Calculation No: 2137-CALC-005 **Revision No: 0**

Title: PF1B Coil Current Limiting Reactor Sizing Analysis and Calculation (NSTXU-CALC-53-08-00)

Purpose of Calculation: (Define why the calculation is being performed.)
See Page 2

Codes and versions:
1: ANSYS MAXWELL: PF1B COIL Model
2: PSCAD v 4.6.2: PF1B Power Supply Model

References (List any source of design information including computer program titles and revision levels.)
[1] System Requirement Document for Power Systems, NSTX-U-SRD-006-00
[2] ANSYS MAXWELL 2018
[3] PSCAD v4.6.2

Assumptions (Identify all assumptions made as part of this calculation.)
Motor-Generator operating frequency is at 60 Hz
PF1BU circuit behavior similar to PF1BL
Inductor cost is driven primarily by stored energy 1/2 LI^2 (and not rms current) so the total installed inductance can serve as a measure of relative cost

Calculation (Calculation is either documented here or attached)
See attached document

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)
See page 22

Cognizant Individual (or designee) printed name, signature, and date

John Dellas 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: 2018.09.19 11:56:35 -04'00'

Preparer's printed name, signature and date

Weiguo Que Weiguo Que Digitally signed by Weiguo Que Date: 2018.09.18 16:15:29 -04'00'

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.

Checker's printed name, signature, and date

John Dellas 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: 2018.09.19 11:57:01 -04'00'

Checks for Calculation No: 2137-CALC-005 **Revision No: 0**

PF1B Coil Current Limiting Reactor Sizing Analysis and Calculation (NSTXU-CALC-53-08-00)

Component was checked against latest design

Per FDR design

All required load cases are included and current

Only one case per NSTX-U-RQMT-SRD-006-01: 21kA/0.95 second every 1200 seconds

Discuss method used in the calculation

ANSYS Maxwell was used to generate impedance vs. frequency data for the PF1B coil in the machine. This data was included as a PSCAD Frequency Dependent Network Equivalent (FDNE) component. The PSCAD power circuit for the PF1BU coil was modeled with the FDNE component as the load.

Discuss how the calculation was checked (*)

Ripple voltage and current waveforms were checked against theoretical waveforms based upon the type of operating mode. The circuit modeling and analysis method was verified using measured data for the PF1C circuit.

List issue identified and how they were resolved

The original method for fitting the Maxwell impedance curve into a model within PSCAD (using a discrete component network) provided inaccurate results. A new method using the Frequency Dependent Network Equivalent (FDNE) component in PSCAD provided a much better curve fit.

The phase locked loop (PLL) component in the circuit model uses the primary transformer voltage as its reference signal. This had to be offset for the different transformer secondary configurations in order to provide the correct timing signal for thyristor firing.

Checker's name: J. Dellas

Technical Authority: Raymond A. Camp Digitally signed by Raymond A. Camp DN: cn=Raymond A. Camp, o=PPPL, ou=Power Systems Group, email=rcamp@pppl.gov, c=US Date: 2018.09.19 11:11:06 -04'00' (sign and date)

(*) independent calculations can be appended

National Spherical Torus eXperiment - Upgrade

NSTX-U

PF1B Coil Current Limiting Reactor Sizing Analysis and Calculation

NSTXU-CALC-53-08-00
Date: September 18, 2018

Weiguo Que
Digitally signed by Weiguo Que
Date: 2018.09.18 16:15:52 -04'00'

Prepared By
Weiguo Que

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: 2018.09.19 11:57:44 -04'00'

Approved By – Responsible Engineer
John Dellas

Table of Contents

NSTX-U CALCULATION

Record of Changes

Rev.	Date	Description of Changes	Revised by
0	09/18/18	Initial Release	Weiguo Que

1. Purpose of Calculation

Analysis of the PF1B coil power supply system is necessary to confirm that it meets the performance requirements. The PF1B coil has a very tight current ripple requirement which is defined as the peak-to-peak ripple amplitude as 0.5% of the full scale current. The full scale current for PF1B coil is 21kA which means that the maximum current ripple is 105 A.

The PF1B coil self-inductance is only 450 uH. The passive structure loops (such as vacuum vessel) reduce the effective inductance of the PF1B coil. An ANSYS Maxwell model of the PF1B coil and the passive structure is used to study the effective inductance and the resistance under variant frequency.

The PF1B power supply system is modeled with the PSCAD software. The initial study showed that, with only the basic circuit inductances, the current ripple for the PF1B coil is about 900A. Additional series inductance is needed to reduce the current ripple to be less than 105 A. Current limiting reactors (CLRs) can be used for this purpose. The CLRs also provide protection for the PF1B circuit by limiting the current flow during fault conditions.

Two possible CLRs arrangements are analyzed in this report. A benchmark case using the PF1C coil test data is also analyzed in this report. One of the two arrangements is recommended for the PF1B coil.

2. Codes and Versions

The 2D axis-symmetric models of the PF1BL coil and the passive structures are established using ANSYS Maxwell 2018 software. The PF1B coil power supply models are built for analysis using PSCAD v4.6.2 software.

3. References

[1] System Requirement Document for Power Systems, NSTX-U-SRD-006-00
[2] ANSYS MAXWELL 2018
[3] PSCAD v4.6.2

4. Assumptions

- Motor-Generator operating frequency is at 60 Hz (worst case for current ripple)
- PF1BU circuit behavior similar to PF1BL
- Inductor cost is driven primarily by stored energy 1/2 LI^2 (and not rms current) so the total installed inductance can serve as a measure of relative cost

5. Calculation and Analysis

5.1 PF1B 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 analyze 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 2D geometry of the PF1BL coil and the passive structures are shown in Figure 1 and Figure 2.

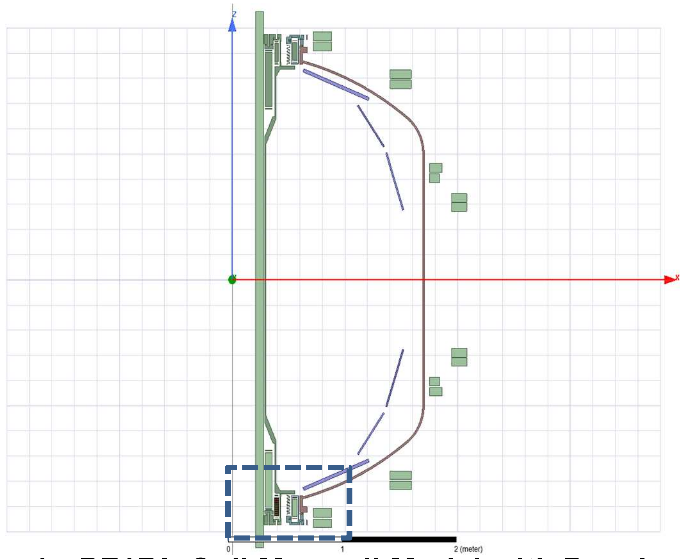


Figure 1 - PF1BL Coil Maxwell Model with Passive Structure

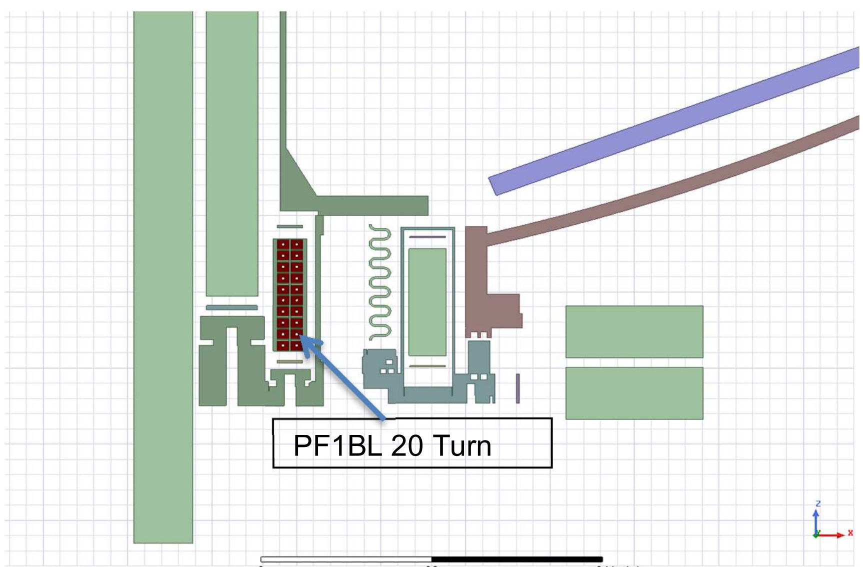
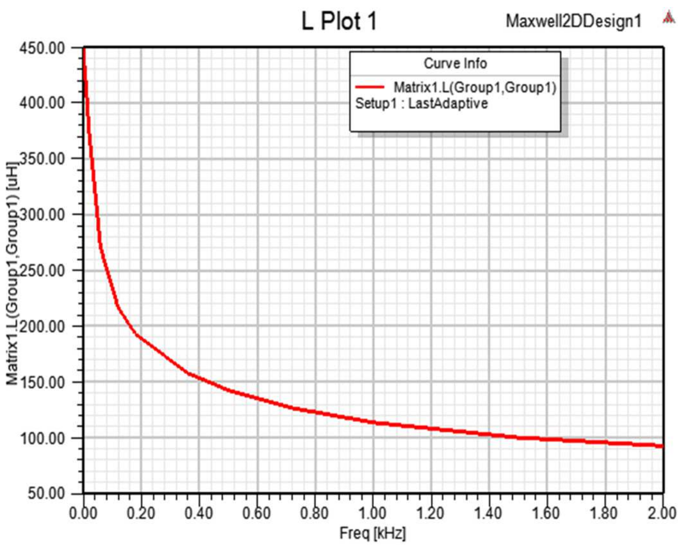


