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December 17, 2014

The Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, Newfoundland & Labrador
A1A 5B2

Attention: Ms. Cheryl Blundon
Director Corporate Services & Board Secretary

Dear Ms. Blundon:

Re: Newfoundland and Labrador Hydro - the Board's Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System: Supplementary Response in Relation to PUB-NLH-457 and PUB-NLH-458

In its responses to the Board's RFIs PUB-NLH-457 and PUB-NLH-458, Hydro indicated that additional documentation would be supplied to the Board when the related work was completed. In this regard, please find enclosed the original and 12 copies of the following:

a) Hydro's analysis of the impact of transmission line contingencies on system losses related to alternate generation dispatches (re: PUB-NLH-457); and,
b) Two reports by Trans Grid Solutions Inc. related to the simulation of the Sunnyside T1 failure and an investigation of the Western Avalon T5 transformer failure concerning whether or not harmonics or system resonance were contributing factors to the system events of January, 2014 (re: PUB-NLH-458).

We trust the foregoing is satisfactory. If you have any questions or comments, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Tracey L. Pennell
Legal Counsel

TLP/jc

cc: Gerard Hayes – Newfoundland Power
Paul Coxworthy – Stewart McKelvey Stirling Scales
ecc: Roberta Frampton Benefiel – Grand Riverkeeper Labrador
Thomas Johnson – Consumer Advocate
Danny Dumaresque

Engineering Support Services for:

Western Avalon Transformer T5 Tap Failure

Newfoundland and Labrador Hydro

Attention:

Mr. Peter Thomas

Report R1335.02.01

PSCAD Investigation of the Western Avalon T5 Transformer Failure

Prepared by:

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Nov.26th, 2014

Disclaimer

Revisions

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Approval not Required	ANR

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1. Introduction

This report presents the findings of the PSCAD simulation to recreate the Newfoundland T5 transformer tap changer fault that occurred at 12:22pm on January 4th, 2014.

The original scope of the project was to model the fault based on delivered Comtrade data which records the pertinent waveforms. Upon receipt of the data, the following was noticed:

1. The Comtrade data delivered forthe events at :
   04/01/2014,13:13:09.000260
   04/01/2014,10:05:34.000260

   Both of which did not match the time of the fault. The Comtrade data which had the same time stamp as the fault was delivered as a pdf file, which is shown in Figure 4-3.

2. The Comtrade data had a very low resolution as shown in Figure 1-1, which made it very hard to match to the PSCAD simulation.

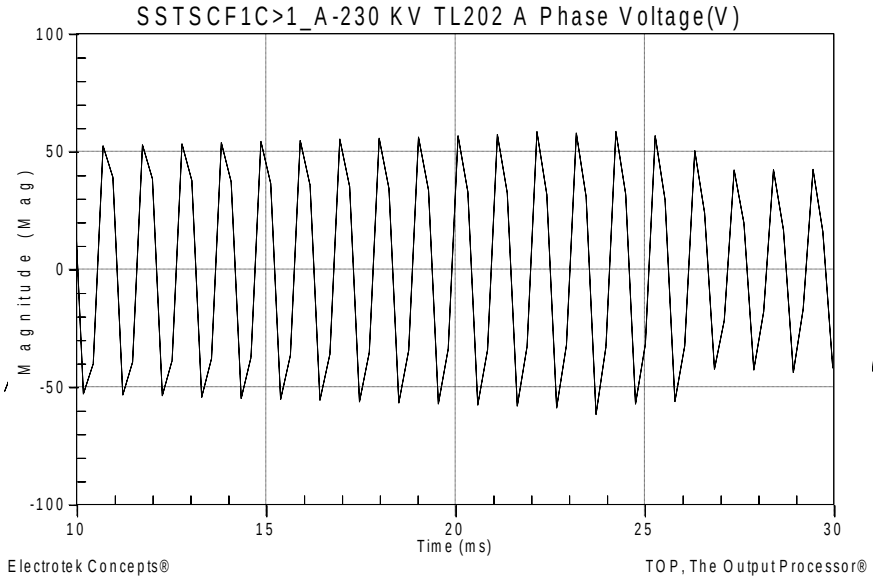

Figure 1-1 Example of Low resolution Waveforms

A PSCAD model was created on the following information in order to recreate the fault based on the pdf Comtrade file.

- Jan 4 1200.sav
- PSS/E data file which represents the Newfoundland System conditions prior to the fault
- Peak Case.dyr
- PSS/E dynamics file
- WAVTS T5 transformer nameplate, test data and transformer data (delivered as pdf files)

- AC Line geometric data based on past work performed by TGS. This included mutual coupling of the lines that shared the same right-of-way.
- AMEC report "Newfoundland and Labrador Hydro Transmission Availability" March 21, 2014. This report gave the details of the sequence of events during the fault of January 4th.

2. PSCAD Model Development

2.1 AC System model

The following files provided by Newfoundland and Labrador Hydro (NLH) and were used as the base case to develop the equivalent PSCAD model:

- Jan 4 1200.sav
- Jan 4 1200.dyr

The equivalent ac system in PSSE was converted to PSCAD. Since this study deals with a transient phenomenon as a result of transformer failure at Sunnyside, the representation of the power system components with more accuracy at higher frequencies than the fundamental frequency is crucial for a better analysis of the event. Therefore the following changes were made to the converted case:

- All the generators were represented with their associated dynamic data, with the exception of the BDP G7 unit as there was some stability issues associated with this machine. Due to the short duration of the simulation, this will not affect the accuracy of the simulation.
- A majority of the transmission lines surrounding the Sunnyside and Western Avalon were modeled with frequency dependent line models according to the tower geometries and conductor configurations
- T5 transformer at Western Avalon was represented based on the latest data provided by NLH

Figure 2-1 shows the single line diagram of the ac system used in this study. Please note that the complete case is not shown in the diagram and only the main portion of the ac system surrounding Sunnyside and Western Avalon is shown.

