Chit Resolution Report: 2137-FDR-006

List of chits closed in this report on the cover, details inside the report

Attach total log of chits, including all those previously closed and those not yet closed.

The following PDR chits were previously closed out:

Review Date	Chit Code	Review	OBS	Element	Recovery WBS	Assigned To	Status	Accountable
27-Feb-2018	PF1BPWRCIRPDR01	PF1B Power Circuits PDR	PWR	PF1B Bipolar Circuit	1.5.1.3	Dellas	Closed	Dellas
27-Feb-2018	PF1BPWRCIRPDR02	PF1B Power Circuits PDR	PWR	PF1B Bipolar Circuit	1.5.1.3	Dellas	Closed	Dellas
27-Feb-2018	PF1BPWRCIRPDR03	PF1B Power Circuits PDR	PWR	PF1B Bipolar Circuit	1.5.1.3	Dellas	Closed	Dellas
27-Feb-2018	PF1BPWRCIRPDR04	PF1B Power Circuits PDR	PWR	PF1B Bipolar Circuit	1.5.1.3	Dellas	Closed	Dellas
27-Feb-2018	PF1BPWRCIRPDR05	PF1B Power Circuits PDR	PWR	PF1B Bipolar Circuit	1.5.1.3	Dellas	Closed	Dellas
27-Feb-2018	PF1BPWRCIRPDR06	PF1B Power Circuits PDR	PWR	PF1B Bipolar Circuit	1.5.1.3	Dellas	Closed	Dellas
27-Feb-2018	PF1BPWRCIRPDR07	PF1B Power Circuits PDR	PWR	PF1B Bipolar Circuit	1.5.1.3	Dellas	Closed	Dellas
27-Feb-2018	PF1BPWRCIRPDR08	PF1B Power Circuits PDR	PWR	PF1B Bipolar Circuit	1.5.1.3	Dellas	Closed	Dellas
27-Feb-2018	PF1BPWRCIRPDR09	PF1B Power Circuits PDR	PWR	PF1B Bipolar Circuit	1.5.1.3	Dellas	Closed	Dellas
27-Feb-2018	PF1BPWRCIRPDR10	PF1B Power Circuits PDR	PWR	PF1B Bipolar Circuit	1.5.1.3	Dellas	Closed	Dellas
27-Feb-2018	PF1BPWRCIRPDR11	PF1B Power Circuits PDR	PWR	PF1B Bipolar Circuit	1.5.1.3	Dellas	Closed	Dellas
27-Feb-2018	PF1BPWRCIRPDR12	PF1B Power Circuits PDR	PWR	PF1B Bipolar Circuit	1.5.1.3	Dellas	Closed	Dellas

The following FDR Chits are being submitted in this report for closure:

Review Date	Chit Code	Review	OBS	Assigned To	Status	Accountable
20-Sep-2018	PF1BPWRCIRFDR01	PF1B Bipolar Circuit FDR	PWR	Dellas	Open	Dellas
20-Sep-2018	PF1BPWRCIRFDR02	PF1B Bipolar Circuit FDR	PWR	Dellas	Open	Dellas
20-Sep-2018	PF1BPWRCIRFDR03	PF1B Bipolar Circuit FDR	PWR	Dellas	Open	Dellas
20-Sep-2018	PF1BPWRCIRFDR04	PF1B Bipolar Circuit FDR	PWR	Dellas	Open	Dellas
20-Sep-2018	PF1BPWRCIRFDR05	PF1B Bipolar Circuit FDR	PWR	Dellas	Open	Dellas
20-Sep-2018	PF1BPWRCIRFDR06	PF1B Bipolar Circuit FDR	PWR	Dellas	Open	Dellas
20-Sep-2018	PF1BPWRCIRFDR07	PF1B Bipolar Circuit FDR	PWR	Dellas	Open	Dellas
20-Sep-2018	PF1BPWRCIRFDR08	PF1B Bipolar Circuit FDR	PWR	Dellas	Open	Dellas
20-Sep-2018	PF1BPWRCIRFDR09	PF1B Bipolar Circuit FDR	PWR	Dellas	Open	Dellas

Cognizant Individual: John Dellas Digitally signed by John Dellas DN: cn=John Dellas, o=Princeton Plasma Physics Laboratory, ou=NSTX-U Recovery Project - Power Systems, email=jdellas@pppl.gov, c=US Date: 2019.02.01 10:54:44 -05'00' (sign and date)

Approver (*): Charles L. Neumeyer Digitally signed by Charles L. Neumeyer DN: cn=Charles L. Neumeyer, o=PPPL, ou, email=neumeyer@pppl.gov, c=US Date: 2019.02.05 15:19:00 -05'00' (sign and date)

(*) Up to and included FDR the DRC, after FDR the Main Approver (A-1: Chief Engineer, A-2 and A-3: DRC) DRC =Design Review Chairperson

Chit Resolution Report

FDR for

PF1B Power Circuits

NSTX-U-REC-127-00

PREPARED BY: John Dellas

Digitally signed by John Dellas
DN: cn=John Dellas, o=Princeton Plasma Physics Laboratory, ou=NSTX-U Recovery Project - Power Systems, email=jdellas@pppl.gov, c=US
Date: 2019.02.01 10:54:21 -05'00'

Cognizant Individual (COG)

APPROVED BY: Yuhu Zhai

Digitally signed by Yuhu Zhai
Date: 2019.02.05 09:45:33 -05'00'

Project Engineer

Record of Changes

Rev.	Date	Description of Changes
0	02/01/2019	Initial Release

Table of Contents

CHIT No.	Description	Page No.

1 PF1BPWRCIRFDR01: Pulsed current discrepancies across various documents

Review	ID	Chit
PF1B Power Circuits FDR	PF1BPWRCIR FDR01	There are discrepancies in the pulsed current requirement: Magnet SRD 400kA-turns/1.0s Inner PF FDR 20kA-20turns/1.0s PS SRD 21kA/0.95s PF1B design document 21kA/1.0s OK, the design target (441kA^2-s) exceeds the requirement (400kA^2-s) but…… This pulse current requirements for PF1B should be brought into alignment. Other circuits should be checked for consistency.

Resolution:

This chit was created prior to the final FDR documentation (due to FDR rescheduling). All the FDR calculation reports and presentations were updated to use 21kA/1sec. Therefore, the FDR documentation is consistent. As is mentioned in the chit, this design assumption is slightly conservative as compared to the PS SRD and the Magnet SRD.

2 PF1BPWRCIRFDR02: Power Supply SRD external circuit values

Review	ID	Chit
PF1B Power Circuits FDR	PF1BPWRCIR FDR02	PS SRD indicates external circuit R of 3 mOhm and L of 272microH. Are these requirements or documentation of a design values? In either case, the R and L of the new PF1B circuit should be calculated and added to nominal CLR R and L values to confirm compatibility with requirement.

Resolution:

The resistance of the external circuit used in the analysis is 14.2mΩ and the external inductance is 2.77 mH (.272mH + 2.5mH). These external values are required to meet the ripple requirement of Table 5.4-7 of the SRD. It is noted that coil ratings in Table 5.4-1 of the SRD refer to the DC values.