Figure 2 - Enlarged PF1BL Coil and Structure Maxwell Model

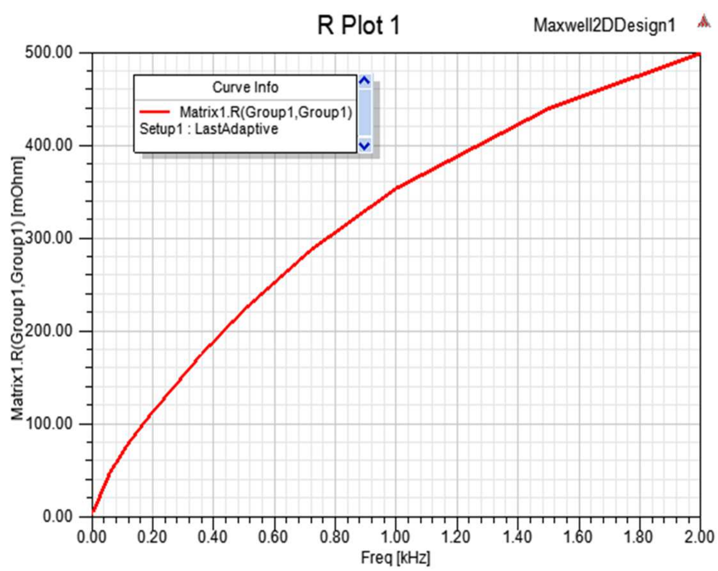
As the different turns are part of a single coil and are series-connected, the overall impedance may be found by grouping the individual turns within a coil. The impedance calculation results for PF1B coil are shown in Figure 3 and Figure 4. The sweep frequency calculation range is from 0.001 to 2 kHz, 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	448.133668
2	0.002000	441.022720
3	0.005000	430.652127
4	0.010000	414.134691
5	0.020000	374.440108
6	0.060000	270.563787
7	0.120000	217.419731
8	0.180000	193.676460
9	0.360000	158.660055
10	0.500000	143.380486
11	0.720000	127.493477
12	1.000000	114.517467
13	1.500000	101.054725
14	2.000000	93.602754

Figure 3 - PF1B Coil Effective Inductance vs. Frequency



R Table 1

	Freq [kHz]	Matrix1.R(Group1,Group1) [mOhm] Setup1 : LastAdaptive
1	0.001000	5.325502
2	0.002000	5.514325
3	0.005000	6.492976
4	0.010000	9.407077
5	0.020000	17.859908
6	0.060000	48.576910
7	0.120000	79.497225
8	0.180000	105.557631
9	0.360000	175.591511
10	0.500000	223.253406
11	0.720000	287.652045
12	1.000000	353.824782
13	1.500000	439.495686
14	2.000000	499.064150

Figure 4 - PF1B Coil Effective Resistance vs. Frequency

5.2 PF1B Power Supply Model

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.

PF1BU and PF1BL 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. Two power supplies are connected in series to provide a maximum terminal voltage of 2026 V.

PSCAD is a simulation software for AC power systems, low voltage power electronic systems, high voltage DC transmission, flexible AC transmission systems, distribution systems and complex controllers. A PSCAD model of the PF1B coil power supply system, including the MG set, the rectifier and the PF1B coils has been developed. This report describes the detailed model and the results of an optimization study to determine the size of the current limiting reactors for the PF1B coils.

The overall structure of the PF1B power supply system model is shown in Figure 5.

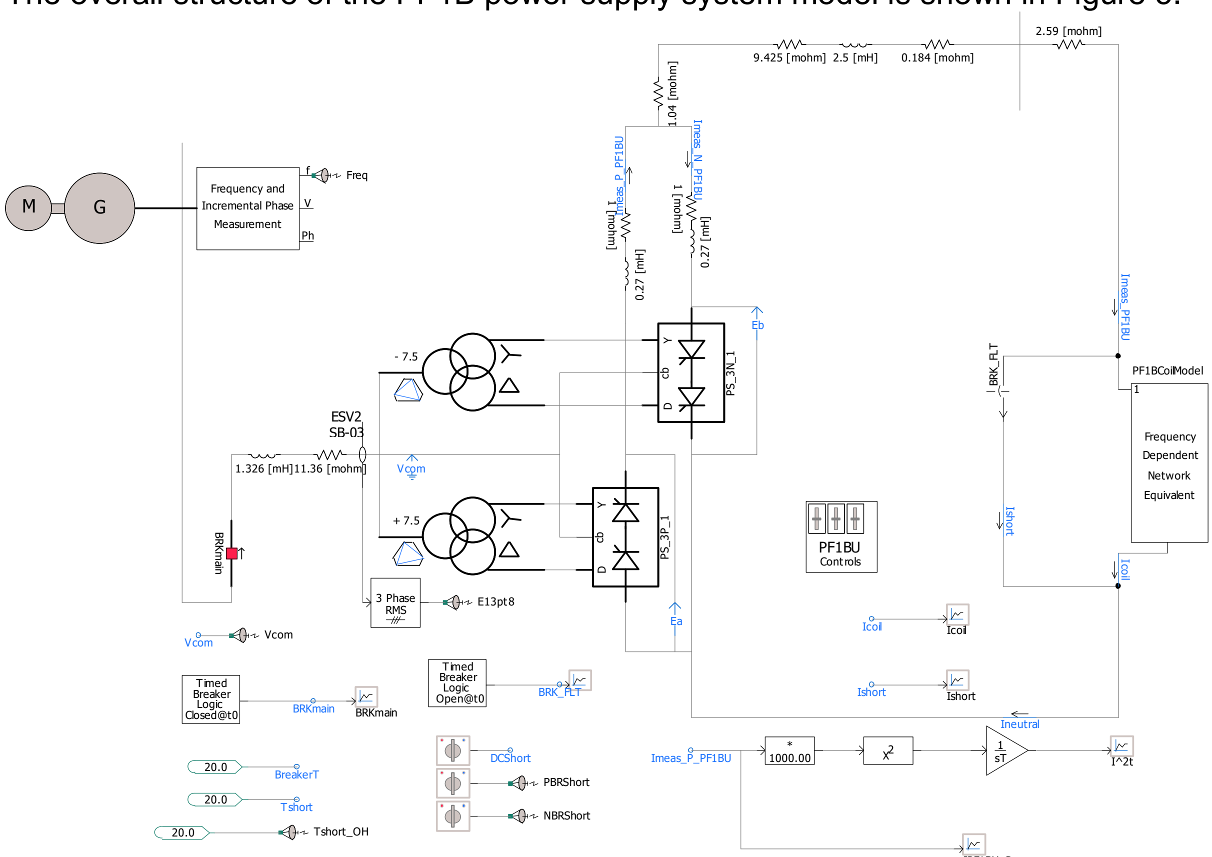


Figure 5 - PF1B Power Supply System

This model includes the motor generator set, the transformer, the AC/DC converter, the PF1B coil, and the current feedback control loop.

5.2.1 Motor Generator Set

A large vertical shaft motor-generator (MG) set is used as an energy storage device to provide pulsed power. The MG set is modeled as shown in Figure 6. Its rated pulse power and output voltage is 475 MVA, 13.8 kV, respectively.. The output frequency is fixed at 60 Hz for this analysis

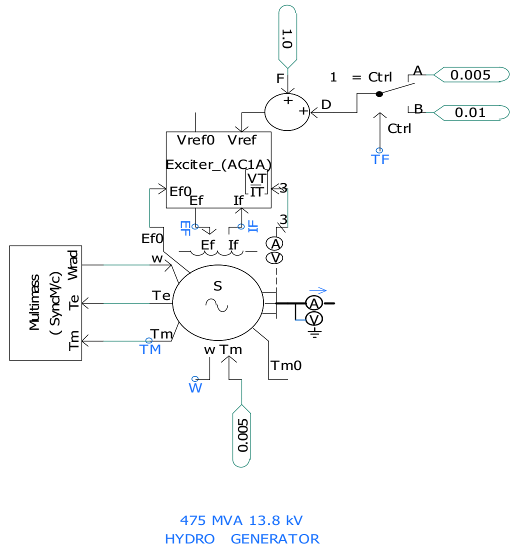


Figure 6 - Motor-Generator System

5.2.2 13.8 kV/0.75 kV Transformer

The 13.8 kV/0.75 kV transformer windings are Polygon (Delta)/Delta-Wye, with the polygon arranged to produce either Y +22.5°, D +7.5°, D -7.5°or Y -22.5° phase shift, where D = delta and Y = wye. A zig-zag PSCAD transformer model is used to achieve the phase shift. This transformer model is shown in Figure 7.

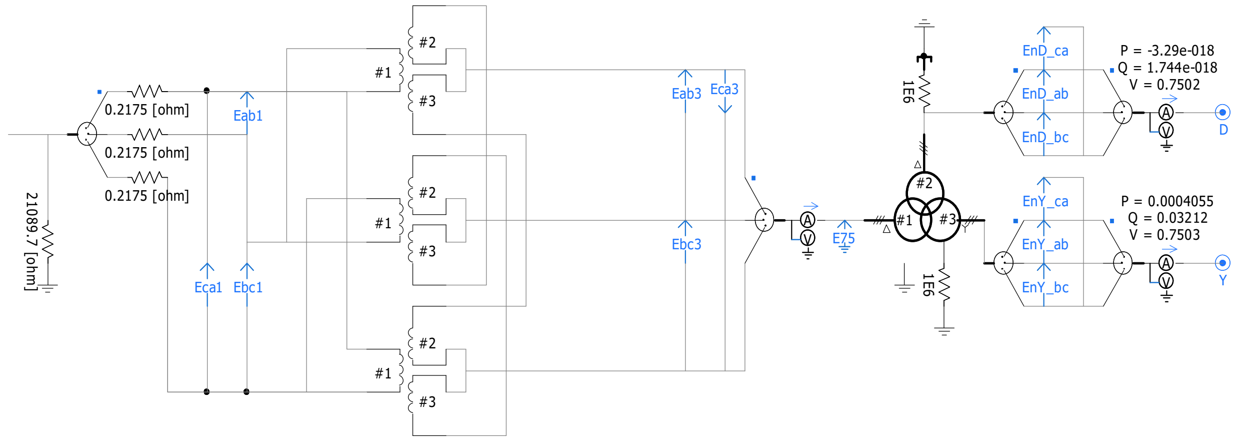


Figure 7 - Transformer with D +7.5°, Y-22.5° Phase Shift

5.2.3 AC/DC Converter and Firing Pulse Generator

A standard, modular thyristor AC/DC converter is used as the PF1B power supply. Each power supply includes a three winding rectifier transformer and consists of a 6-pulse bridge rectifier and external bypass thyristor. All thyristors are identical with an on-state resistance of 152 μΩ and forward voltage drop of 0.94 V. Each thyristor is equipped with an RC snubber with R=15Ω and C=1μF.