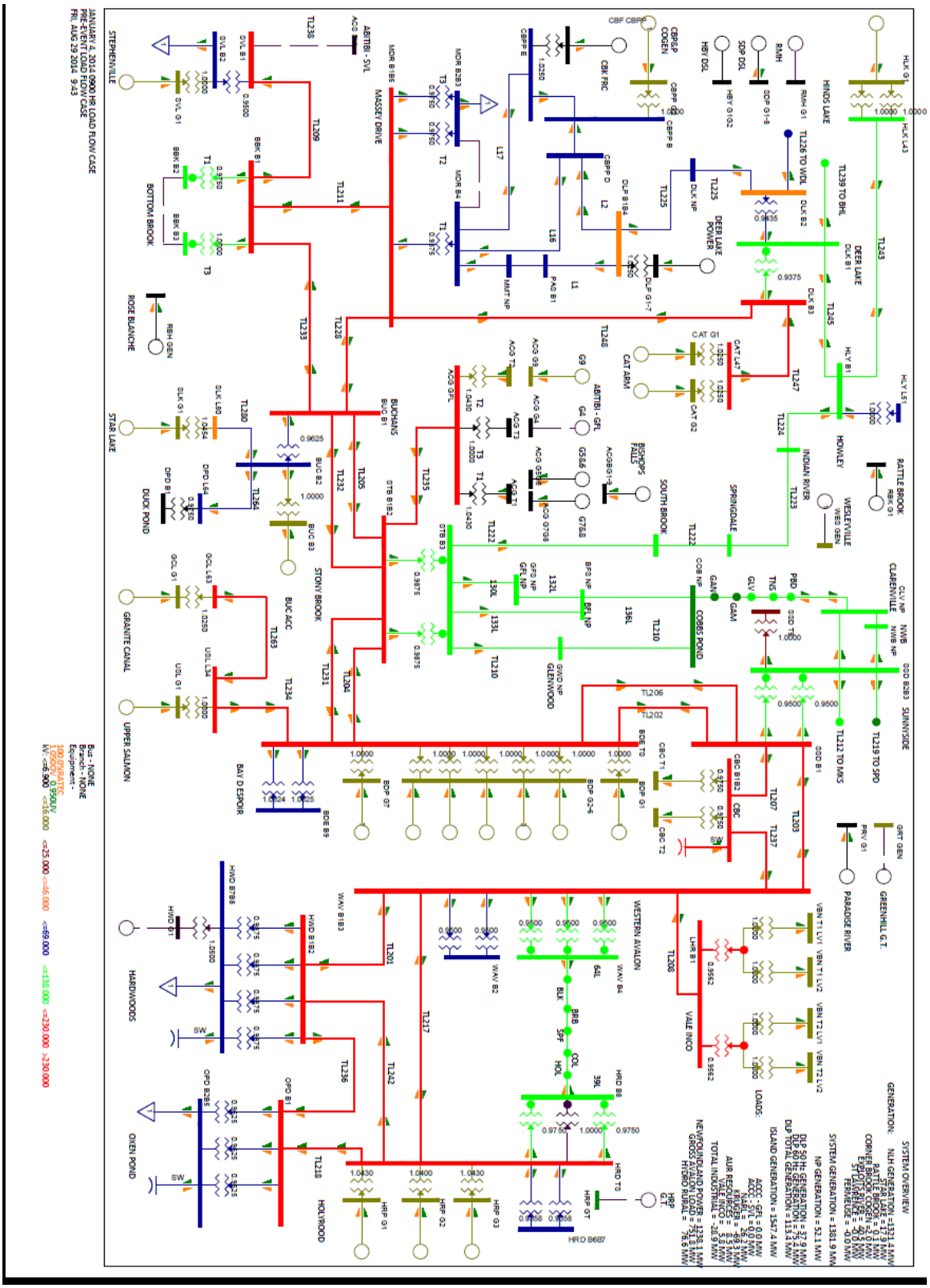

Figure 2-1 SLD of Newfoundland System

2.2 AC Transmission Lines

The major transmission line models in the PSCAD case which when originally converted from PSS/E, were represented as pi-sections and Bergeron line models

The Bergeron and pi-section line representations are only adequate for studies that essentially require the correct fundamental frequency impedance. However, in order to get a higher degree of accuracy, some of the lines near the affected buses were replaced with frequency dependent line models.

Table 2-1 lists of the lines that were modeled as frequency dependent lines.

Table 2-1 Frequency Dependent AC lines

From Bus#	To Bus#	From Bus#	To Bus#
195229	195230	195167	195169
195222	195227	195169	195171
195221	195216	195171	195173
195216	195215	195173	195175
195221	195220	195222	195229
195220	195218	195227	195229
195215	195208	195229	195236
195215	195205	195229	195234
195205	195536	195234	195236
195205	195208	195236	195238
195622	195625	195221	195222
195625	195627	195152	195153
195124	195122	195153	195154
195122	195120	195155	195157
195120	195115	195157	195159
195115	195112	195152	195159
195112	195111	195620	195620
195209	195210	195621	195622
195208	195209	195112	195113
195205	195206	195600	196500
195500	195620	-	-

Figure 2-2 shows an example of one of the more detailed line representation, which includes the mutual coupling of lines TL201, TL242 and TL218 and the mutual coupling of lines TL201 and TL217. Figure 2-3 shows the detailed line model for the lines TL201, TL242 and TL218.