3 PF1BPWRCIRFDR03: Basis of Design Document to be rewritten

Review	ID	Chit
PF1B Power Circuits FDR	PF1BPWRCIR FDR03	"Basis of Design" document should be rewritten. It contains requirements and design information mixed together without consistent structure (section heading and contents). Recommend following guidance for "NSTX-U Final Design Report". Should be readable by SME without unique knowledge of FCPC acronyms/minutiae. Missing information should be included (....as indicated on drawing NSTX B-4F1005 sheet __). Should reference formal checked calculation number for cable heating, not present separately in Appendix. Appendix 3 FCPC Task List/L.J. Corl is included without explanation in body of document and has a mixture of actions to be taken and descriptive text. Recommend more concise presentation. Section on 10kV/in should be deleted (I hope we are not allowing 2/10 of an inch spacing!). Use of 1" steel plate under CLR is not technically acceptable (interferes with CLR function) and references to it should be deleted, and should not be shown on figure on p. 8. Etc.

Resolution:

This chit was created prior to the final FDR documentation (due to FDR rescheduling). A new Basis of Design Document was prepared for the rescheduled FDR addressing the concerns of the chit.

4 PF1BPWRCIRFDR04: PDR Chit Resolution Information

Review	ID	Chit
PF1B Power Circuits FDR	PF1BPWRCIR FDR04	Chit resolution information should be conveyed in a controlled document that can be cited by the project's master chit resolution XL sheet, not just in .ppt presentation.

Resolution:

This chit was created prior to the final FDR documentation (due to FDR rescheduling). A new PDR Chit Resolution Report was prepared for the rescheduled FDR. The review board comment at the FDR for this chit was “Completed”.

5 PF1BPWRCIRFDR05: Power Supply currents in CLRs to cause attractive forces and additive mutual inductance

Review	ID	Chit
PF1B Power Circuits FDR	PF1BPWRCIR FDR05	Confirm that PS circulating (and short circuit) current will flow in CLRs with polarity causing attractive, not repulsive forces, and additive mutual inductance. Although CLRs are not in scope or this review, B4F1005 sh. 1518 shows (+) current entering A1 and B2 terminals, which implies repulsive force if terminal "1" has the "dot" on both A and B CLRs.

Resolution:

This chit was created prior to the final FDR documentation (due to FDR rescheduling). The CLRs were ultimately included in the rescheduled FDR and the documentation was updated addressing the chit. The review board comment at the FDR for this chit was “Completed”.

6 PF1BPWRCIRFDR06: Power Supply currents in upper and lower circuits and repulsive forces

Review	ID	Chit
PF1B Power Circuits FDR	PF1BPWRCIR FDR06	With respect to opposing current flow in upper and lower circuits and therefore potential repulsive forces on CLRs, consider evaluating this operating case and/or fault case with respect to loads on the insulators and any protection that may be useful.

Resolution:

The typical current flow is indicated in Figure 1. The stacked CLR’s connection orientation will be such that the CLR insulators are in compression under this current flow condition.

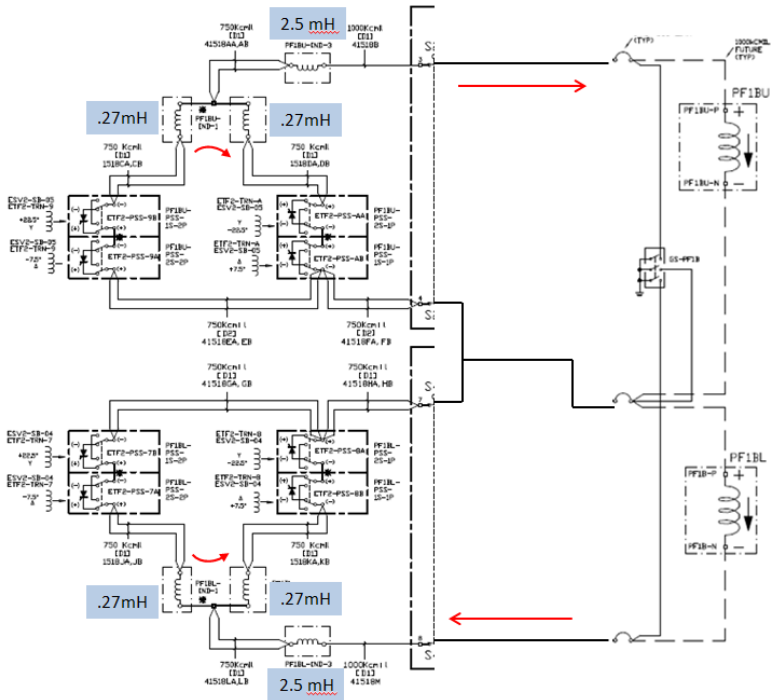


Figure 1 – Typical Current Flow Condition

Figure 2 shows an alternate current flow condition with a net common current (Icm) in the common leg as a result of the coil current requests. All bi-polar, three wire circuits of NSTX-U, (PF1B, PF3 and PF1C) have the possibility for this current flow condition. Assuming a worst case of 21kA being requested simultaneously by both the upper and lower coils, the 2.5 mH stacked inductors will see a maximum tensile force associated with opposing currents of 21kA. The supplier "budgetary number" design (based upon the specification requirement) indicates a fault current mechanical peak withstand for the stacked coil design of 45 kA, significantly higher than the opposing current case.

It is noted that from a thermal standpoint, the common leg conductor will see 2x21kA current for 1 sec. All of the bi-polar, three wire circuits presently in use are designed with the same conductor size in the common leg as in the non-common legs. It may be worthwhile to incorporate within the programming of the power supply control a limitation such that the common leg current for PF1B, PF3 and PF1C cannot exceed the rated peak pulse current of one of its coils.

Under a ground fault condition, the ground fault detection system will trip the power supplies upon detection of the first fault to ground. As the circuit is effectively high impedance grounded, there is no impact to forces on the stacked CLR insulators under these conditions.

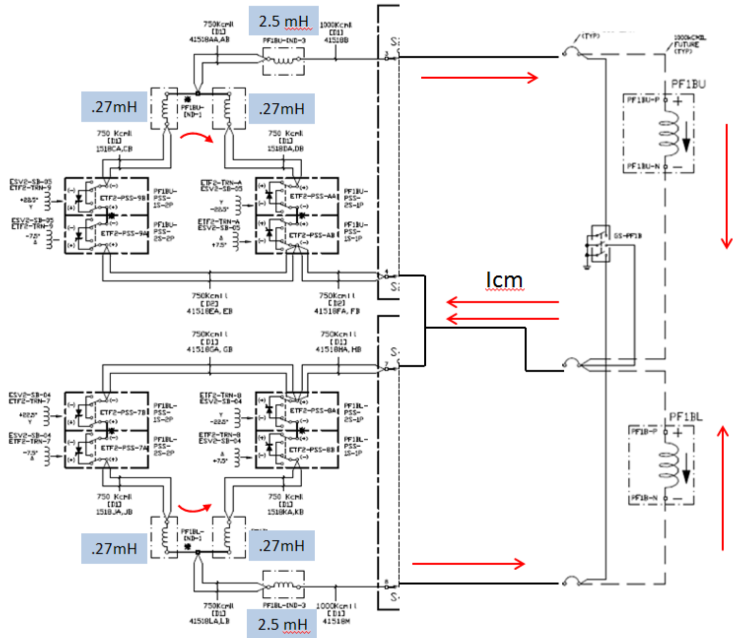


Figure 2 – Alternate Current Flow

7 PF1BPWRCIRFDR07: Penetrations between fire zones

Review	ID	Chit
PF1B Power Circuits FDR	PF1BPWRCIR FDR07	Please ensure that drawings showing penetrations between fire zones show the fire stop. The one that triggered this was the penetration from the MER to the SHB

Resolution:

Four new penetration drawings showing firestop details have been developed (B-5AA027, B-5AA028, B-5AA029 and B-5AA030) for the three test cell basement east wall penetrations into the MER and for the floor penetration into the south high bay.