The firing pulses for the 6-pulse bridge are generated as shown in Figure 8. The phase lock loop (PLL) is synchronized to the phase A input voltage (Va) from the primary 13.8 kV. The firing pulse needs to be synchronized with the transformer secondary voltage which has an offset angle to the primary voltage. This is a critical input to the PLL that generates the synchronized firing pulse. The offset angle to the PLL for the different transformer secondary phasing orientations as shown in Table 1.The offset angle was obtained through a trial and error process to achieve the correct thyristor firing angle.

Table 1 - Offset Angle to PLL for Different Transformer Connections

Transformer Setup	Offset Angle to PLL (rad)	Offset Angle to PLL (deg)
Δ +7.5°	0.77	44°
Δ -7.5°	1.0318	59°
Y +22.5°	0.5082	29°
Y -22.5°	1.2936	74°

When using the equation: 51.5°-(44°,59°,29°,74°)=(+7.5°,-7.5°,+22.5°,-22.5°), this 51.5° degree shift is due to the PLL error and the phase shift between the transformer primary and secondary voltage.

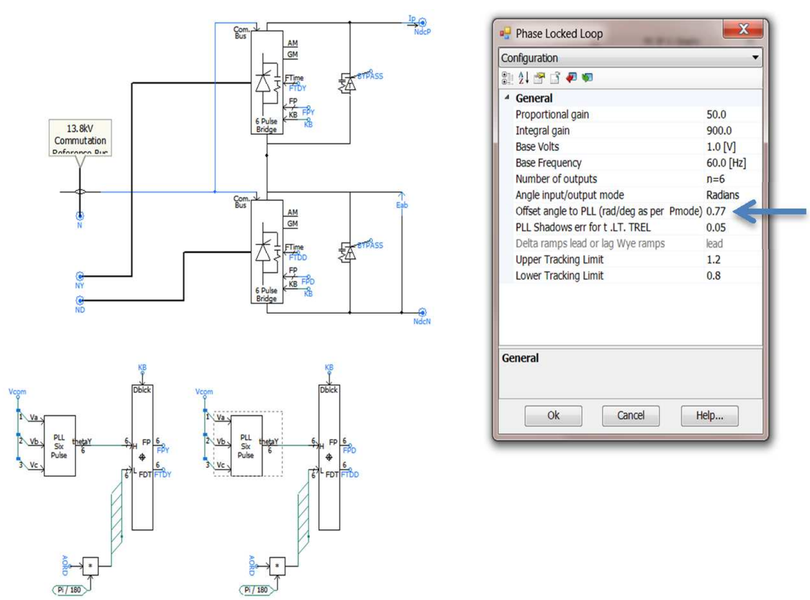


Figure 8 - AC/DC Converter and Firing Pulse Generator Model

In the 2kV operating mode, the firing angle (alpha in degrees), the voltage (Eab) across one thyristor and the zero crossing of the positive branch current (Ip) are shown in Figure 9 for the zero average coil current condition.

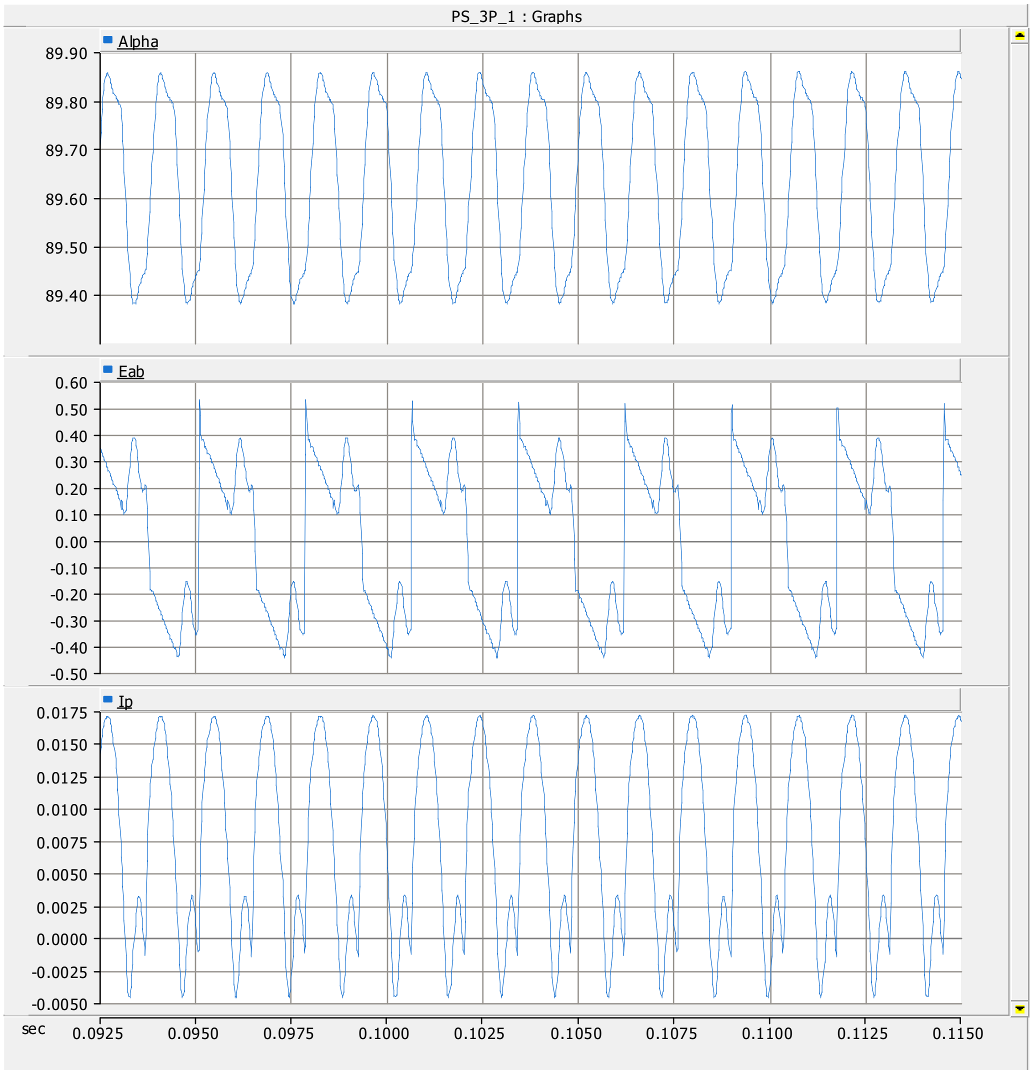


Figure 9 - Firing Angle, Thyristor Voltage and Zero Crossing Current Waveform

5.2.4 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 PF1B coil is represented using this FDNE model as shown in Figure 10.

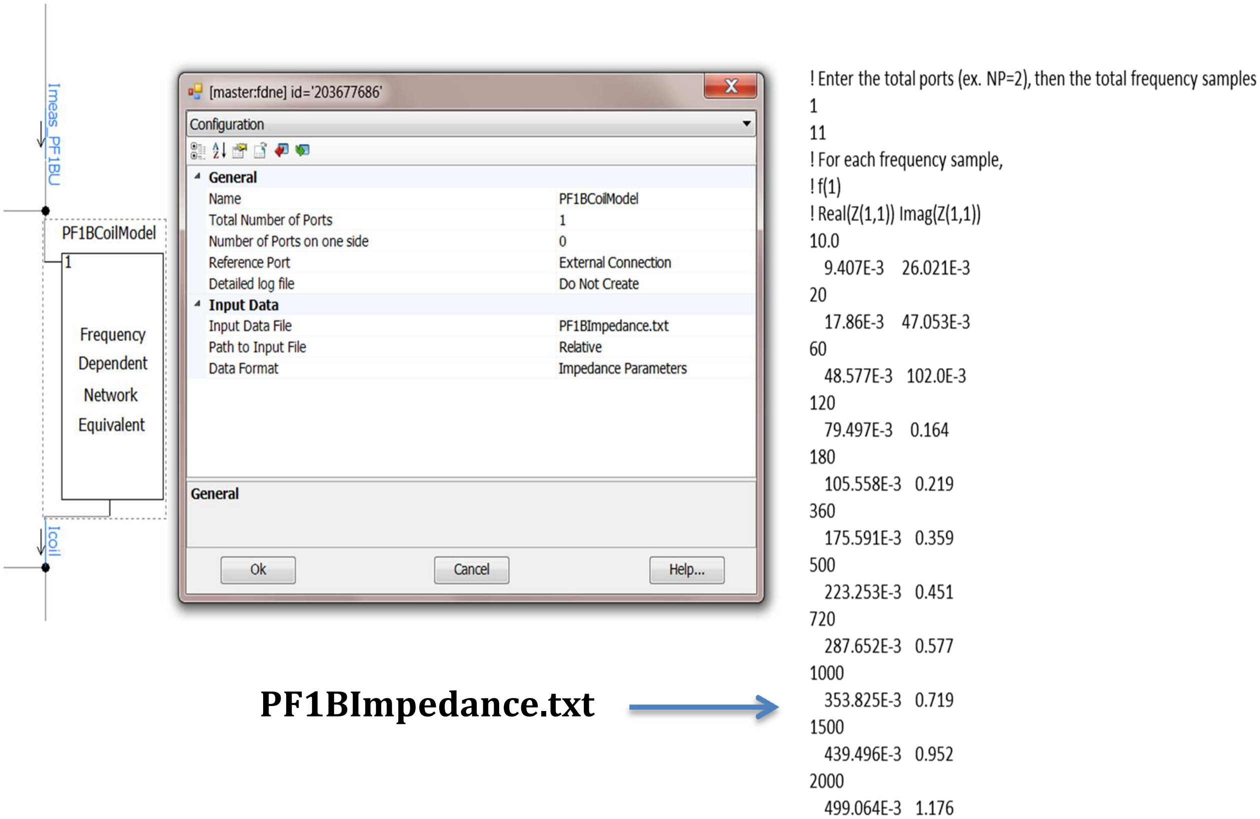


Figure 10 - FDNE Model for PF1B Coil Using Impedance Data

The FDNE model for the PF1B coil is also verified by using a single phase AC source with adjustable frequency as shown in Figure 11. 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.