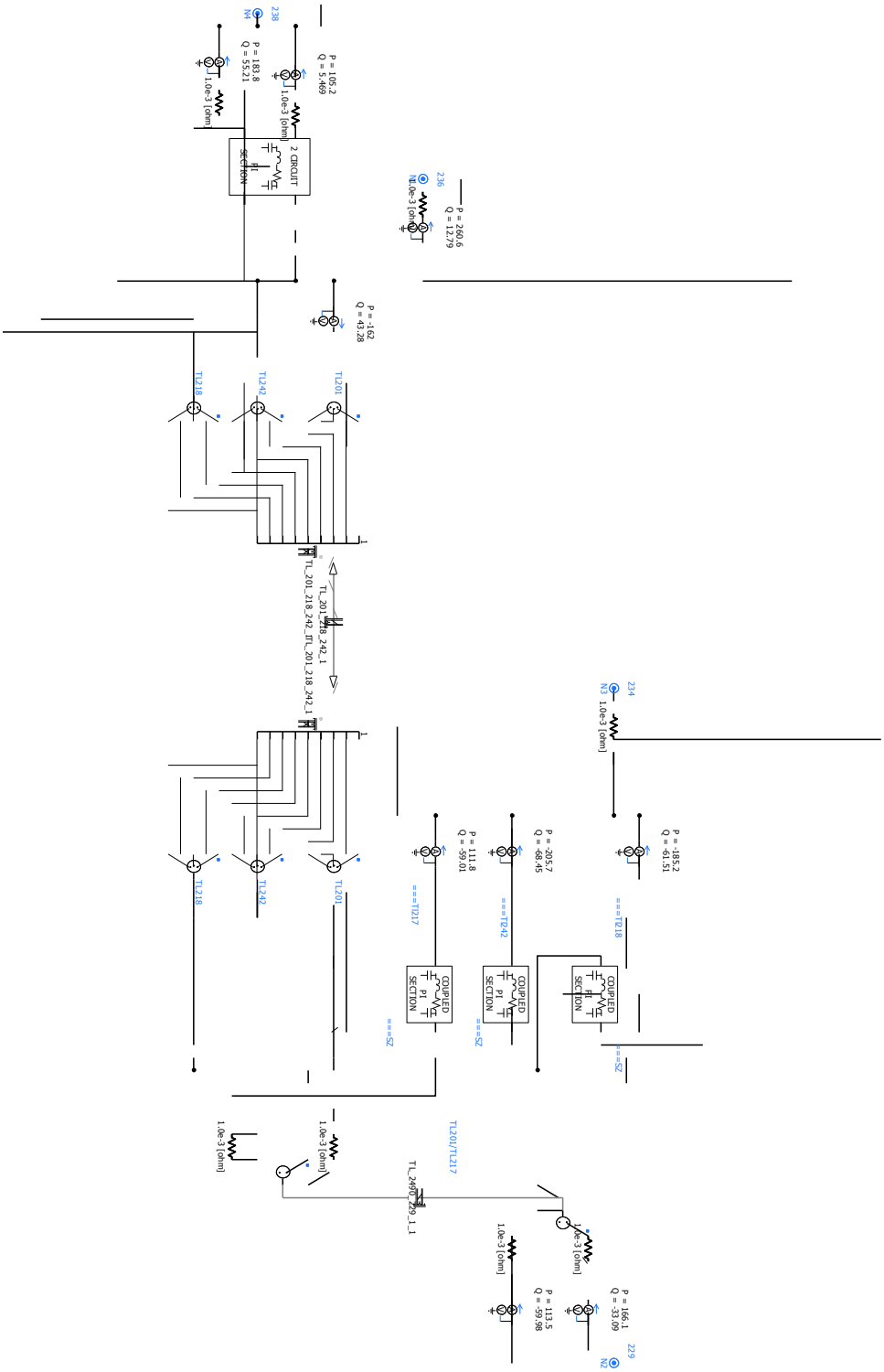

Figure 2-2 Example Line representation

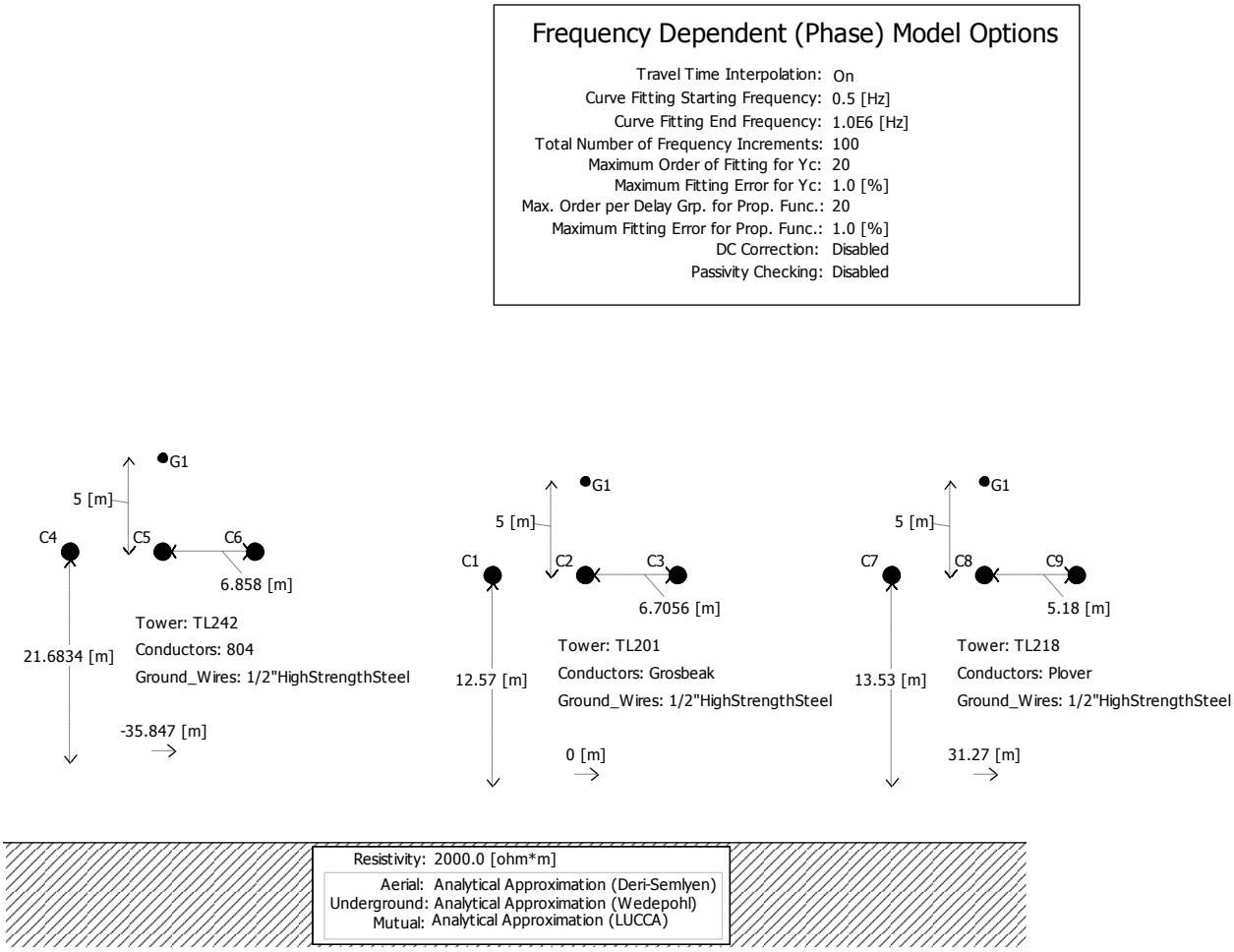

Figure 2-3 Detailed Line Model

2.3 Power Transformers

The power transformer models T5 at Sunny Side are updated based on the following data files received from NLH:

- "WAVTS T5 nameplate.pdf"
- "WAVTS T5 Test Report.pdf"
- "Western Avalon-T5.pdf"

2.4 T5 Transformer at Sunny Side and T1 Transformer at Western Avalon

The T5 transformer at Sunnyside is modeled based on the data provided by NLH. Figure 2-4 shows the PSCAD model and Table 2-2 shows the data used to model the transformers.

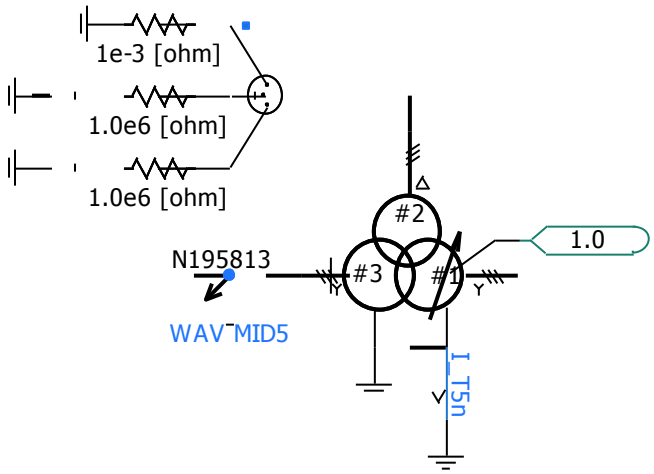

Figure 2-4 T1 - SSD T5 – WAV

Table 2-2 SSD T5 - WAV

Name	Tmva	f	YD1	YD2	YD3
T5	75 [MVA]	**60.0 [Hz]**	Y	Delta	Y
Name	Lead	Xl12	Xl13	Xl23	Ideal
T5	Lags	0.1796 [pu]	0.0563 [pu]	0.1347[pu]	Yes
Name	NLL	CuL	Tap	V1	V2
T5	0.000533 [pu]	0.00123335[pu]	#1	230.0 [kV]	6.9 [kV]
Name	V3	Enab	Sat	Hys	
T5	138.0 [kV]	Yes	Middle	Jiles_Atherton	

2.5 PSCAD Model Benchmarking Against PSS/E

After development of the ac network in PSCAD based on the equivalent developed model in PSS/E, it was necessary to validate the PSCAD case against the equivalent case in PSSE. The validation was performed through comparison of the short circuit levels at certain buses and the results of the load flow and power transfer at some selected transmission lines.