8 PF1BPWRCIRFDR08: Coil Power Cabling and Maximum Rep Rate

Review	ID	Chit
PF1B Power	PF1BPWRCIR FDR08	Perform Cost Benefit Analysis to determine if the cost of protecting coil power cabling with software or electronics exceeds the cost of cables that can withstand the maximum rep-rate.

Circuits FDR		

Resolution:

The most cost effective solution for ensuring the rep-rate of the coil circuits is not reduced, such that the maximum temperature rise of the power cabling is exceeded, is to place the PDP Timer under administrative control. Controlling access to the PDP Timer enclosure will prevent unrestricted reduction of the period time (without engineering review).

9 PF1BPWRCIRFDR09: Checking of analysis with updated polar region model

Review	ID	Chit
PF1B Power Circuits FDR	PF1BPWRCIR FDR09	It looked to me (from maybe slide 4 of Dr. Que's talk) that the modeling is using an old version of the "polar region". I say this because I see a ceramic insulator. While my intuition is that this does not functionally matter, this should be checked against an updated version of the polar region to see that the ultimate conclusions do not change.

Resolution:

The analysis was redone with the updated polar region models. In summary, the analysis with the new models indicated slightly less worst case ripple current with the 2.5mH series inductor, as indicated in Table 1. This slight reduction is not significant enough to warrant changing the planned inductor sizes.

	1kV	2kV
Old Model	92.5	38
New Model	90.3	37.4

Table 1 – PF1B Worst Case Ripple Current (A)

The details of the updated analysis is provided below.

Updated PF1BL and PF1BU Coil ANSYS Maxwell Model

The machine passive structure loop (Vacuum Vessel) reduces the effective inductance of the inner PF 1B coils. The ANSYS Maxwell software is used to analysis the effective inductance and the resistance of the PF1B coil with varying frequency. Maxwell is an interactive software package that use finite element analysis to solve electrostatic, magnetostatic, eddy current and transient problems. The updated 2D geometry of the PF1BL coil and the passive structures are shown in Figure 1.

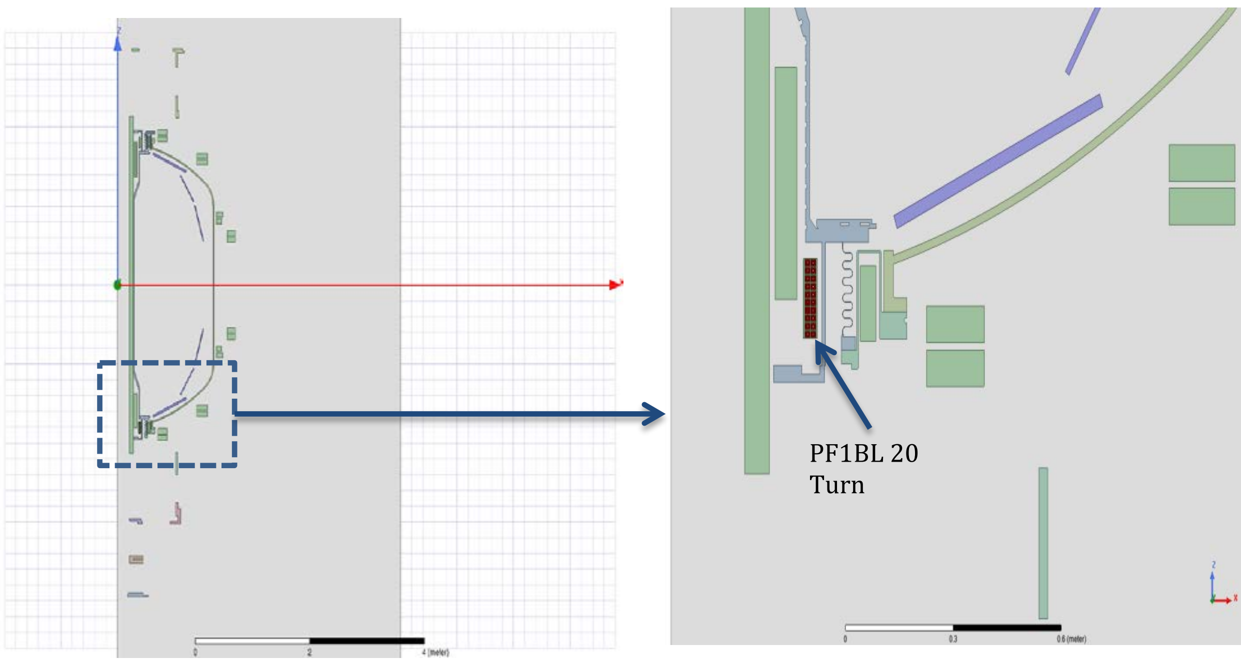
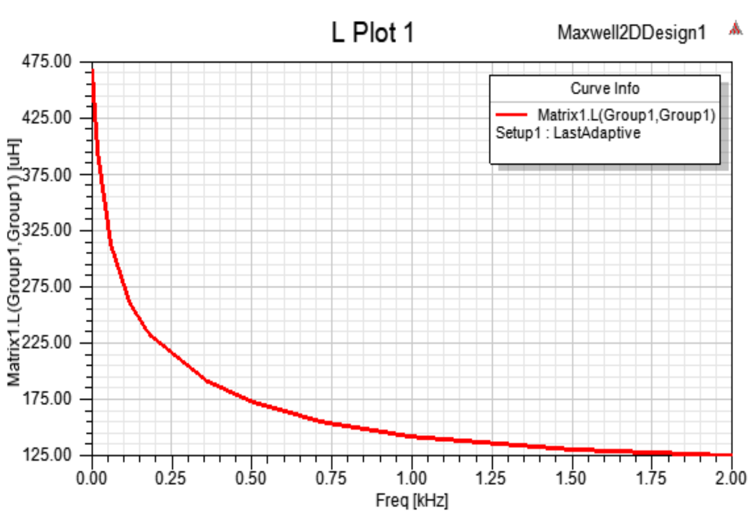