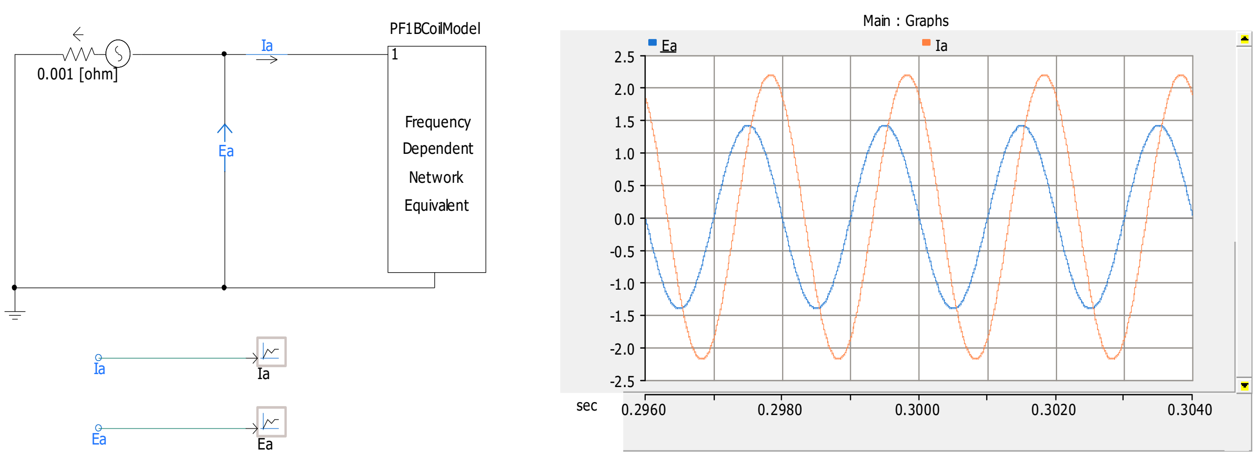
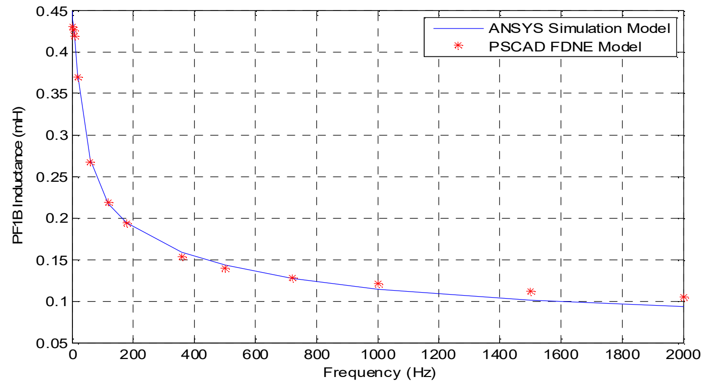
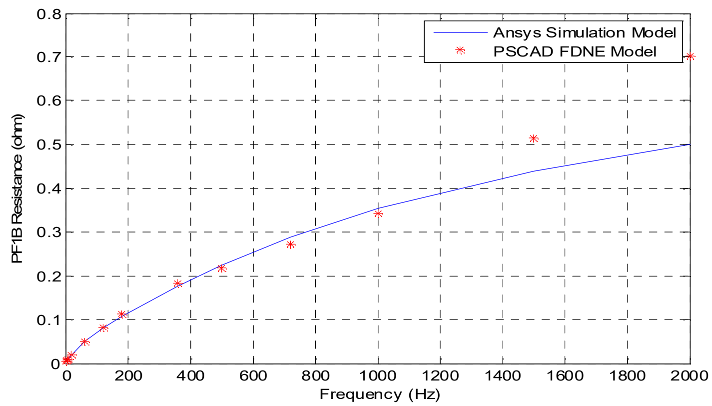


Figure 11 - PSCAD Model Used to Verify PF1B FDNE model

The results in Figure 12 show that the PF1B coil PSCAD FDNE model matches the PF1B Maxwell simulation model very closely.



(a) PF1B Inductance



(b) PF1B Resistance

Figure 12 - PF1B FDNE Model vs Maxwell Simulation Model

5.2.5 PF1B Coil Current Control Loop

The PF1B closed-loop current controller is a PI controller as shown in Figure 13. The lookup table is used for the input of the desired current waveform (the ordered pulse current).

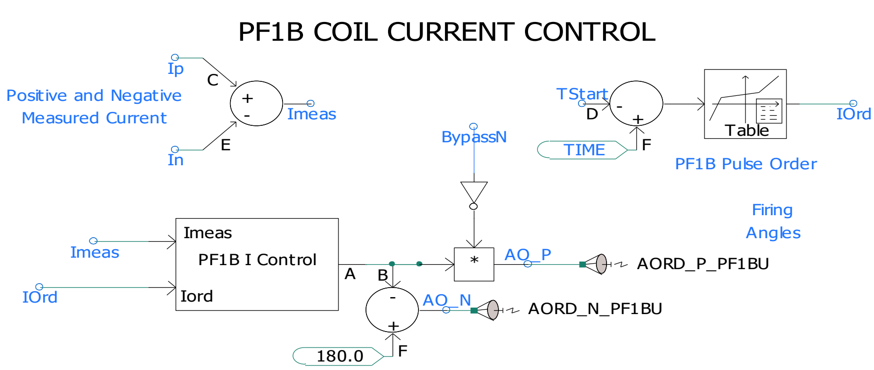


Figure 13 - PF1B Coil Current Control Loop

5.3 PF1B Coil Current Limiting Reactor Sizing Calculation

The current limiting reactors are needed to reduce the current ripple on the PF1B coils. There are two possible arrangements of the CLRs in the PF1B coil circuit. In case I, three CLRs are used. Two of them are used in the positive and the negative branches. The third one is used in series with the PF1B coil. In case II, only two CLRs are used. One is in the positive branch and the other is in the negative branch. Case III is a benchmark case using actual data from PF1C power supply operation.

5.3.1 Case I: PF1B Coil with Three CLRs

In case I, two 270 uH CLRs are used, one in each branch, to limit the circulating current. 270 uH is the standard FCPC CLR value. In this simulation case, the two branch inductor values are held fixed. To constrain the current ripple to 105 A, one additional series inductor 3 is used as shown in Figure 14. This inductor value is varied in the optimization process.

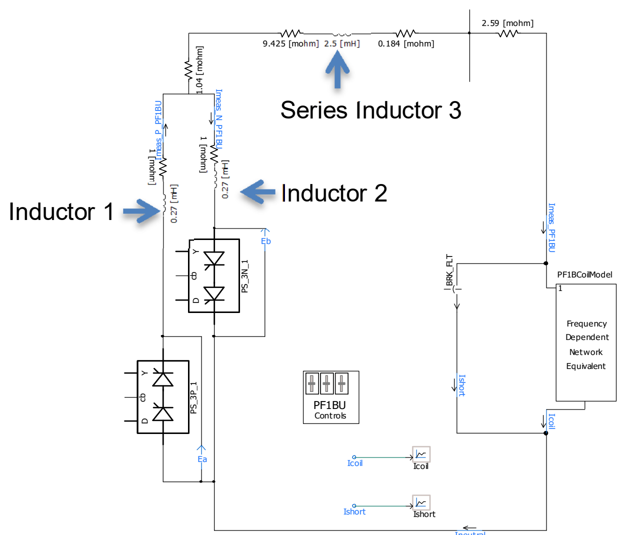
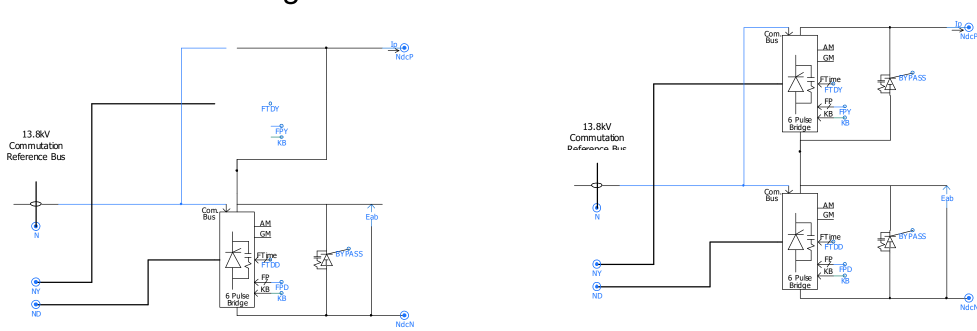


Figure 14 - Case I: PF1B Coil Using Three CLRs

There are two operation modes for the PF1B coil. One is the 1 kV mode and the other is the 2kV mode as shown in Figure 15.



(a) 1kV mode (b) 2kV mode

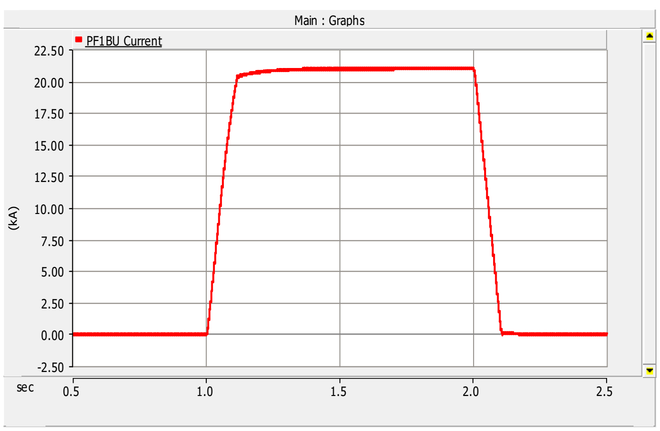
Figure 15 – PF1B Operation Modes

The current ripple vs. the series inductor value in the 1kV mode with different transformer secondaries in operation for the positive (PB) and negative (NB) branches is shown in Table 2. A 2.5 mH series inductor constrains the maximum current ripple to 92.5 A which is 12% less than the required 105 A.