The results of the comparison are shown in Table 2-3 and Table 2-4. The results compare very well

Table 2-3 SCL Comparison

Bus	Bus Number	SCL (MVA)		% difference
		PSS/E Equivalent	PSCAD	
Western Avalon	195229	678	702	-3.54%
Sunny side	195222	999	1027	-2.80%
Bay D Espoir	195221	2913	2904	0.31%
Hollyrood	195234	536	570	-6.34%
Stony Brook	195216	1615	1633	-1.11%
Oxen Pond	195238	523	551.44	-5.44%

Table 2-4 Loadflow Comparison

From Bus Number	To Bus Number	Line	Real Power (MW)			Reactive Power (MVAR)		
			PSS/E Equivalent	PSCAD	% difference	PSS/E Equivalent	PSCAD	% difference
195229	195234	TL217	81.7	84.35	-3.24%	-4	-4.53	-13.25%
	195236	TL201	84.9	82.95	2.30%	-7.1	-6.67	6.06%
	195227	TL237	-166.6	-167.6	-0.60%	13.8	13.86	-0.43%
195221	195216	TL204	207	207.45	-0.22%	20.6	20.95	-1.70%
	195216	TL231	207	207.45	-0.22%	20.6	20.95	-1.70%
	195220	TL234	-103.5	-103.6	-0.10%	3.8	0.5903	84.47%
	195222		93.7	94.11	-0.44%	-12.7	-12.7	0.00%

In the actual fault, the transformer T5 was energized by closing the breaker L01L03 at Western Avalon and T5 failed 22 seconds later. In the above load flow, the breaker L01L03 (and therefore line TL237) were already connected. In order to accurately simulate the fault, the line TL237 was opened at Western Avalon prior to the fault being applied.

3. Modeling of Fault Sequence

The modeling of the fault sequence was based on the AMEC report "Newfoundland and Labrador Hydro Transmission Availability" March 21, 2014. The supplied load flow was configured to represent the ac system just prior to the T5 transformer being energized. The detailed sequence of events is as shown Table 3-1 below:

Table 3-1 AC System Fault Sequence

Time	event
2	Close Breaker L01L03 and energize T5 via TL237
5.07	Apply phase to phase fault
5.15333	Open ac breaker and trip transformer

4. Results

4.1 Time Domain Simulation

As described in the AMEC report, during the system restoration, one of the first steps taken was to try and energize the Western Avalon B1 and B3 buses from Come-by-Chance via line TL237 using breaker B1L37, which failed. During the subsequent incident investigation, it was found that only two phases of the breaker B1L37 closed, which means transformer T5 was energized via two phases. Figure 4-1 shows an example of energizing the transformer 2 times, with only phases A and B closing. Assuming typical parameters for core characteristics, the remnant flux density is approximately -0.064 on phase A , -1.335 on phase B and 1.131 on phase C. These flux densities will be included in the transformer model.

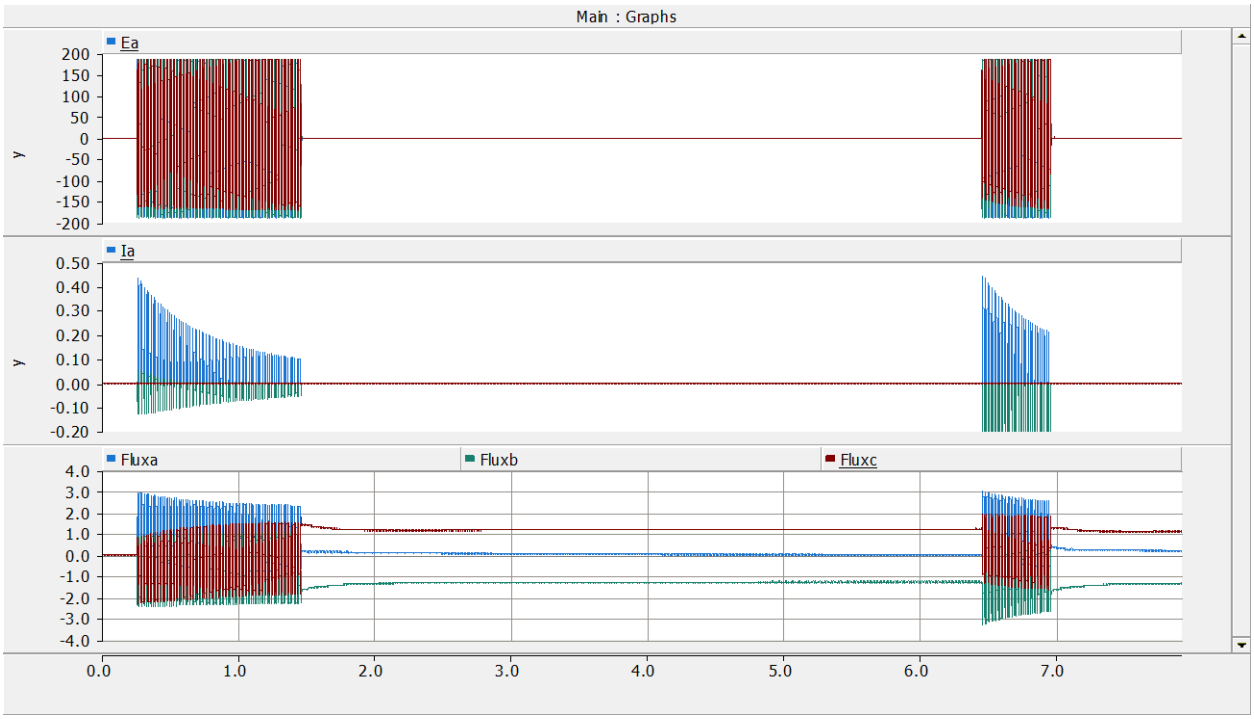

Figure 4-1 PSCAD Simulation of remnant flux

Figure 4-2 shows the enenergization of transformer T5 via line TL237. There is a peak current of about 250A in the neutral (I_T5n).