Figure 3 - PF1BL Coil Maxwell Model with Passive Structure

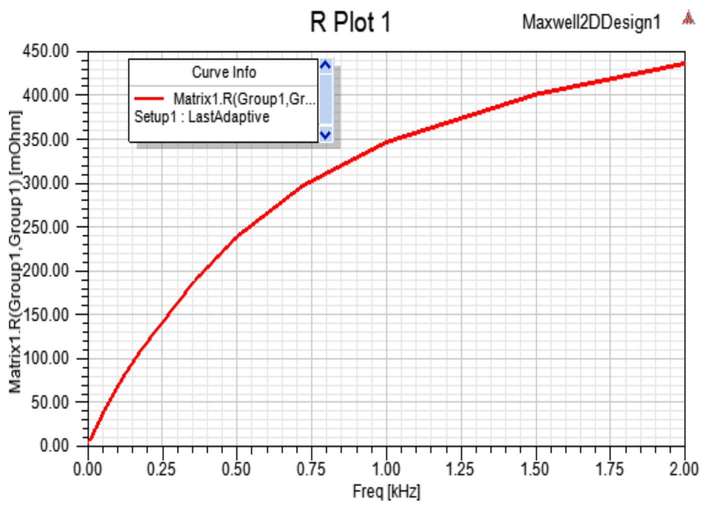
As the different turns are part of a single coil and are series-connected, the overall impedance may be found by grouping the individual turns within a coil. The impedance calculation results for PF1BL coil are shown in Figure 2 and Figure 3. The sweep frequency calculation range is from 0.001 to 2 kHz, which covers the ripple frequency of the 12-pulse rectifier even at maximum MG frequency (12 x 90 = 1080 Hz).



L Table 1

	Freq [kHz]	Matrix1.L(Group1,Group1) [uH] Setup1 : LastAdaptive
1	0.001000	467.735697
2	0.002000	465.474206
3	0.005000	453.406328
4	0.010000	430.115611
5	0.020000	392.405437
6	0.060000	312.781913
7	0.120000	260.198091
8	0.180000	233.078968
9	0.360000	191.681694
10	0.500000	173.421140
11	0.720000	155.380654
12	1.000000	142.360668
13	1.500000	130.977396
14	2.000000	125.564210

Figure 2 - PF1BL Coil Effective Inductance vs. Frequency



R Table 1

	Freq [kHz]	Matrix1.R(Group1,Group1) [mOhm] Setup1 : LastAdaptive
1	0.001000	5.263243
2	0.002000	5.447717
3	0.005000	6.551761
4	0.010000	9.361975
5	0.020000	16.192231
6	0.060000	44.447825
7	0.120000	80.447119
8	0.180000	111.031461
9	0.360000	189.916009
10	0.500000	239.292195
11	0.720000	297.175599
12	1.000000	346.614162
13	1.500000	400.818198
14	2.000000	435.968359

Figure 3 - PF1BL Coil Effective Resistance vs. Frequency

The updated geometry of the PF1BU coil and the passive structures are shown in Figure 4.

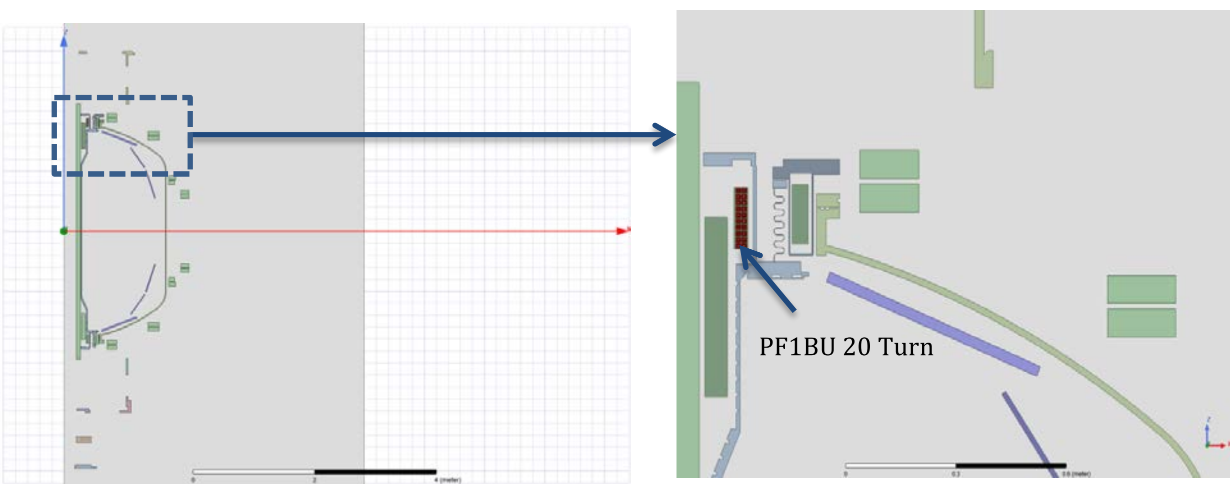
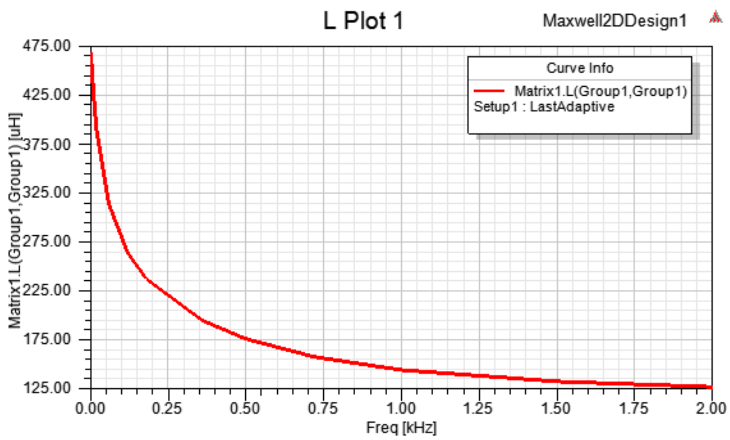


Figure 4 - PF1BU Coil Maxwell Model with Passive Structure

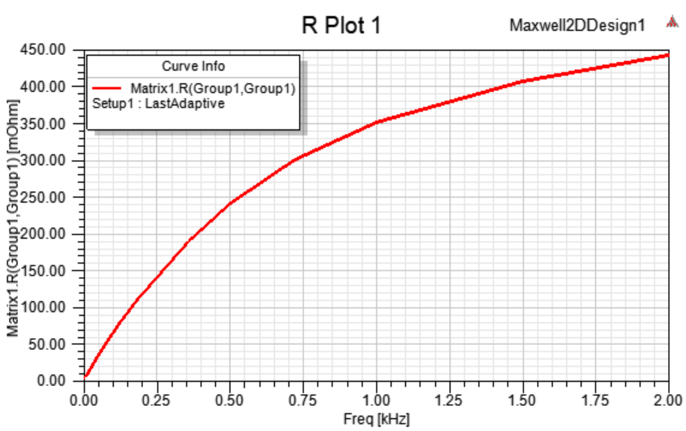
The impedance calculation results for PF1BU coil are shown in Figure 5 and Figure 6.