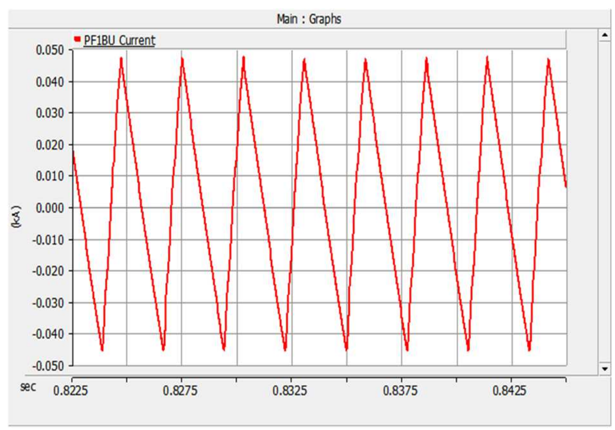
Table 2 - Case I: Current Ripple vs. Series Inductor Value at 1kV

	PB:Y-22.5° NB: Y+22.5°		PB:Δ+7.5° NB: Δ-7.5°		PB:Δ+7.5° NB: Y+22.5°	
Series Inductor (mH)	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)
1	110	205	128	203.6	110.6	205
2	63.4	113	73	111.2	64	112.7
2.5	51	92	59	91.4	51	92.5

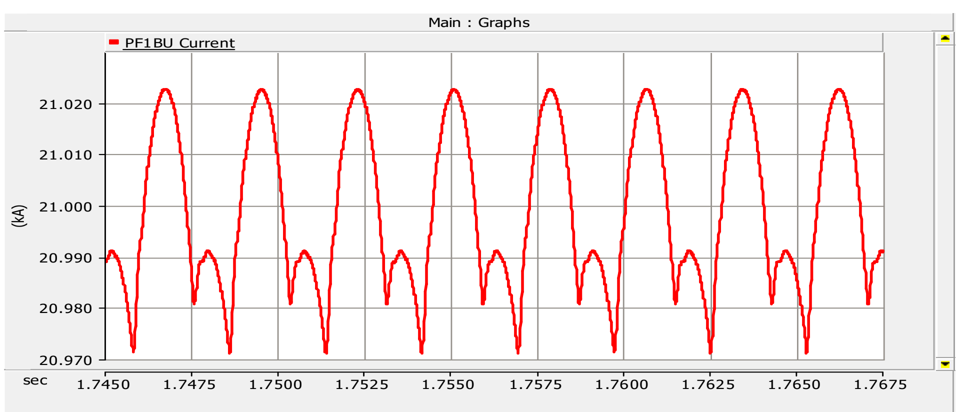
The PF1B coil current waveform and ripple with 2.5 mH CLR is shown in Figure 16.



(a) PF1B Coil Current Pulse at 1kV



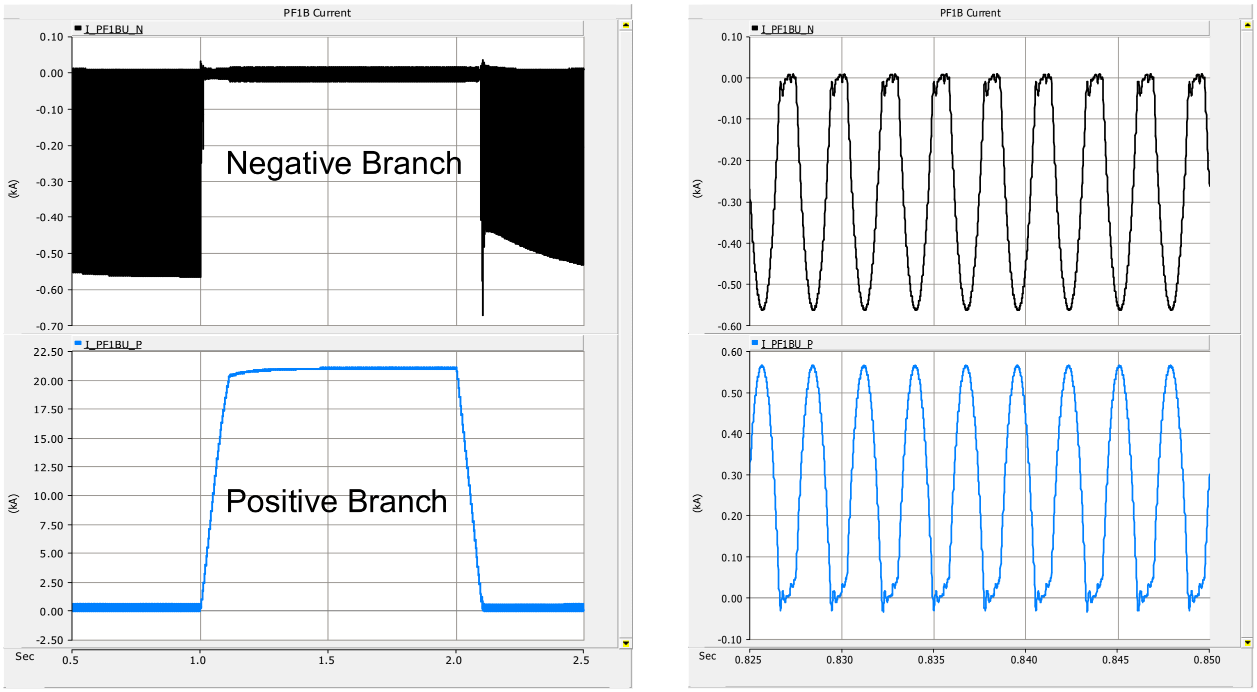
(b) PF1B Coil Zero Current Ripple



(c) PF1B Coil 21 kA Flat Top Ripple

Figure 16 - Case I: PF1B Coil Current Waveform and Ripples at 1kV

The positive and negative branch currents are also calculated shown in Figure 17. The magnitude of the circulating current is less than 600 A.



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

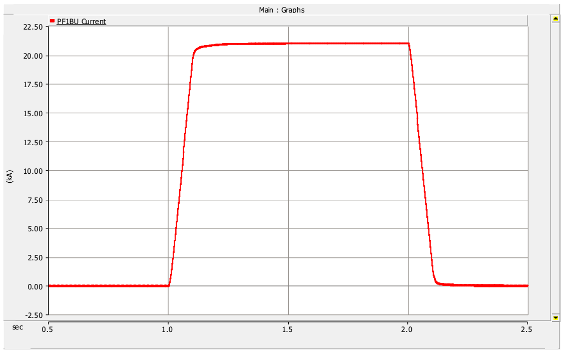
Figure 17 - Case I: PF1B Coil Negative and Positive Branch Current at 1kV

When operating at 2KV, two 1kV power supplies are connected in series resulting in a 12 pulse rectifier operating mode. The current ripple vs. the series inductor value in the 2kV mode is shown in Table 3. The current ripple magnitude with 0.75 mH inductor at 2kV is 91 A. The required the inductor size in the 2kV mode is significantly smaller than the 1kV mode. The maximum current ripple with 2.5 mH inductor is only 38 A as shown in Table 3.

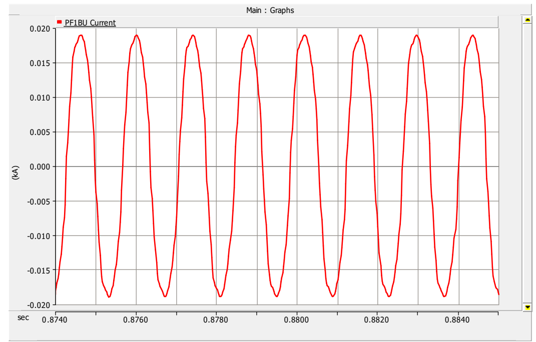
Table 3 Case I: Current Ripple vs. Series Inductor Value at 2kV

	PB: Y -22.5 and Δ +7.5 NB: Y+22.5 and Δ -7.5	
Series Inductor (mH)	Flat top Current Ripple (A)	Zero Crossing Current Ripple (A)
0.25	109	205
0.5	82	114
0.75	66	91
2.5	29	38

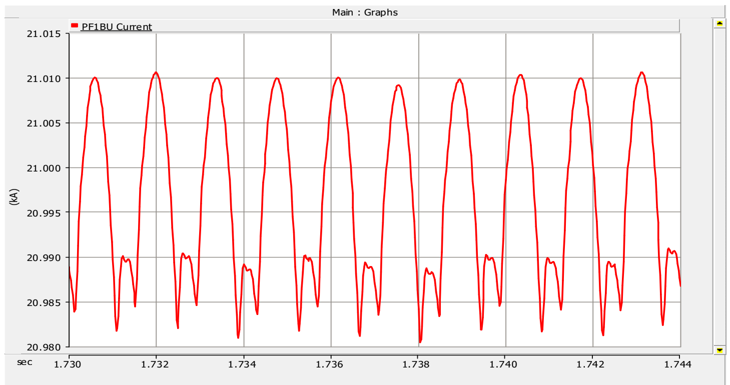
The PF1B coil current waveform and ripple with 2.5 mH CLR at 2kV is shown in Figure 18. The ripple frequency is 720 Hz.



(a) PF1B Coil Current Pulse at 2kV



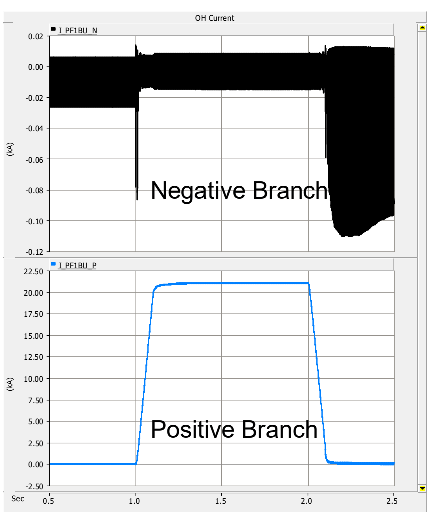
(b) PF1B Coil Zero Current Ripple at 2kV



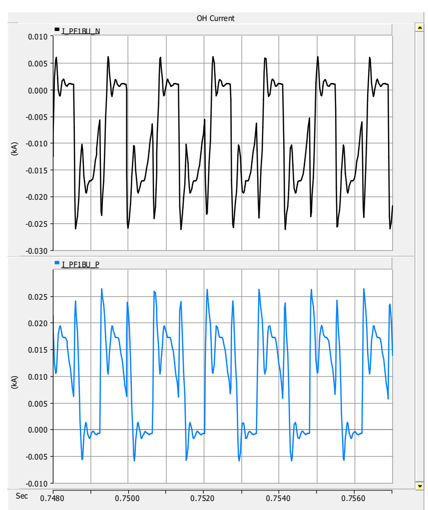
(c) PF1B Coil 21 kA Flat Top Ripple at 2kV

Figure 18 - Case I: PF1B Coil Current Waveform and Ripples at 2kV

The positive and negative branch currents at 2kV are plotted and shown in Figure 19. The magnitude of the circulating current is less than 30 A.



