WAPA COTP Series Capacitor Bank Replacement

EMTP Study

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Protection

- Background & Objective:

- The California Oregon Transmission Project (COTP) Capacitor Replacement Project (the "Project") is being implemented because the fixed series capacitor banks (FSCB) on the COTP are fast approaching their 30-year operational life.
- The Project will install a new set of modern fixed series capacitors, associated relays and equipment, including the motor-operated disconnects (MOD).
- It will replace all the existing 525 kV FSCB with new but the same identical capacitor sizes, ratings, two-switching step or segment configuration and maintain the same line series compensation level as the existing one.

System Model:

The 340-mile 525-kV transmission system that will be represented in the EMTP model will consist of the boundary equivalent 525-kV WAPA lines from Tracy – Olinda North. Tracy-Maxwell-Olinda line section is modeled in detail using EMTP's frequency dependent line model option. At a later point in time the system from Tracy to Los Banos and Tracy to Tesla and Olinda to Captain Jack will be modeled using the frequency dependent line re-build option. Bus work at Tracy and Olinda will be modeled.

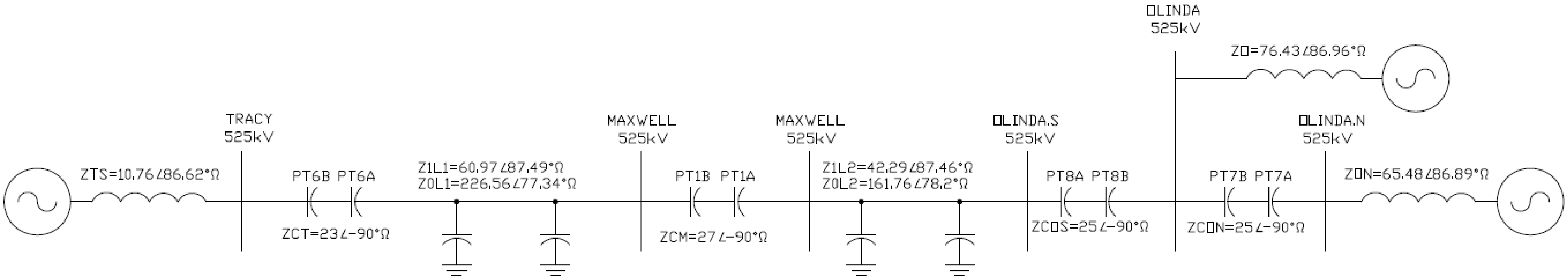


Figure 1: System Boundary Equivalent

Purpose of EMTP Simulation:

The EMTP study will have simulations run to determine the energy requirements for the MOV protective devices across the series capacitors at Tracy, Maxwell, and Olinda substations.

The basis for selecting the MOV shall have adequate capability to avoid by-passing the MOV for all external faults with fault durations of 5 cycles or less, also the series capacitors shall not be by-passed during maximum swing current conditions and the protective level of the MOV shall not exceed 2.2 per unit.