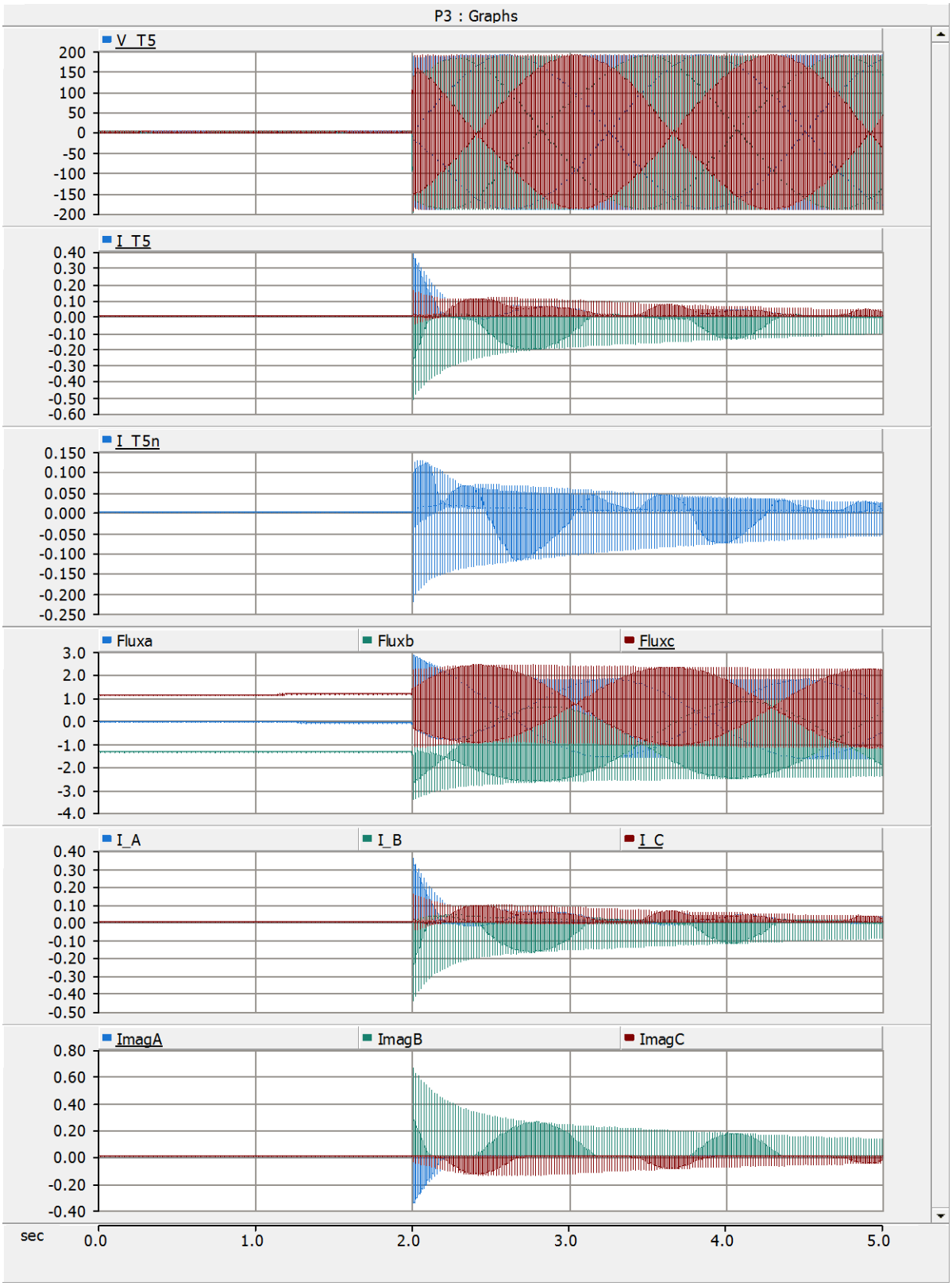

Figure 4-2 Energization of Western Avalon transformer T5 via line TL237

Figure 4-3 shows the actual measurements taken at Sunnyside for the T5 tapchanger failure