(a) Negative and Positive Branch Current



(b) Circulating Current

Figure 19 - Case I: PF1B Coil Negative and Positive Branch Current at 2kV

5.3.2 Case II: PF1B Coil with Two CLRs

In Case II, inductors are used in the positive and the negative branch as shown in Figure 20. These inductors serve to limit the circulating current and also to reduce the coil current ripple. The PF1B coil current ripple was analyzed in the 1kV and 2kV operating modes for different values of these branch inductors.

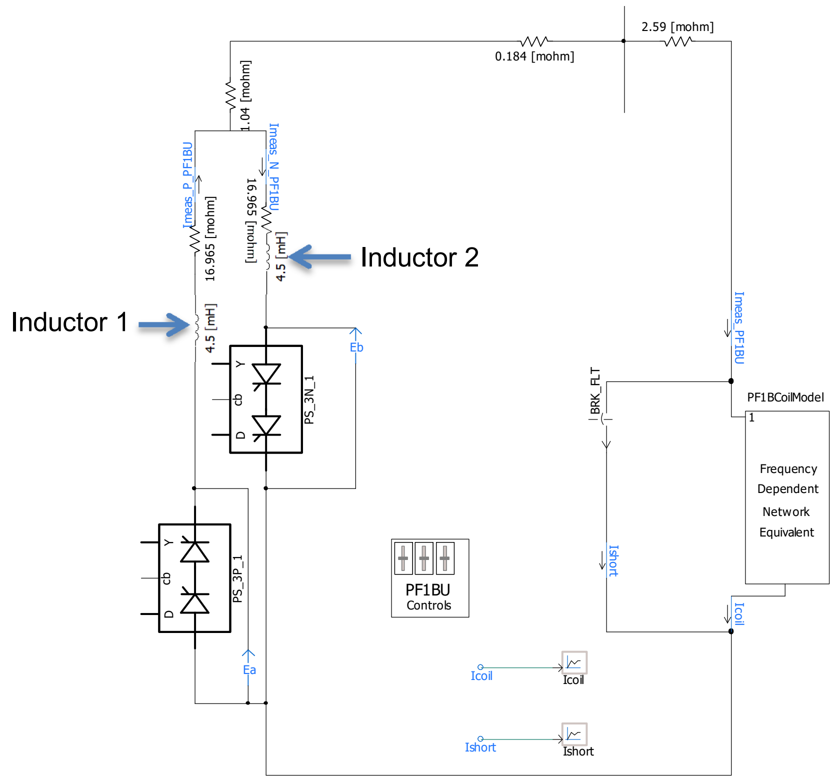


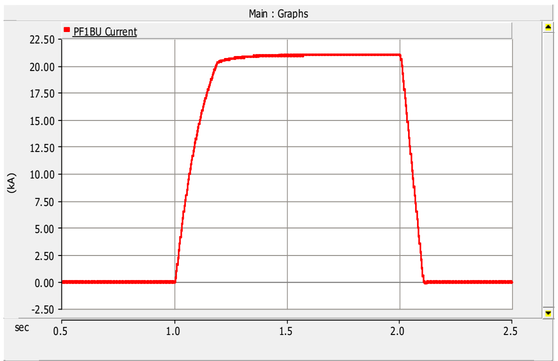
Figure 20 - Case II: PF1B Coil Using Two CLRs

The current ripple vs. the branch inductor value in the 1kV operating mode with different transformer connections is shown in Table 4. Using the 4.5 mH inductor, the maximum current ripple is 104 A which is less than the requirement 105 A.

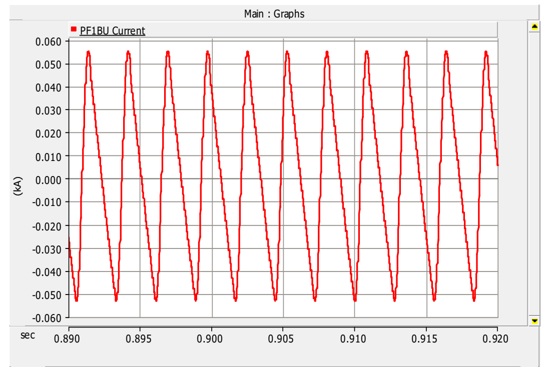
Table 4 - Case II: Current Ripple vs. Branch Inductor Value at 1kV

	PB:Y-22.5° NB: Y+22.5°		PB:Δ+7.5° NB: Δ-7.5°		PB:Δ+7.5° NB: Y+22.5°	
Branch Inductor (mH)	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)
3	46.5	140	46.4	139.4	47	139.2
3.5	38	125	38.5	125	38.1	124.9
4.0	33	114	32.4	113.8	32.5	113.7
4.5	27.5	104	27.7	104	27.3	104

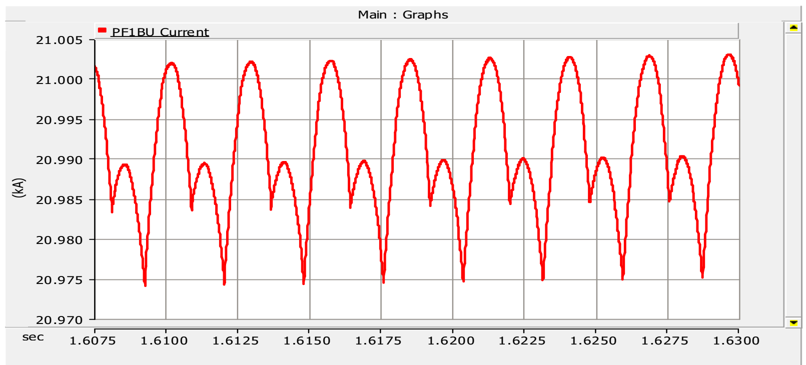
The PF1B coil current waveform and ripple with 4.5 mH CLR is shown in Figure 21.



(a) PF1B Coil Current Pulse at 1kV



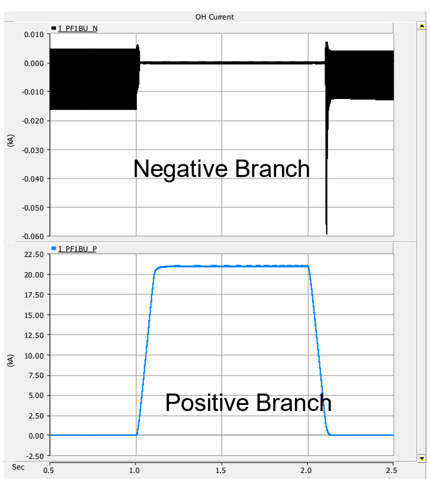
(b) PF1B Coil Zero Current Ripple



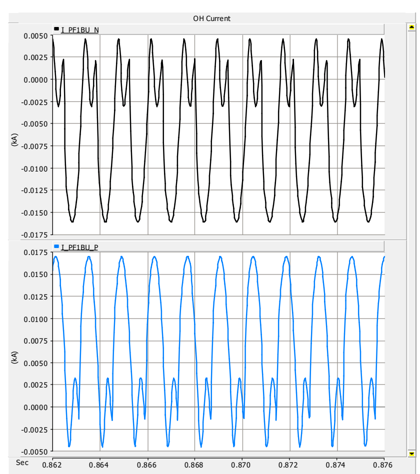
(c) PF1B Coil 21 kA Flat Top Ripple

Figure 21 - Case II: PF1B Coil Current Waveform and Ripples at 1kV

The positive and negative branch current is also calculated as shown in Figure 22.



(a) Negative and Positive Branch Current



(b) Circulating Current

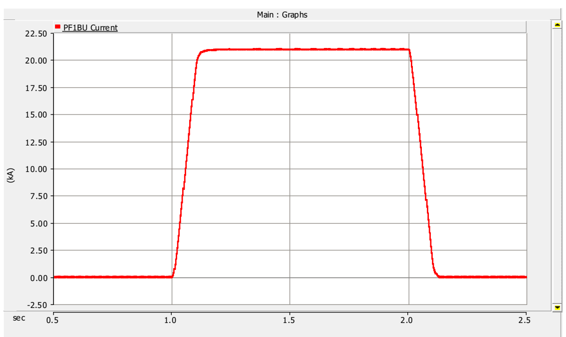
Figure 22 - Case II: PF1B Coil Negative and Positive Branch Current at 1kV

The current ripple vs. the branch inductor value for 2kV operation is shown in Table 5. The current ripple magnitude with a 1.3 mH inductor at 2kV is 92 A. The maximum current ripple with a 4.5 mH inductor is 40 A as shown in Table 5.