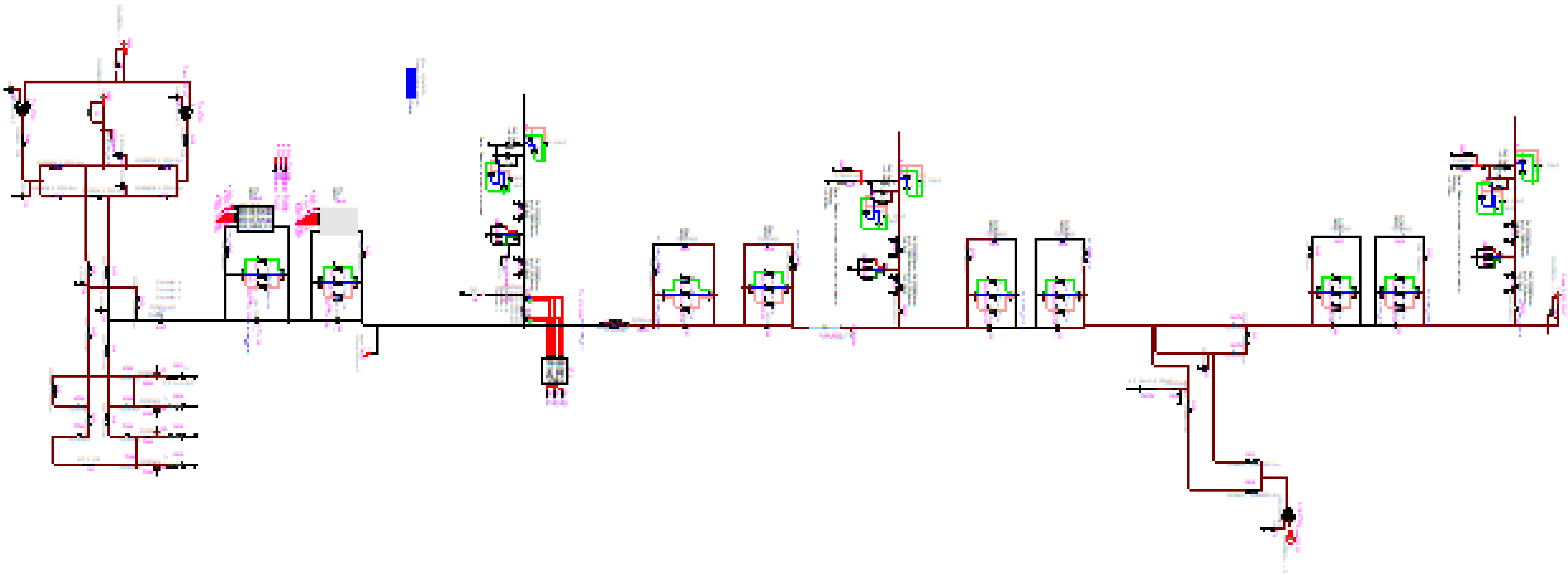


Figure 2: EMTP System Boundary Equivalent Model

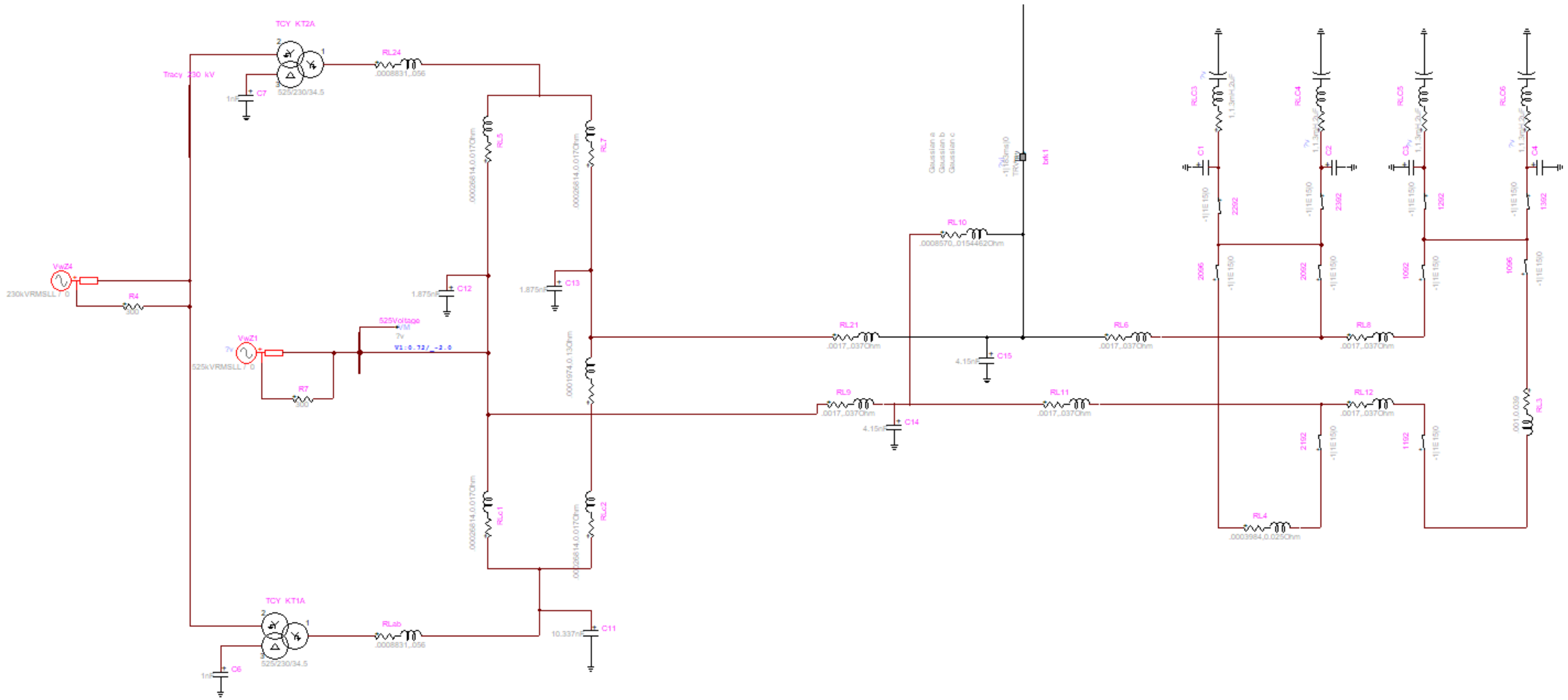


Figure 3: Tracy Substation modeled in EMTP:

Stray Capacitance Approximation

Table 1: Stray Capacitance Values used in model from tables in Annex B of IEEE C37.011-2019

Location		Steam Turbine (pf)	Surge Arrester (pf)	Outdoor Bushing (pf)	Instrument XFMR (pf)	CCVT (pf)	BUS (pf)	Circuit Breaker (pf)	Disconnect Switches (pf)	Misc (pf)	XFMR			Total (pf)	Total (nf)
A2	VT1A-JT3A,B	0	0	150	600	5825	3537	175	300	50	0			10,637	10.637
B2	VT2A-JT4A,B	0	0	150	600	5825	3537	175	300	50	0			10,637	10.637
A3	JT3A-JT4A	0	0	150	300	0	900	175	300	50	0			1,875	1.875
B3	JT3B-JT4B	0	0	150	300	0	900	175	300	50	0			1,875	1.875
A4	Bus-Breaker	0	0	300	600	0	2700	250	250	50	0			4,150	4.15
B4	Bus-Breaker	0	0	300	600	0	2700	250	250	50	0			4,150	4.15
5	JT6B-JT6C	0	100	600	300	5825	900	1400	1200	150	0			10,475	10.475
6	JT6C-VT6A	0	100	600	300	5825	900	1400	1200	150	0			10,475	10.475

Moving North from Tracy along Tracy to Maxwell is the Line Breaker and Series Capacitor Bank.