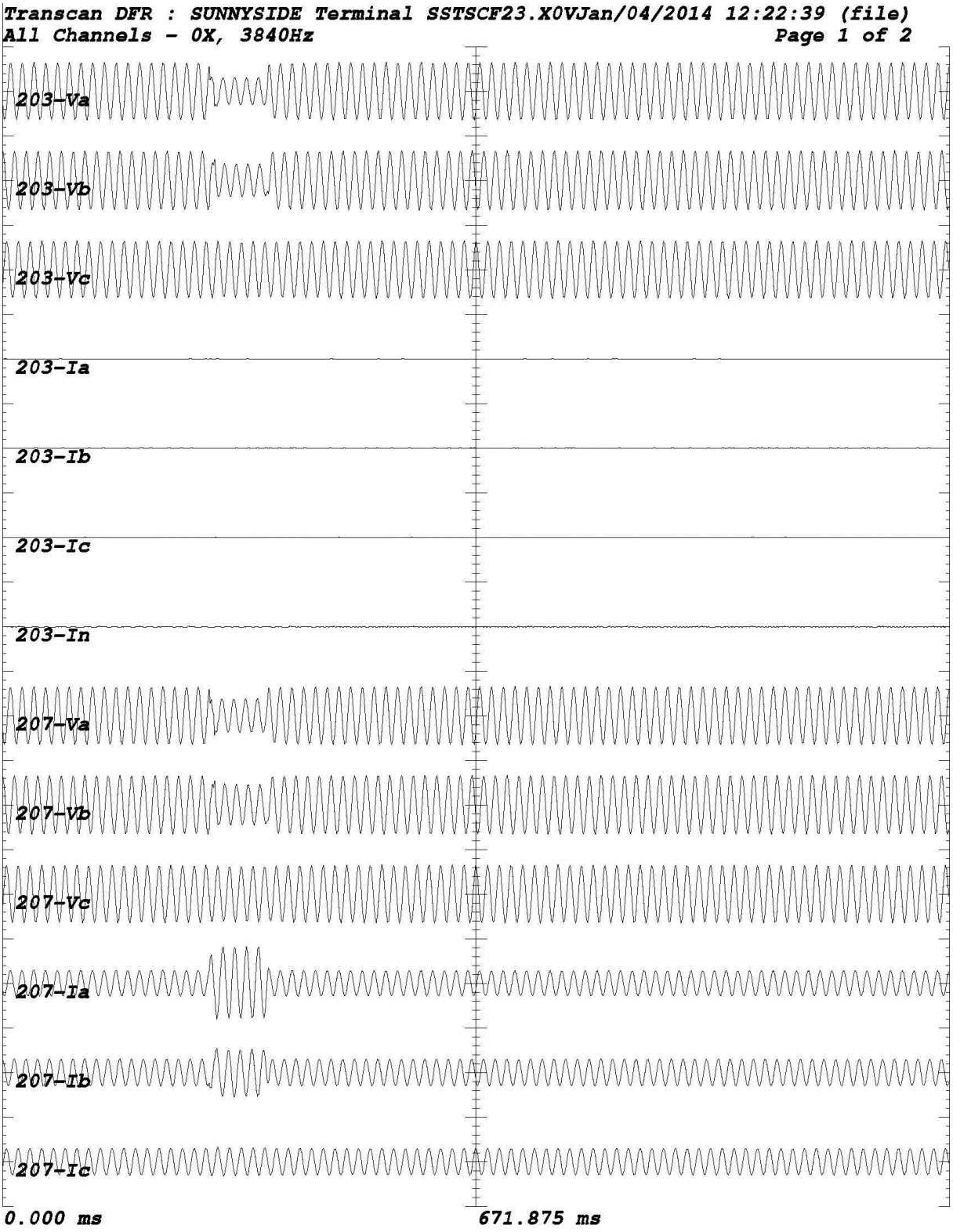

Figure 4-3 SSD DFR traces for T5 Failure

Figure 4-4 TL207 Values

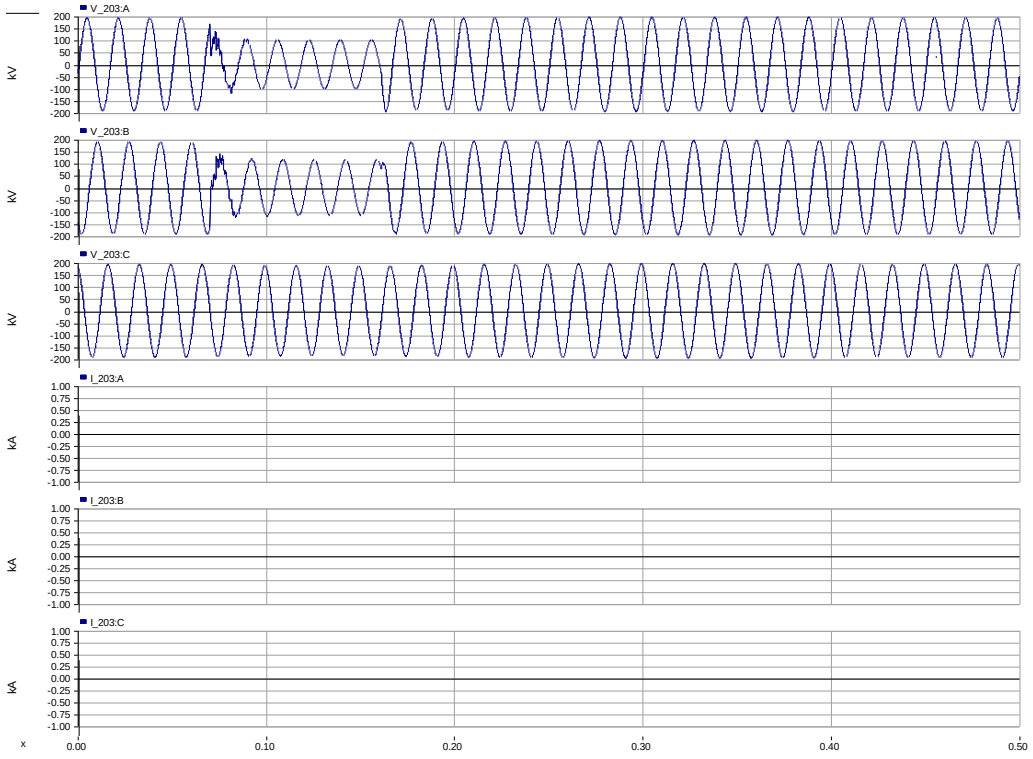

Figure 4-5 TL203 Values

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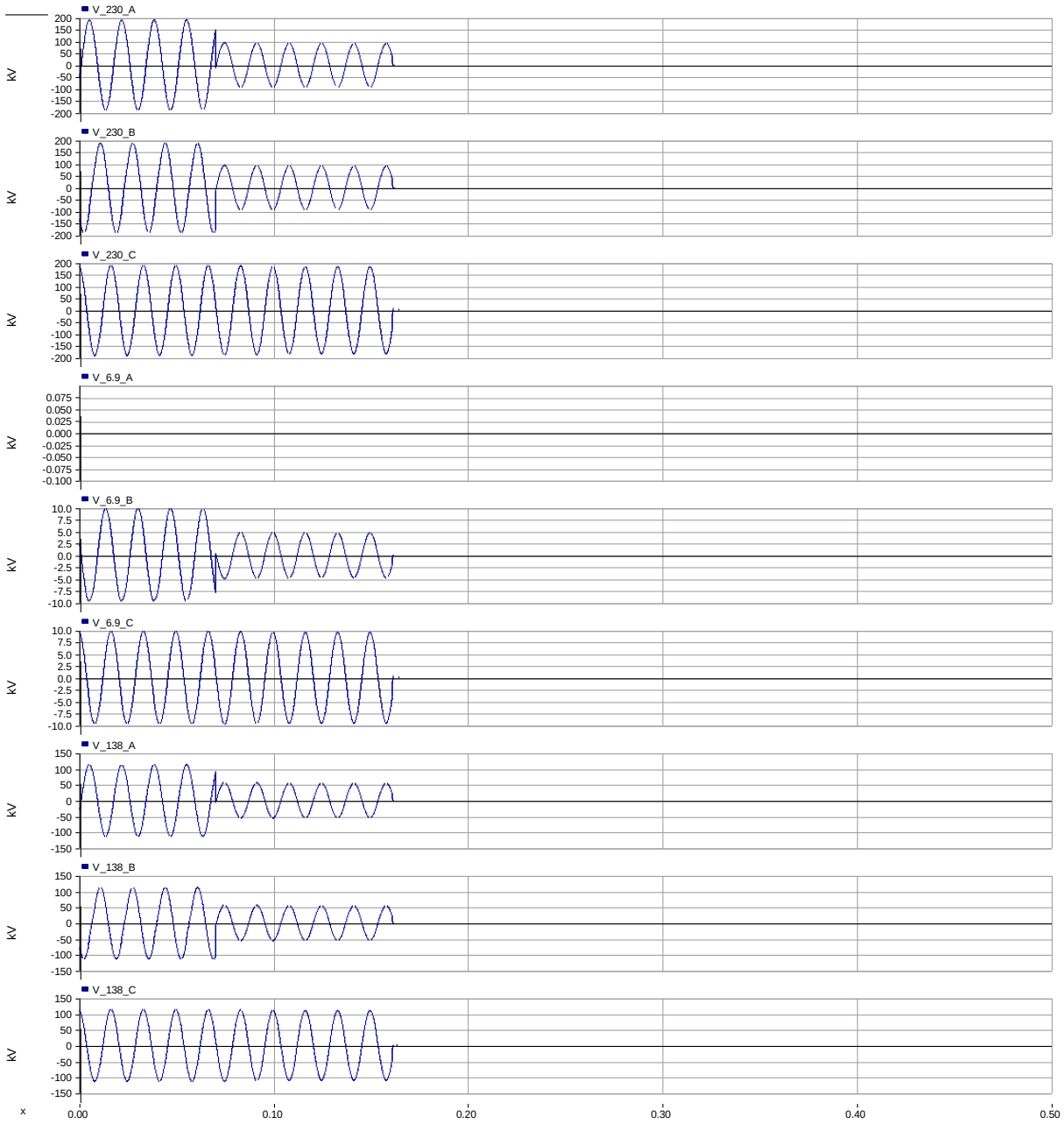