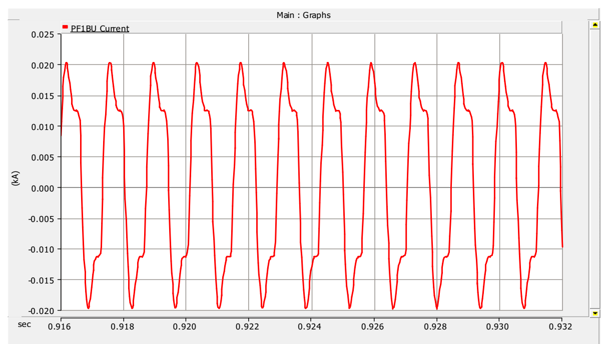
Table 5 - Case II: Current Ripple vs. Branch Inductor Value at 2kV

	PB: Y -22.5 and Δ +7.5 NB: Y+22.5 and Δ -7.5	
Series Inductor (mH)	Flat top Current Ripple (A)	Zero Crossing Current Ripple (A)
0.25	162	259
0.5	109	177
1	66	113
1.3	53	92
4.5	19	40

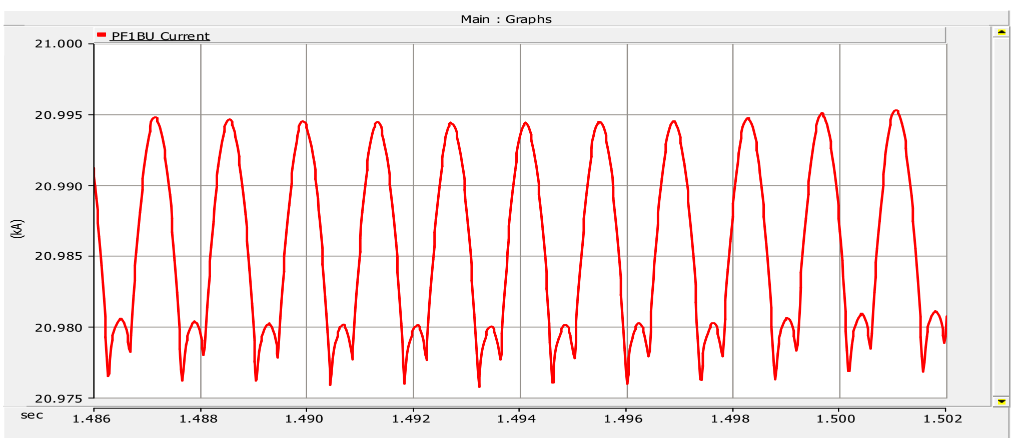
The PF1B coil current waveform and ripple with 4.5 mH CLR at 2kV is shown in Figure 23. The ripple frequency is at 720 Hz.



(a) PF1B Coil Current Pulse at 2kV



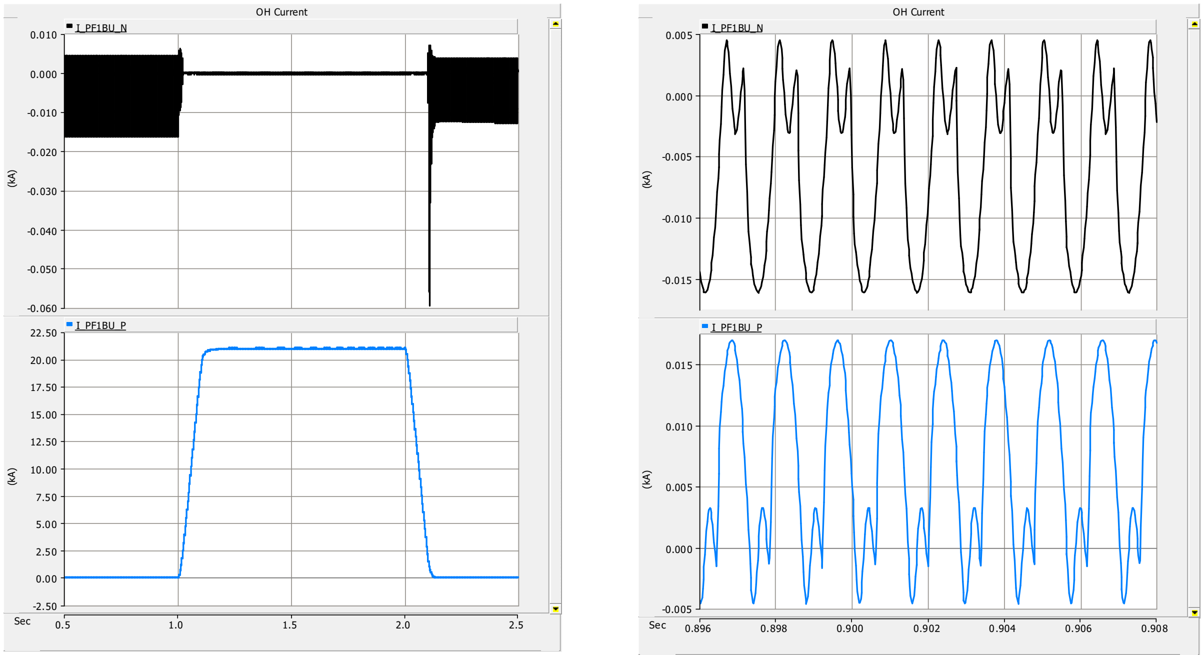
(b) PF1B Coil Zero Current Ripple at 2kV



(b) PF1B Coil 21 kA Flat Top Ripple at 2kV

Figure 23 - Case II: PF1B Coil Current Waveform and Ripples at 2kV

The positive and negative branch current at 2kV is plotted and is shown in Figure 24.



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

Figure 24 - Case II: PF1B Coil Negative and Positive Branch Current at 1kV

5.3.3 Case I and Case II Comparison

The comparison between Case I and Case II is shown in Table 6. Case I is with one 2.5 mH and two 0.27 mH inductors.. Case II is with two 4.5 mH inductors. Since each inductor must be rated to carry the full load current, and assuming that inductor cost is driven primarily by stored energy 1/2 LI^2 (and not rms current) the total installed inductance can serve as a measure of relative cost. The total inductance needed in Case I is significantly lower than in Case II. This means the size and the cost of the inductors in Case I is significantly reduced compared to Case II. Case I is also suitable for the PF1A and PF1C coil power supply systems which already have the 0.27 mH CLR. This can significantly reduce the overall cost. So Case I is recommended.

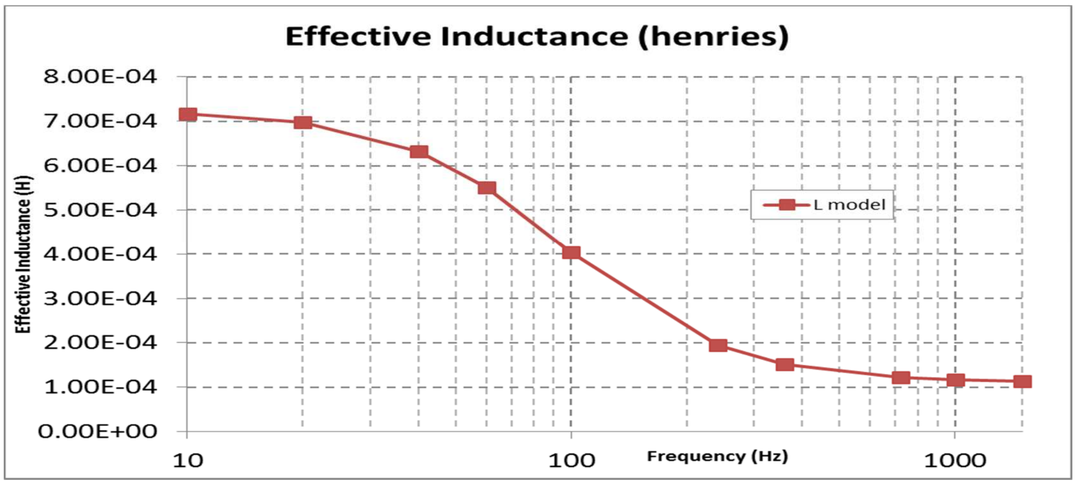
Table 6 Case I and Case II Comparison

	Case I (0.27mHx2, 2.5mHx1)		Case II (4.5mHx2)	
Operation Mode	Series Inductor Value (mH)	Maximum Current Ripple (A)	Branch Inductor Value (mH)	Maximum Current Ripple (A)
1 kV	2.5	92.5	4.5	104
2 kV	0.75	91	1.3	92

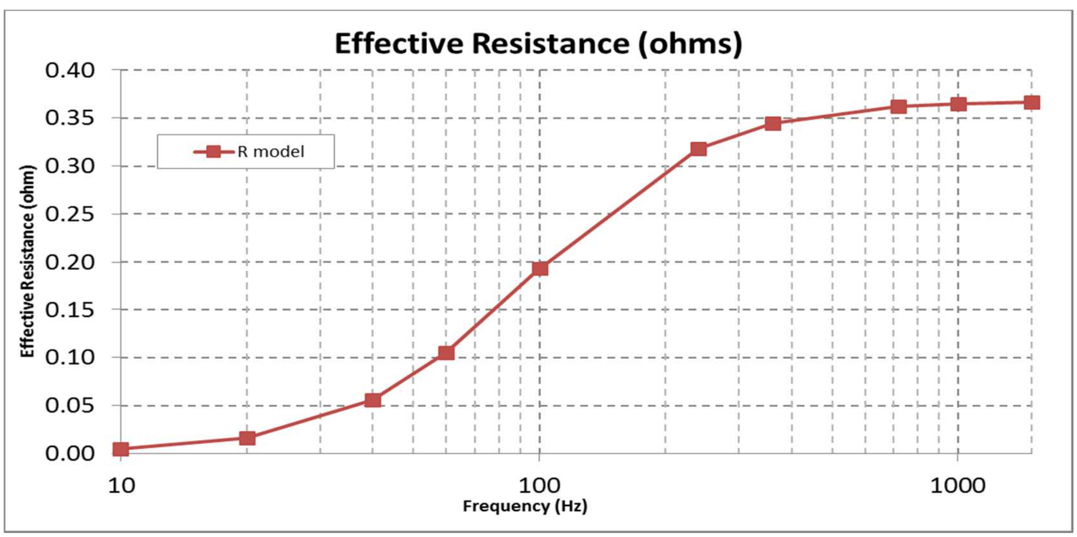
5.3.4 Case III: Benchmark Case using Shot #201990

The existing PF1B coils were never in operation (no circuits were provided) and therefore, no data exists for benchmarking purposes. The old PF1C coil has been tested in practice. The inductance of the old PF1C coil is similar to the new PF1B coil. The PF1C coil and power supply system is simulated using the PSCAD software. The physical PF1C impedance measurement result was used to derive the PF1C coil PSCAD FDNE model.

The PF1C coil impedance measurement result is shown in Figure 25.