L Table 1

	Freq [kHz]	Matrix1.L(Group1,Group1) [uH] Setup1 : LastAdaptive
1	0.001000	467.673494
2	0.002000	465.239020
3	0.005000	452.303533
4	0.010000	427.768965
5	0.020000	389.443669
6	0.060000	313.416399
7	0.120000	264.121113
8	0.180000	237.463646
9	0.360000	195.114099
10	0.500000	176.407088
11	0.720000	158.004198
12	1.000000	144.687710
13	1.500000	132.982369
14	2.000000	127.408711

Figure 5 - PF1BU Coil Effective Inductance vs. Frequency



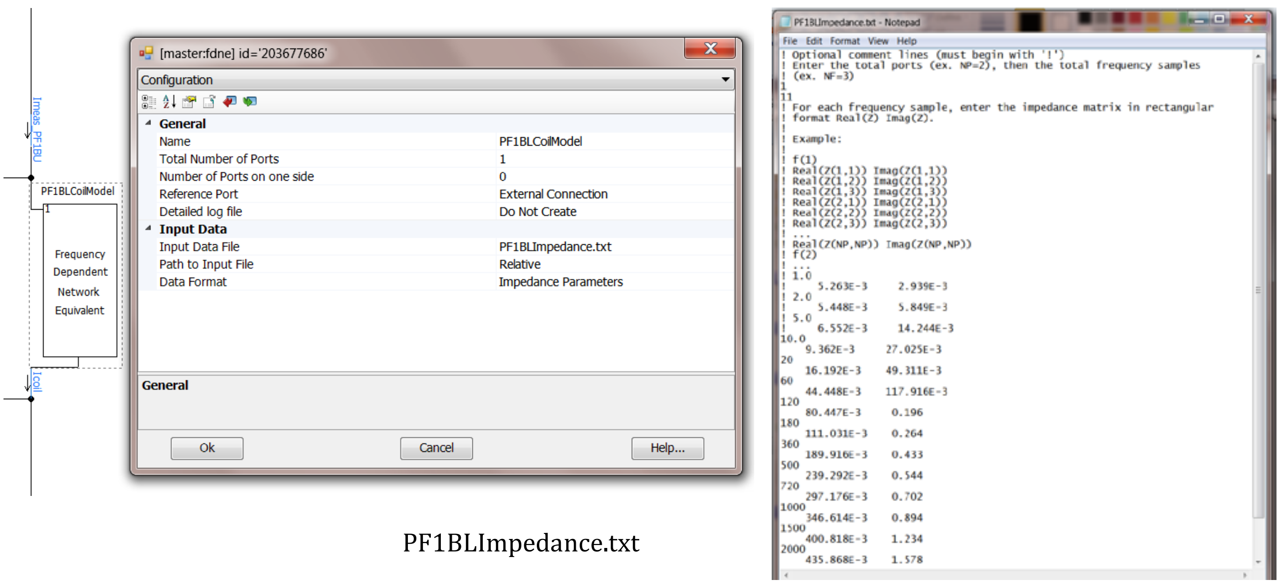
R Table 1

	Freq [kHz]	Matrix1.R(Group1,Group1) [mOhm] Setup1 : LastAdaptive
1	0.001000	5.265580
2	0.002000	5.456491
3	0.005000	6.588909
4	0.010000	9.407078
5	0.020000	16.045433
6	0.060000	42.809998
7	0.120000	78.398786
8	0.180000	109.911871
9	0.360000	191.248850
10	0.500000	241.626766
11	0.720000	300.776879
12	1.000000	351.573197
13	1.500000	407.121695
14	2.000000	442.598997

Figure 6 - PF1BU Coil Effective Resistance vs. Frequency

Frequency Dependent Network Equivalent PF1B Coil Model

In the PSCAD, a frequency dependent network equivalent (FDNE) model is used to simulate the complex behavior of the coil and passive structure impedance. This component creates a multi-port, frequency-dependent network equivalent from given characteristics, such as impedance data, directly. If the impedance data is given as a function of frequency, it is approximated in the model using the Vector Fitting technique. The PF1BL coil is represented using this FDNE model as shown in Figure 7.



PF1BLImpedance.txt

Figure 7 - FDNE model for PF1BL coil using the impedance data

The FDNE model for the PF1BL coil is also verified by using a single phase AC source with adjustable frequency as shown in Figure 8. Since the voltage Ea, the current Ia and the phase angle can be measured, the PF1B impedance can be calculated and checked against the Maxwell data.

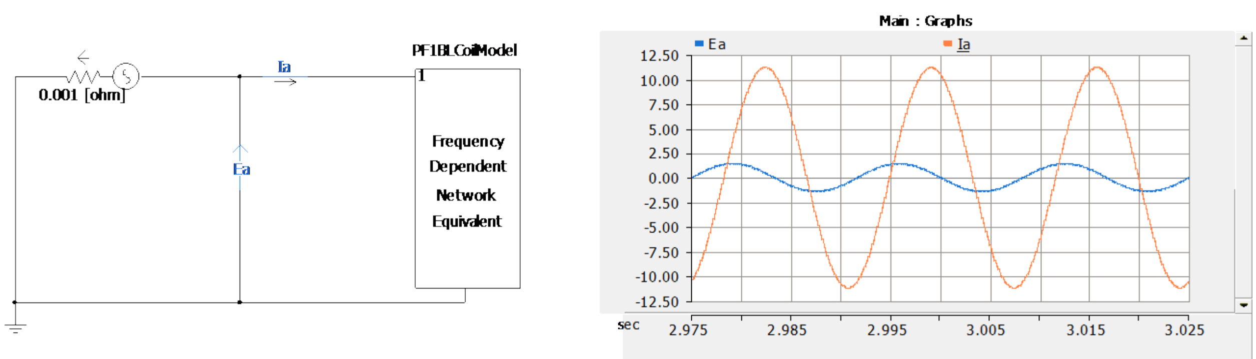
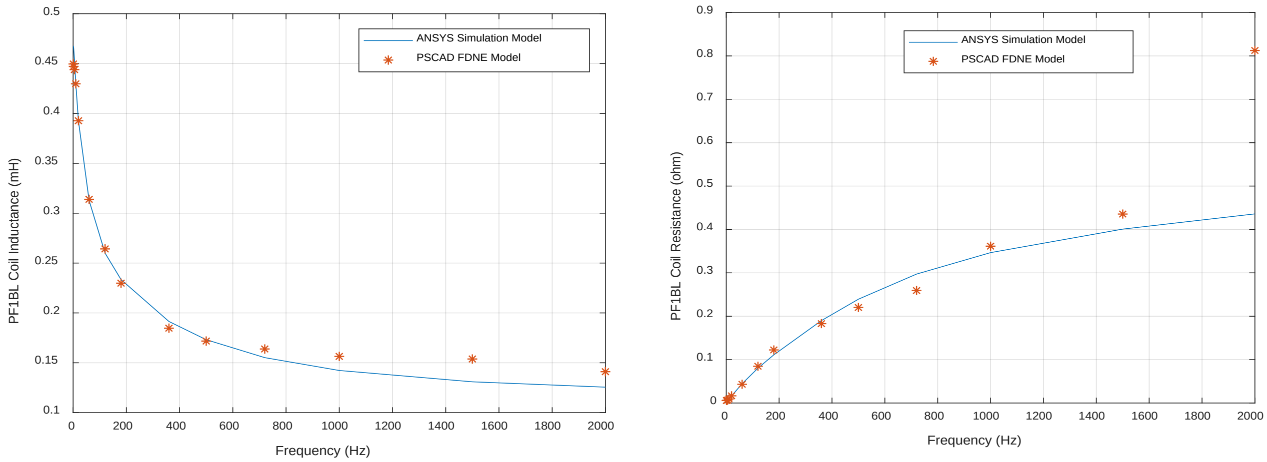


Figure 8 - PSCAD model used to verify the PF1B FDNE model

The result in Figure 9 shows that the PF1BL coil PSCAD FDNE model matches the PF1BL Maxwell simulation model very closely.