Figure 4-6 T5 Voltages

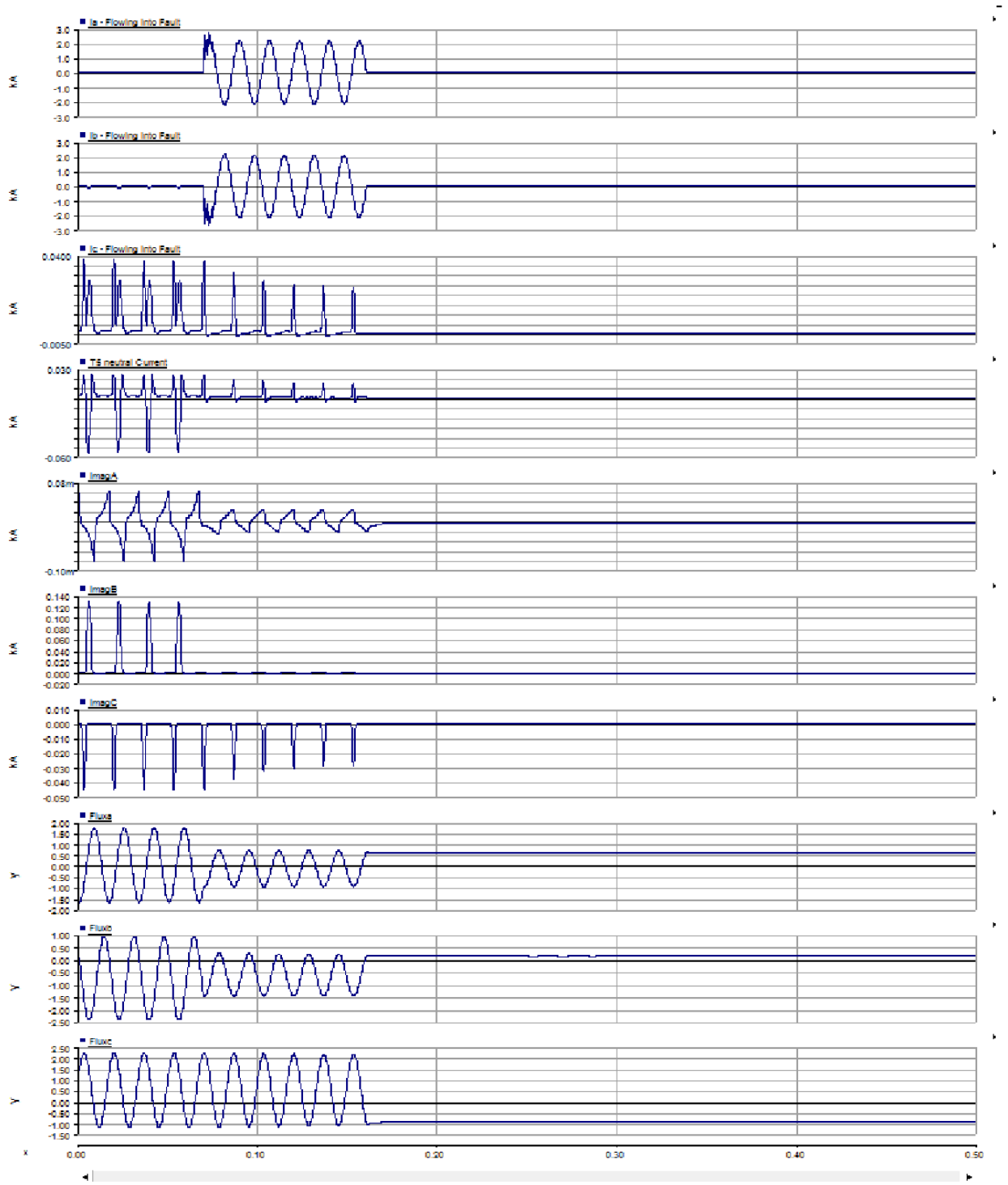

Figure 4-7 T5 Currents and Flux

Referring to the above figures, as the PSCAD model cannot represent a fault on the tap-changer, the fault was applied externally to the transformer as a phase to phase fault. This did show that 2 KA fault current in a and b phase windings.

A harmonic analysis was performed on the 230kV ac voltage just prior to the trip and there was approximately a 2.5% 2nd harmonic voltage distortion present, which is due to the energizing of the transformer. No other major harmonics were present.