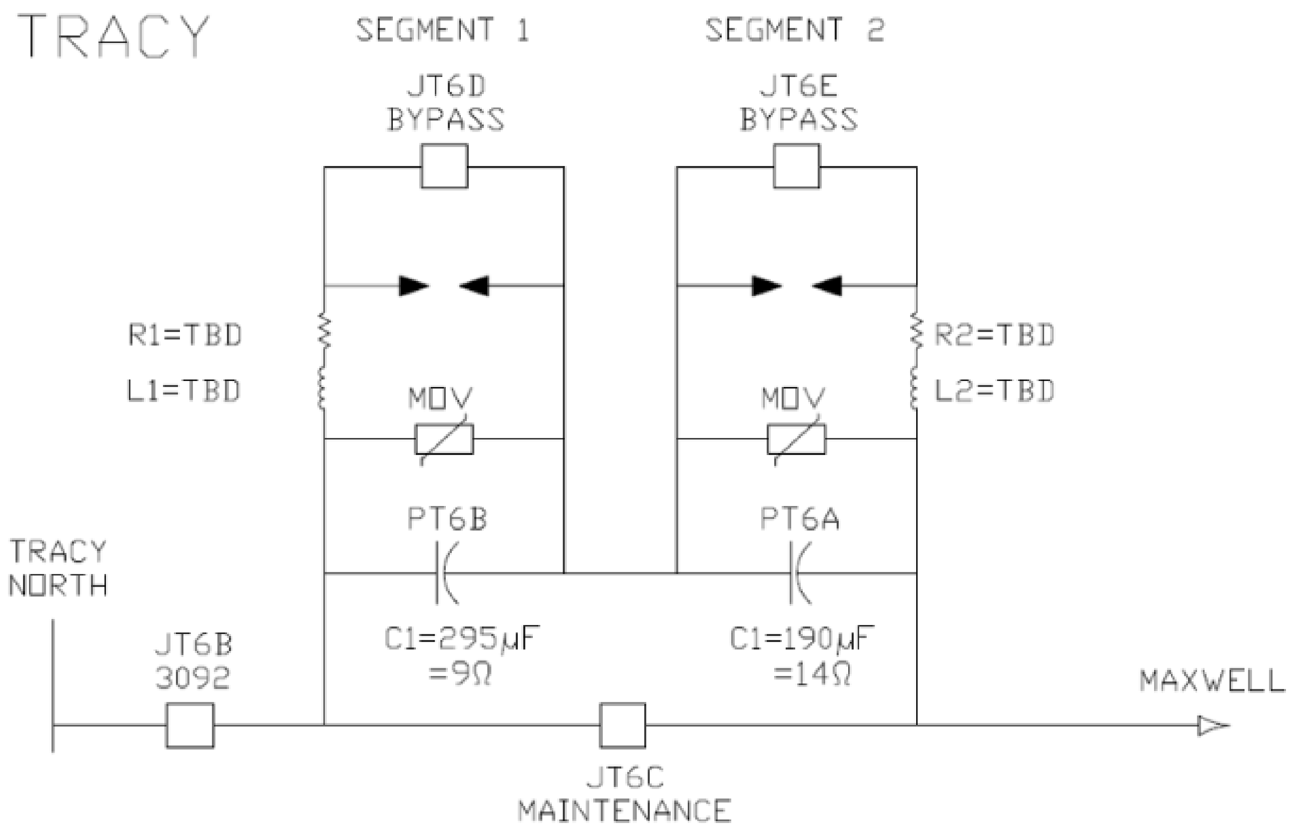


Figure 4: Tracy Series Capacitor Bank diagram:

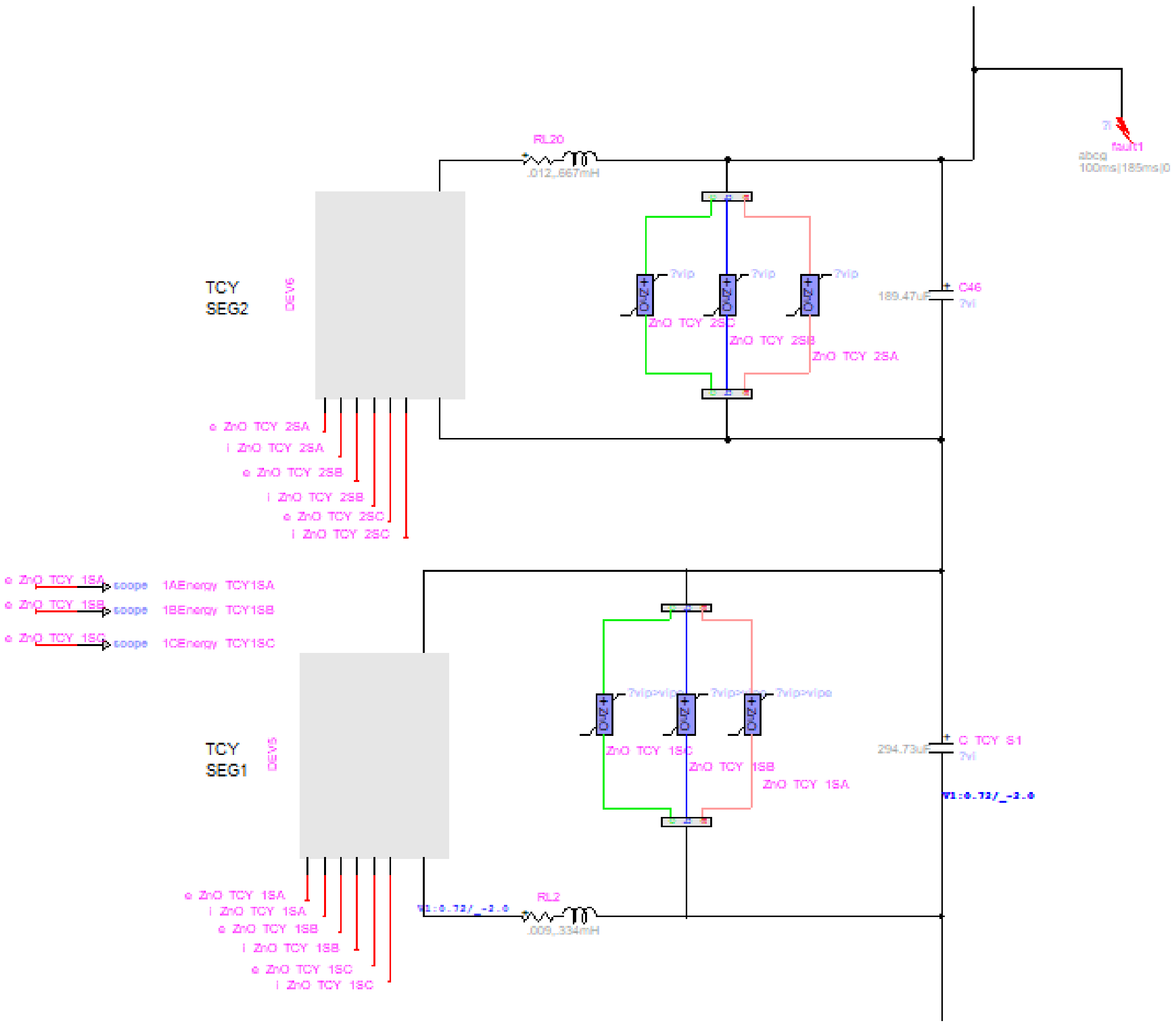


Figure 5: Tracy Series Capacitor Bank EMTP model:

Table 2: Manufacture Provided MOV VI curves

Total Varistor Current Apk	Tracy #1 (PT6B) Varistor Voltage kV pk	Tracy #2 (PT6A) Varistor Voltage kV pk	Maxwell #1 (PT1A) Varistor Voltage kV pk	Maxwell #2 (PT1B) Varistor Voltage kV pk	Olinda S. #1 (PT8B) Varistor Voltage kV pk	Olinda S. #2 (PT8A) Varistor Voltage kV pk	Olinda N. #1 (PT7A) Varistor Voltage kV pk	Olinda N. #2 (PT7B) Varistor Voltage kV pk
200	70.07	108.27	71.54	137.08	70.54	122.02	64.01	115.44
300	70.45	108.85	71.99	137.94	70.94	122.70	64.36	116.08
400	70.72	109.28	72.32	138.61	71.22	123.21	64.62	116.54
500	70.94	109.61	72.59	139.13	71.46	123.63	64.82	116.94
750	71.35	110.24	73.08	140.13	71.91	124.41	65.23	117.67
1000	71.66	110.73	73.47	140.86	72.23	124.98	65.52	118.20
1500	72.11	111.43	74.01	142.13	72.72	125.83	65.95	119.00
2000	72.45	111.95	74.55	143.20	73.08	126.46	66.27	119.58
3000	72.95	112.71	75.36	144.79	73.62	127.40	66.75	120.46
4000	73.32	113.28	75.96	146.01	74.00	128.14	67.10	121.10
5000	73.62	113.75	76.45	146.97	74.41	128.87	67.40	121.77
7500	74.21	114.66	77.36	148.73	75.21	130.27	68.10	123.07
10000	74.76	115.50	78.02	150.02	75.80	131.32	68.64	124.04
15000	75.58	116.78	78.99	152.05	76.70	132.89	69.43	125.51
20000	76.20	117.73	79.80	153.71	77.35	134.01	70.02	126.57
30000	77.11	119.13	81.07	156.34	78.28	135.64	70.86	128.09
40000	77.77	120.14	82.08	158.42	78.98	136.89	71.47	129.23
50000	78.28	120.94	82.93	160.09	79.59	137.99	71.98	130.24

Segment 1 Ratings:

$I_{RATED} := 2850\ A$ Arms

$V_{RATED} := (I_{RATED} \cdot 9\ \Omega) = (25.65 \cdot 10^3)\ V$ Vrms

$V_{CREST} := V_{RATED} \cdot \sqrt{2} = (36.275 \cdot 10^3)\ V$ Vpeak

$MCOV := 1.1 \cdot V_{RATED} = (28.215 \cdot 10^3)\ V$ Maximum Continuous Operating Voltage

