

DC CT Installation in the Cable Spread Room (completed)



REFERENCE DRAWINGS:
B-4F1005 SH. 1615, 1616, 1618A, 1618B, 1618C, 1618D, 2039,1506C1, 1506C2, 1506D1, 1506D2, 1506E1, 1596E2, 1506F1, 1506F2.

NOTES:
1. EXISTING SPARE AVAILABILITY; SPARE CONDUCTORS TO JCT RM & FCPC PLC. B-4F38 HAS #4 SPARE AC BREAKERS.

OH Circuit Reconfiguration (completed)

OH SDS Mod for new cable configuration

NCRs and ECNs During Power Loop and Breaker Activities to Date

Drawing Number	ECN Number	Description of the Change
Multiple	8159	PF1B DCCT Install
B-4F10045 SH. 1568, B-4F1005 SH. 1033	8162	Decommission abandoned SPA 1 DC feed circuit
Multiple	8157	Removal of decommissioned power panel PP-318
Multiple	8180	OH Coil Power Feed 6kV Conversion
Multiple	8164	PF1B PCTS Bus and Tray Layout

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Project Risks are Actively Being Managed

Risk	Score (1-81)	Open/Retired	Risk Retirement Event
FPDP Output Module Serial (FOMs) fail operational testing	20	OPEN	completion of component testing
If components for the PF-1b power loop are difficult to procure	20	RETIRED	end of procurement
If issues are uncovered with spare converters (Power supplies)	16	OPEN	Completion of assembly testing
If there is difficulty to provide acceptable path for routing of power cables	15	OPEN	Completion of subassemblies
If there is insufficient space for additional cable terminators on PCTS	15	OPEN	Completion of subassemblies
Current Limiting Reactors (CLRs) do not pass routine testing at supplier factory	15	OPEN	completion of procurement
Available space issues in FCPC	1	RETIRED	

FMECA - PSS Breakers

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
AC Breakers and Switchgear	52UVD coil fails on SV breaker causing corresponding breaker to trip free	wire becomes disconnected; contact corrosion	Interruption to NSTX-U operations	2	AC Breakers and Switchgear	Personnel Safety System (SIS)	None	2
AC Breakers and Switchgear	52UVD coil fails on S2B5 or S1B10 breaker causing corresponding breaker to trip free	wire becomes disconnected; contact corrosion	Interruption to NSTX-U operations	2	AC Breakers and Switchgear	Personnel Safety System (SIS)	None	2
AC Breakers and Switchgear	52UVD coil fails on S1B1 breaker causing corresponding breaker to trip free	wire becomes disconnected; contact corrosion	Interruption to NSTX-U operations	2	AC Breakers and Switchgear	Personnel Safety System (SIS)	None	2

Fail-safe trip mechanism means that failures are inconvenient, but do not have safety implications

PF-1b Power Loop follows legacy design principles

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Quality, Environmental, Safety, & Health

- PF1B CLR Supplier and PSS Breaker refurbishment contractor are pre-qualified through Procurement Quality Assurance
- PF1B power circuit design is a repetition of existing bi-polar circuits (PF3, PF1C) and will be operated in the same manner. No new hazards will be introduced.
- PSS breakers are largely a refurbishment job. No new hazards will be introduced.
- During installation, addressed with PPPL Worker Safety Program
  - Pre-Job Briefs
  - JHAs
  - LOTO (& PPE)
  - Elevated Work Safety Practices

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Summary

- Requirements have been met via analysis benchmarked against field test data
- Interfaces are considered in the design and documented in the ICDs
- All chits related to the PF-1b Power Loop and the PSS Breaker Mods have been addressed and are closed
- Project risks are actively managed - no risks are Level I
- Safety is addressed through close adherence to the PPPL Worker Safety Program