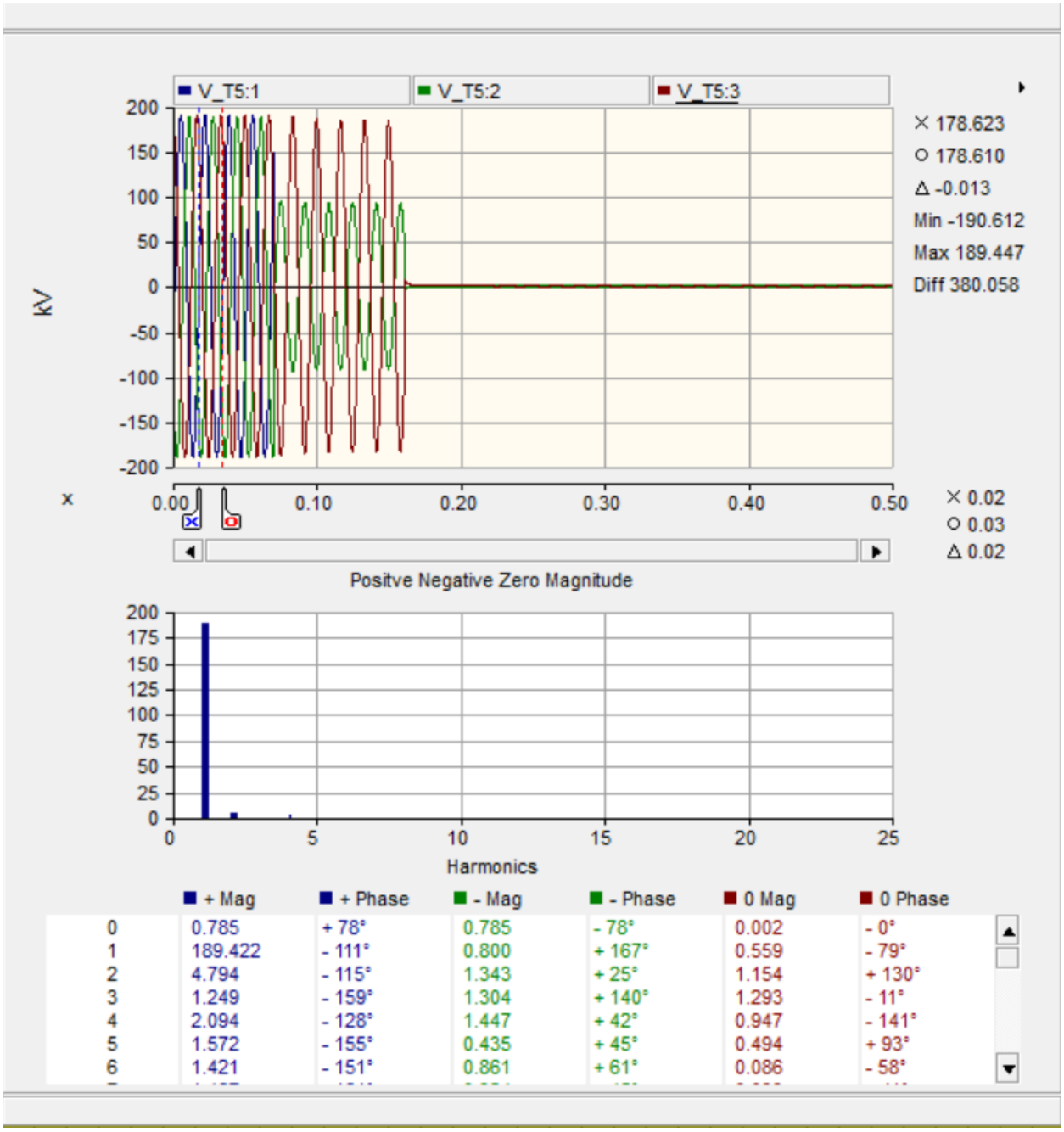

Figure 4-8 FFT of 230kV ac voltage

4.2 Harmonic Impedance Scan

In order to determine if there was a potential for a harmonic impedance resonance, a harmonic impedance scan was performed at three intervals:

1. At the Western Avalon bus just after connecting line TL237
2. At the Western Avalon bus just after connecting line TL237 and T5 transformer
3. Impedance as seen from the 138kV side of the T5 transformer looking towards the Western Avalon 230kV bus.

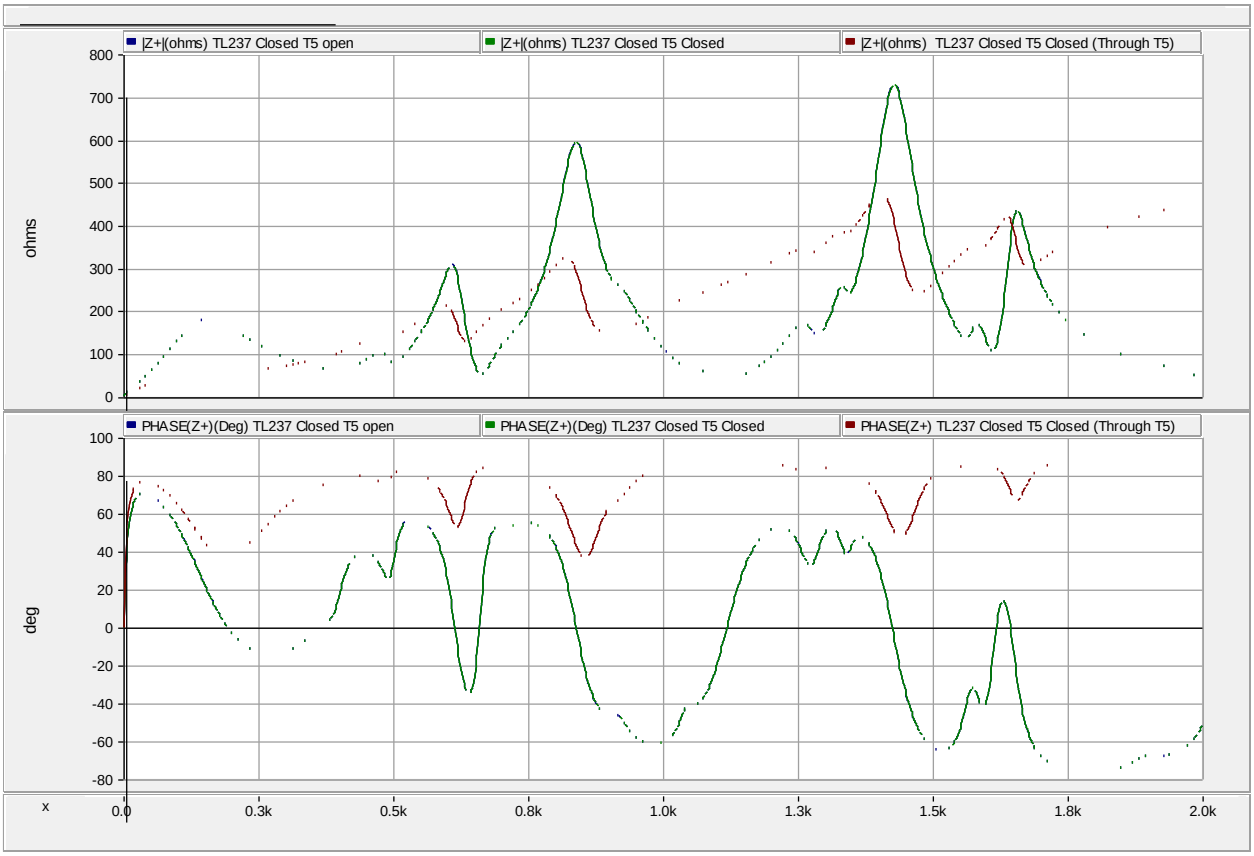

Figure 4-9 Harmonic Impedances as seen from WAV bus

Referring to figure 4-9, there is negligible differences in the impedance when both line TL237 and T5 are connected compared to when just line TL237 is connected. For these cases, there are some resonant cases around 189Hz and 383Hz, but are away from the areas of concern. If we look at the impedance through the T5 unit, we see there are no resonances for this case.

5. Conclusions and Recommendations

Although the simulation did not reproduce the exact fault, a comparable one was simulated. The simulations do not point to an exact failure cause, but the simulations have shown that energizing 2 phases on the transformer numerous times before energizing all three phases does produce some remnant flux and an unbalanced loading on the transformer that could have contributed to the failure.

TGS recommended that once more details are available about the actual fault of the transformer, that the model be updated and simulations rerun to recreate what happened. This new information will give further confidence in the developed model and allow for future studies to be done either as a system strengthening exercise or for a post-mortem on future faults.