$MCOV_{Peak} := MCOV \cdot \sqrt{2} = (39.902 \cdot 10^3)\ V$

$PLV := V_{CREST} \cdot 2.2 = (79.804 \cdot 10^3)\ V$ Protective Level

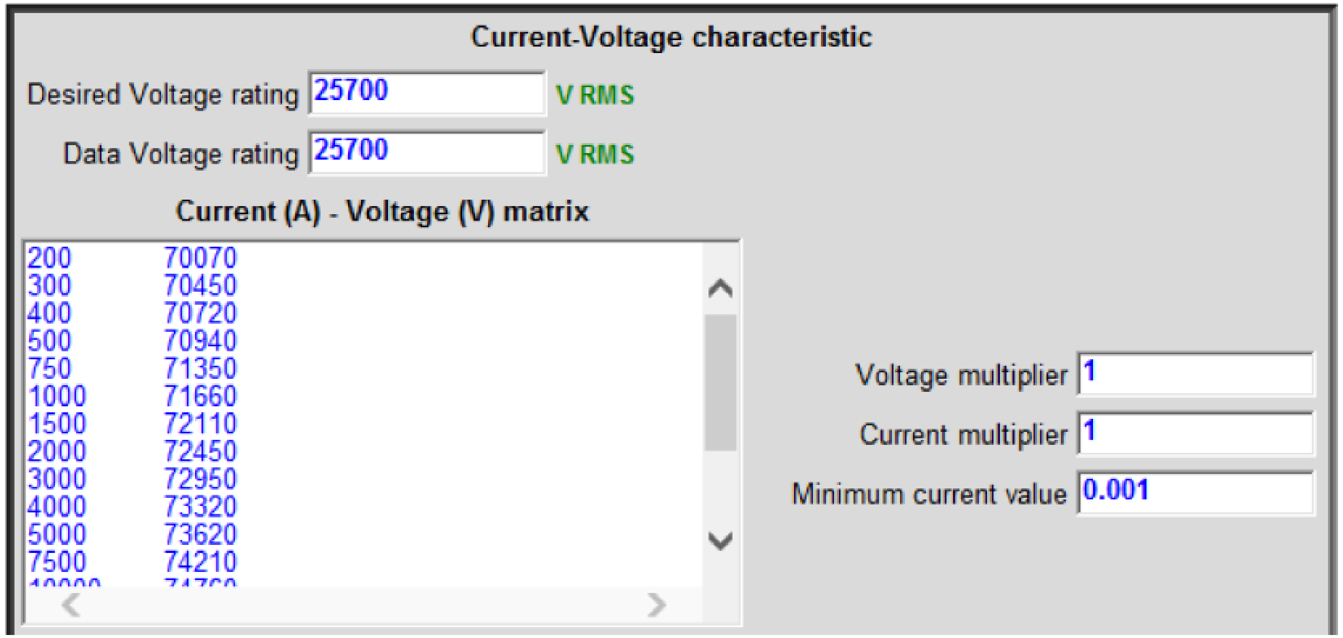
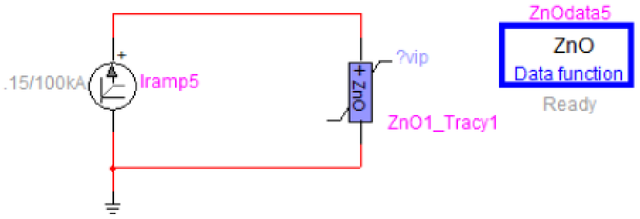
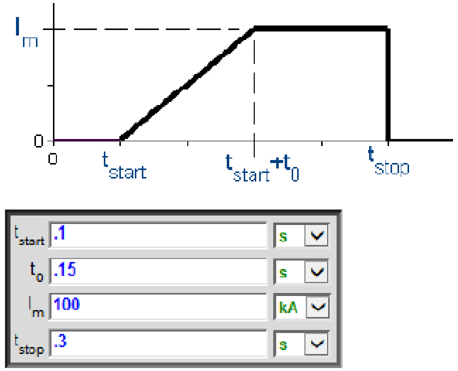
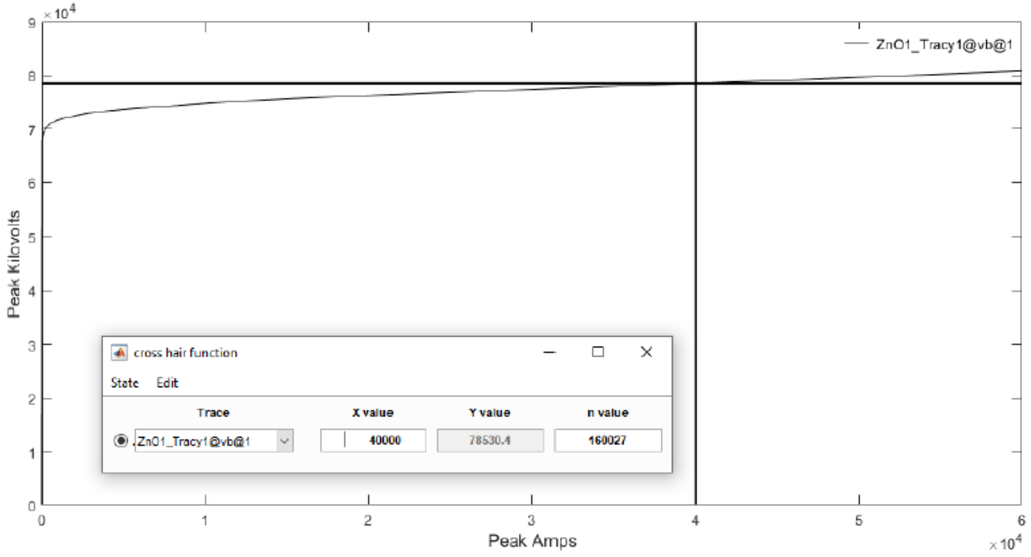