(a) Frequency Scan of PF1C Coil Inductance



(b) Frequency Scan of PF1C Coil Resistance

Figure 25 - Old PF1C Coil Measurement Impedance Results

The overall structure of the PF1C power supply system model is shown in Figure 26.

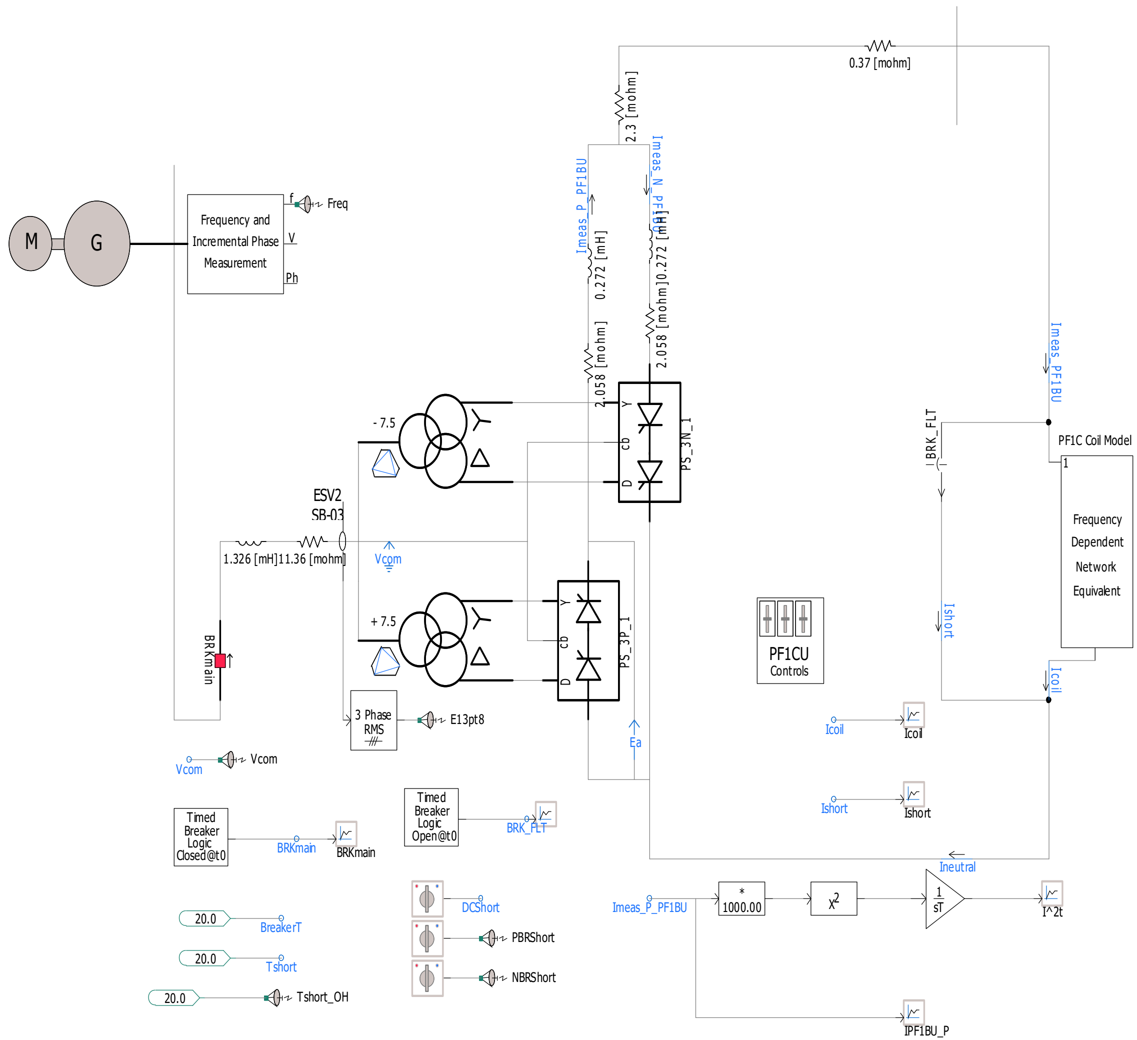
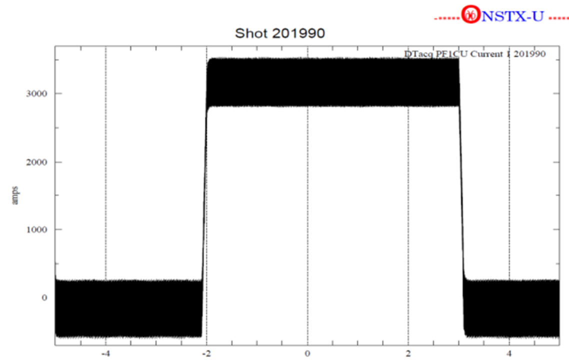
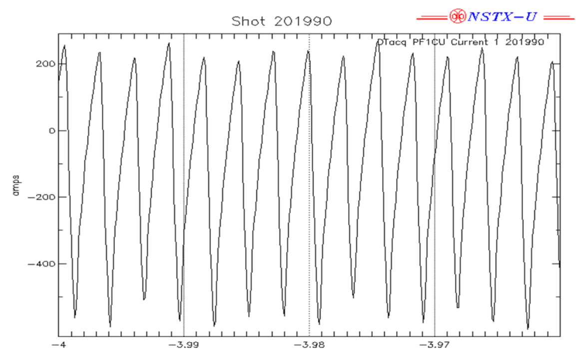


Figure 26 - PF1C Coil Power Supply System

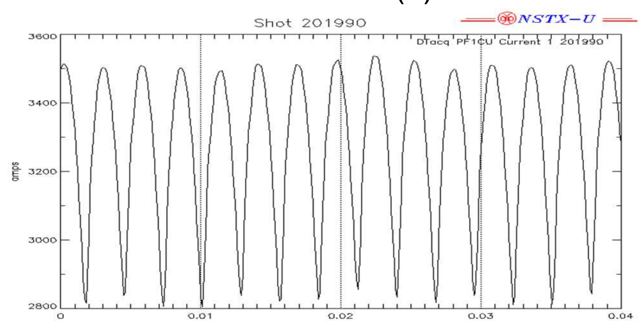
Shot #201990 is used as the benchmark case. In this shot, only the PF1CU coil is energized by the bipolar 1kV power supply. The rise and fall time is 100ms and the flat top is 5 sec. The PF1C coil test current waveform is shown in Figure 27. The peak-peak current ripple at zero crossing is about 800 A. The peak-peak current ripple at the flat top is about 700 A. The simulation current waveform for the PF1C coil is shown in Figure 28. In the simulation, the peak-peak current ripple at zero crossing is about 700 A and the peak-peak current ripple at the flat top is about 700 A. The simulation results show that the current ripple magnitude and shape are very close to the real measured data.



(a) PF1C Coil Current Pulse

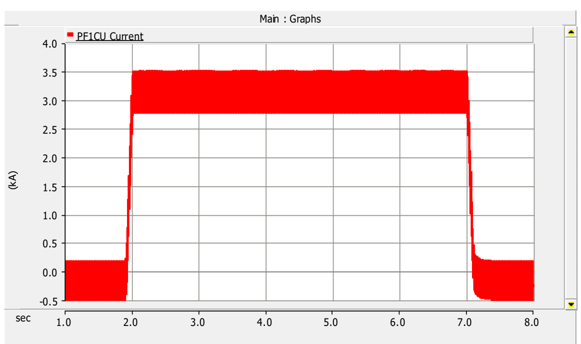


(b) PF1C Coil Zero Current Ripple

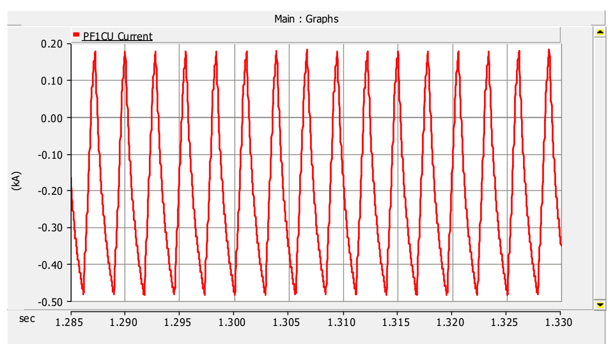


(C) PF1C Flat Top Ripple

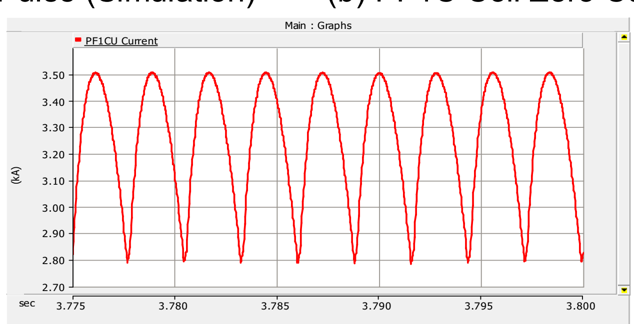
Figure 27 - PF1C Current Waveform at Shot #201990



(a) PF1C Coil Current Pulse (Simulation)



(b) PF1C Coil Zero Current Ripple



(C) PF1C Coil Flat Top Ripple

Figure 28 - PF1C Coil Current Waveform Simulation Results

6. Conclusions

The effective inductance and resistance under varying frequency for the PF1B coil was analyzed using ANSYS Maxwell. This impedance vs. frequency data was then used as input for constructing a FDNE component in PSCAD. The PF1B coil power supply system was modeled in PSCAD using the FDNE model as the load, representing the PF1B coil's frequency dependent impedance due to the passive structure effects. CLRs are needed to reduce the current ripple on the PF1B coils to meet the inner PF coils ripple requirement as defined in the Power Systems SRD (peak-to-peak ripple amplitude as 0.5% of the full scale current) There are two possible arrangements of the CLRs in the PF1B coil circuit. In Case I, one 2.5 mH and two 0.27 mH inductors are needed to reduce the current ripple to 92.5 A. In Case II, two 4.5mH are needed to reduce the current ripple to 104 A. Case I is recommended due to the smaller inductance ratings and size. Case I also allows for a cost effective solution for the PF1A and PF1C circuits, as the .27 mH branch circuit inductors are already installed.