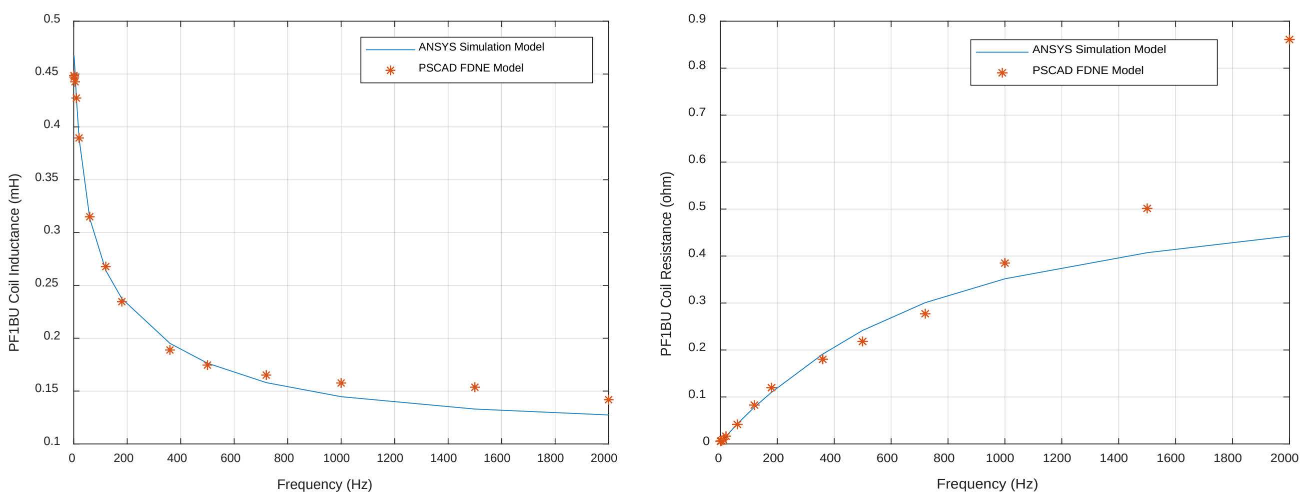


(a) PF1BL Inductance

(b) PF1BL Resistance

Figure 9 - PF1BL FDNE model vs Maxwell simulation model

Similarly, the result in Figure 10 shows that the PF1BU coil PSCAD FDNE model matches the PF1BU Maxwell simulation model very closely.



(a) PF1BU Inductance

(b) PF1BU Resistance

Figure 10 - PF1BU FDNE model vs Maxwell simulation model

PF1B Coil Current Limiting Reactor Sizing Calculation

The PF1B power supplies are used to energize the PF1B coils to control the plasma equilibrium from plasma current ramp-up through the plasma current flat-top through the plasma current ramp-down and then return the coil currents to zero.

PF-1bU and PF-1bL power supplies are bipolar power supplies which are required for the control of the divertor magnetic geometry through the OH coil flux swing. The max current is 21 kA.

The PSCAD model of PF1B coil power supply system including the MG set, rectifier and PF1B coils are developed. The overall structure of the PF1B power supply system model is shown in Figure 11.

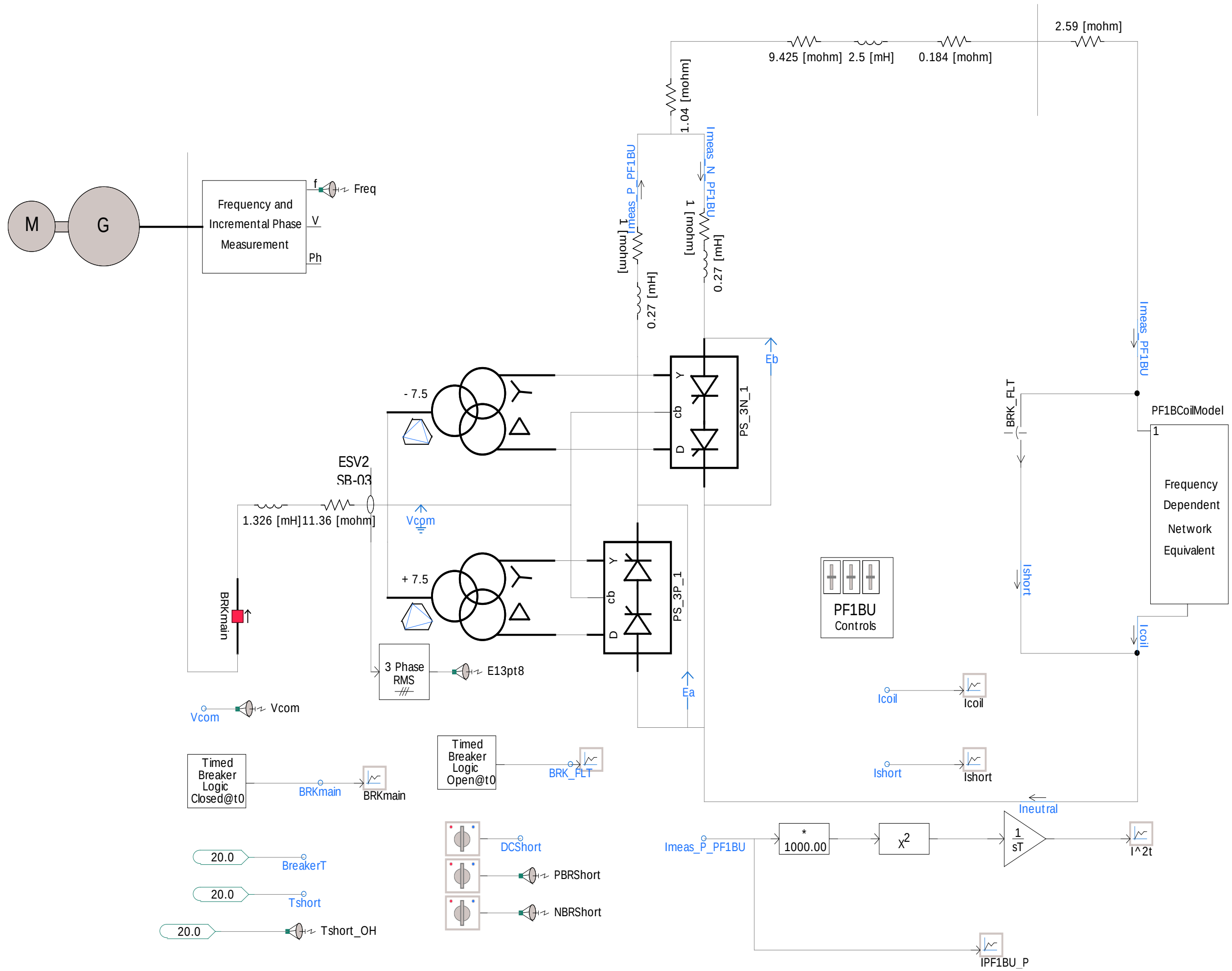


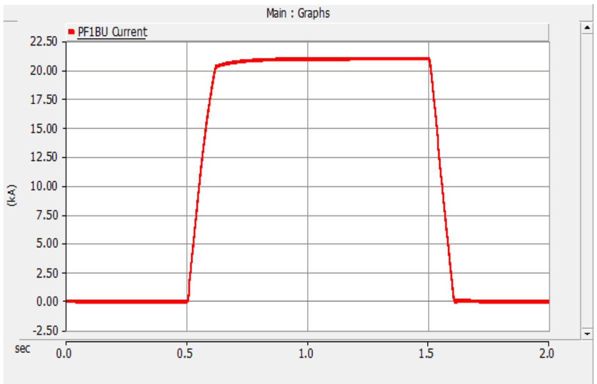
Figure 11 - PF1B Coil Power Supply System

The calculated current ripple for the PF1BL coil and the PF1BU coil using 2.5 mH series inductor under 1kV operation with different transformer setup are shown in Table 1. By using the 2.5 mH series inductor, the maximum current ripple is 90.3 A which is 14% less than the required 105 A.

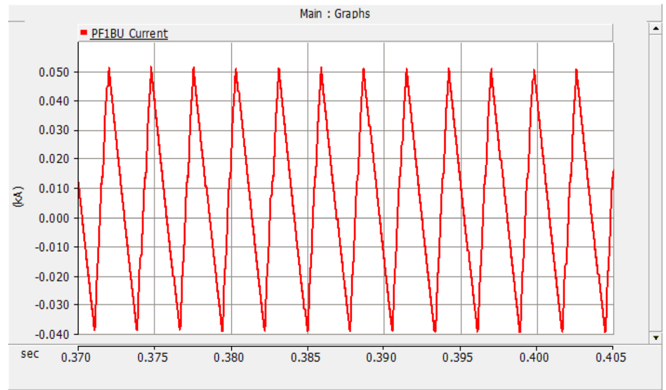
Table 2 PF1B Current Ripple with 2.5mH Series Inductor Value at 1kV

	PB:Y-22.5° NB: Y+22.5°		PB:Δ+7.5° NB: Δ-7.5°		PB:Δ+7.5° NB: Y+22.5°	
PF 1B Coil	Flat top Current Ripple (A)	Zero Crossing Current Ripple (A)	Flat top Current Ripple (A)	Zero Crossing Current Ripple (A)	Flat top Current Ripple (A)	Zero Crossing Current Ripple (A)
PF1BL	49.7	90.1	50.6	90.2	50.6	90.3
PF1BU	49.3	89.7	49.1	89.7	48.5	89.4

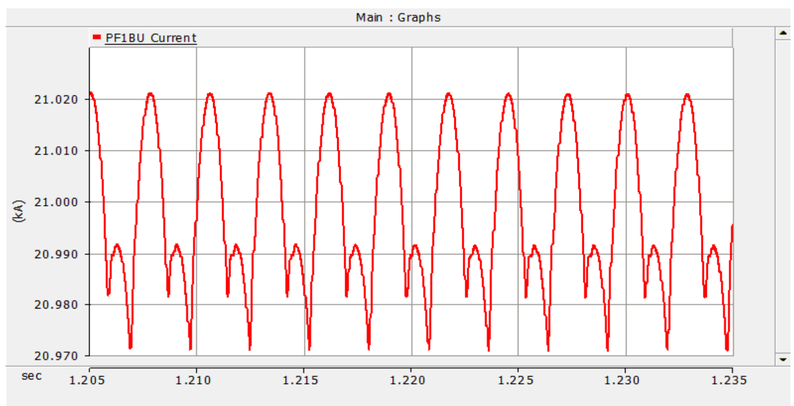
The PF1BU coil current waveform and ripple with 2.5 mH CLR is shown in Figure 12.



(a) PF1BU Coil Current Pulse at 1kV



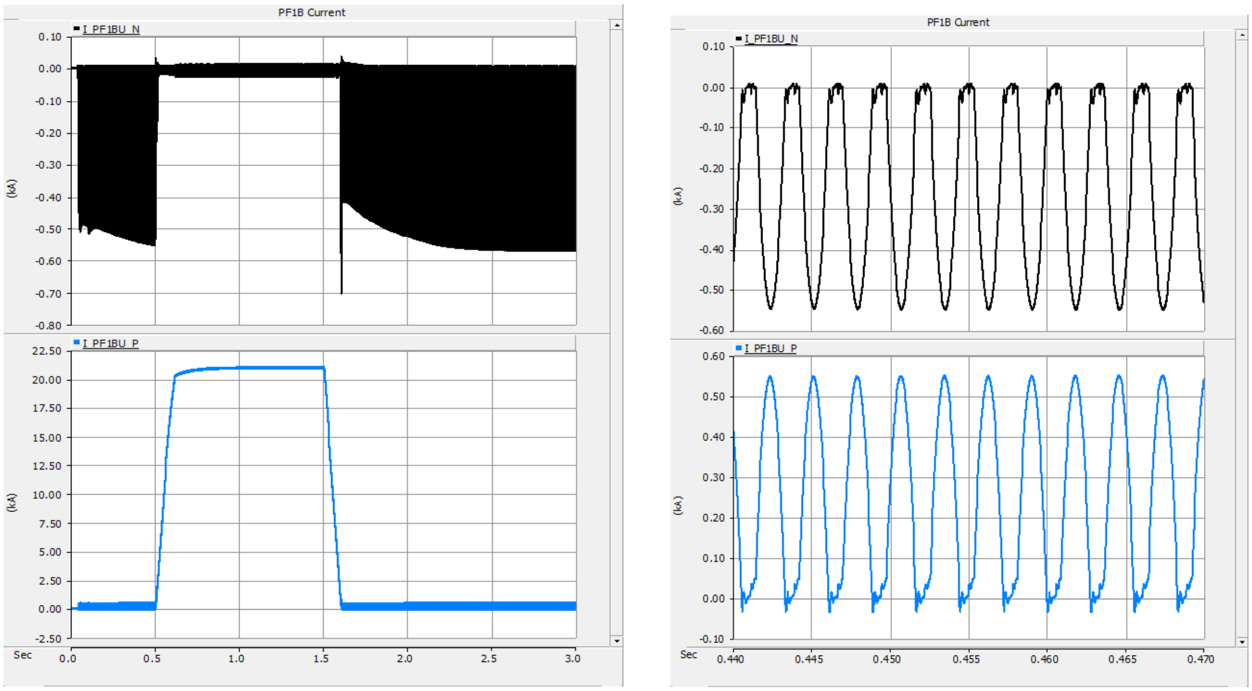
(b) PF1BU Coil Zero Current Ripple



(c) PF1BU Coil 21 kA Flat Top Ripple

Figure 12 - PF1BU Coil Current Waveform and Ripples at 1kV

The positive and negative branch current is also calculated which is shown in Figure 13. The magnitude of the circulating current is less than 600 A.



(a) Negative and Positive Branch Current (b) Circulating Current

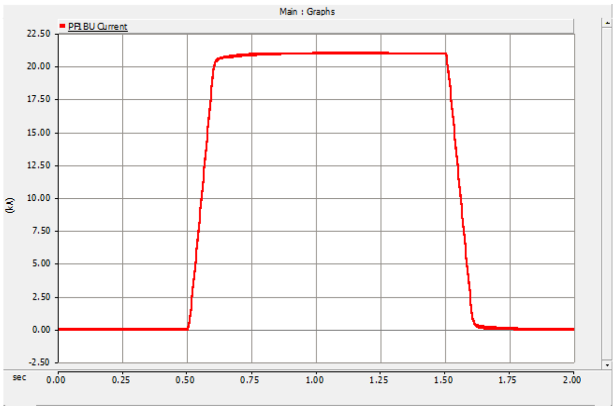
Figure 13 - PF1BU Coil Negative and Positive Branch Current at 1kV

When operating at 2KV, two 1kV power supplies are connected in series which are in 12 pulse rectifier operation mode. The current ripple for the PF1BL coil and the PF1BU coil with 2.5mH series inductor value under 2kV operation is shown in Table 2. The maximum current ripple with 2.5 mH inductor is only 37.4 A as shown in Table 2.

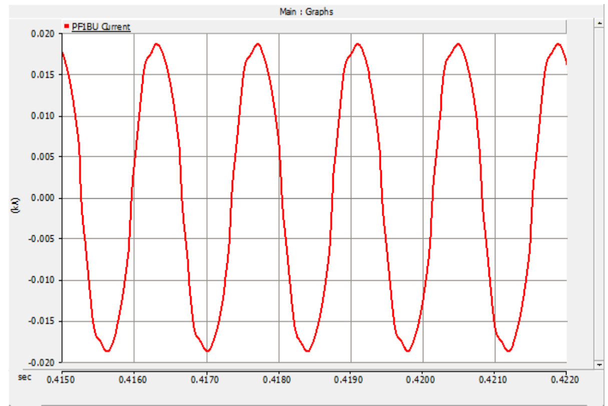
Table 3 PF1B Current Ripple with 2.5mH Series Inductor Value at 2kV

	PB: Y -22.5 and Δ +7.5 NB: Y+22.5 and Δ -7.5	
PF 1B Coil	Flat top Current Ripple (A)	Zero Crossing Current Ripple (A)
PF1BL	27	37.4
PF1BU	28	37.4

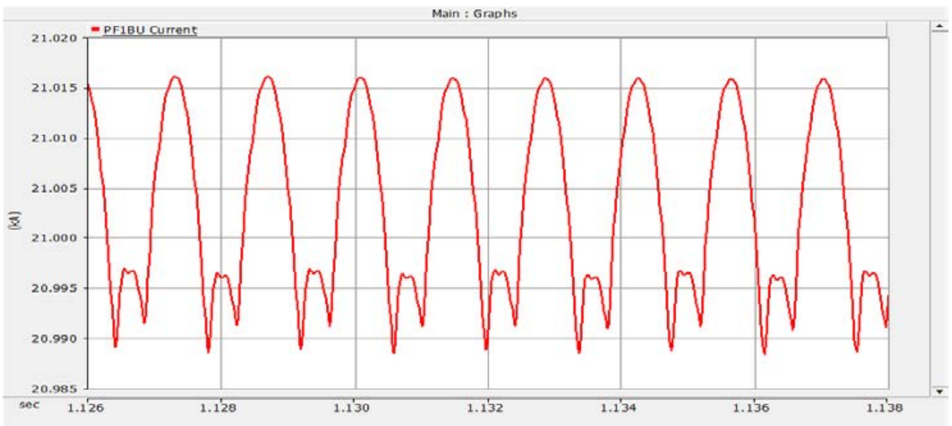
The PF1B coil current waveform and ripple with 2.5 mH CLR at 2kV is shown in Figure 14. The ripple frequency is at 720 Hz.



(a)PF1BU Coil Current Pulse at 2kV



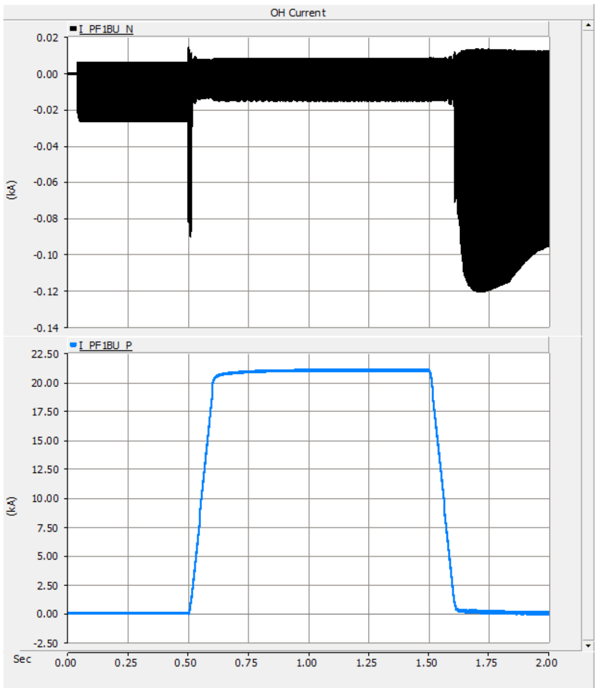
(b) PF1BU Coil Zero Current Ripple at 2kV



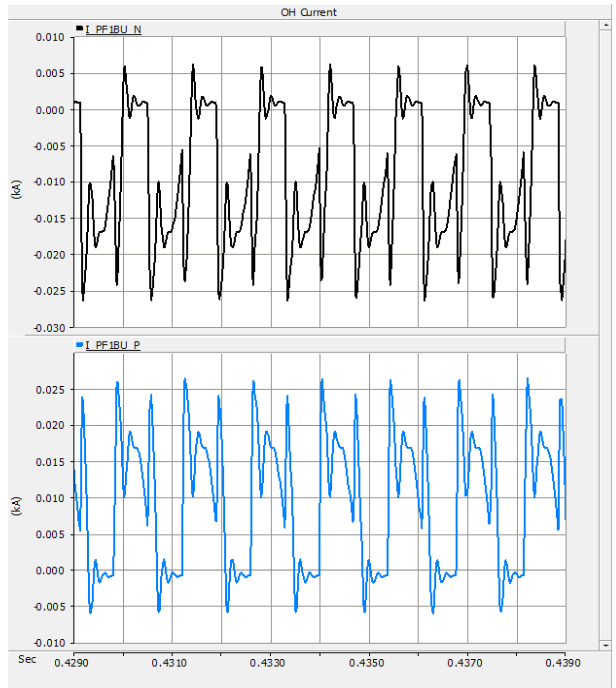
(c) PF1BU Coil 21 kA Flat Top Ripple at 2kV

Figure 14 - PF1BU Coil Current Waveform and Ripples at 2kV

The positive and negative branch current at 2kV is also calculated which is shown in Figure 15. The magnitude of the circulating current is about 30 A.



(a) Negative and Positive Branch Current



(b) Circulating Current

Figure 15 - PF1BU Coil Negative and Positive Branch Current at 2kV