Figure 6: VI input for EMTP's ZnO Data Funtion tool

Below is the EMTP test circuit that was used to compare EMTP’s modeled arrestor with manufactures MOV VI values. The curve below in figure 4 shows that EMTP’s model is within an acceptable range.







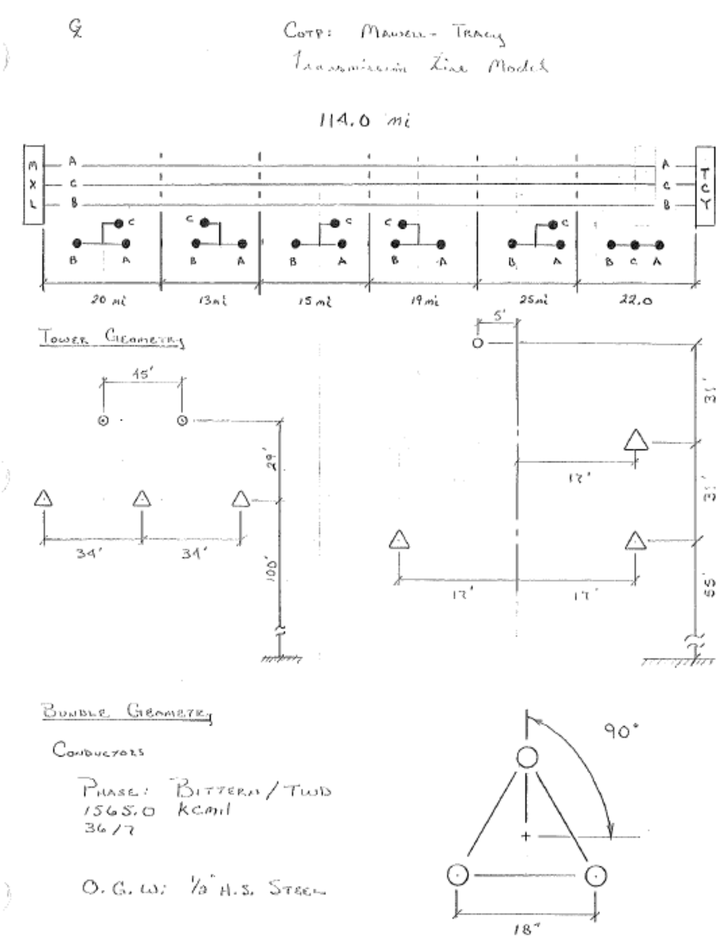
$v_A := 77770\ kV$ GE MOV kV @ 40kA

$v_E := 78530\ kV$ EMTP Simulation kV@ 40kA

$$\delta := \left|\frac{v_A - v_E}{v_E}\right| = 0.968\%$$ Percent Error

Figure 7: Zno Test Circuit and MPLOT Verification

Line Modeling Using Standard Conductor Data:



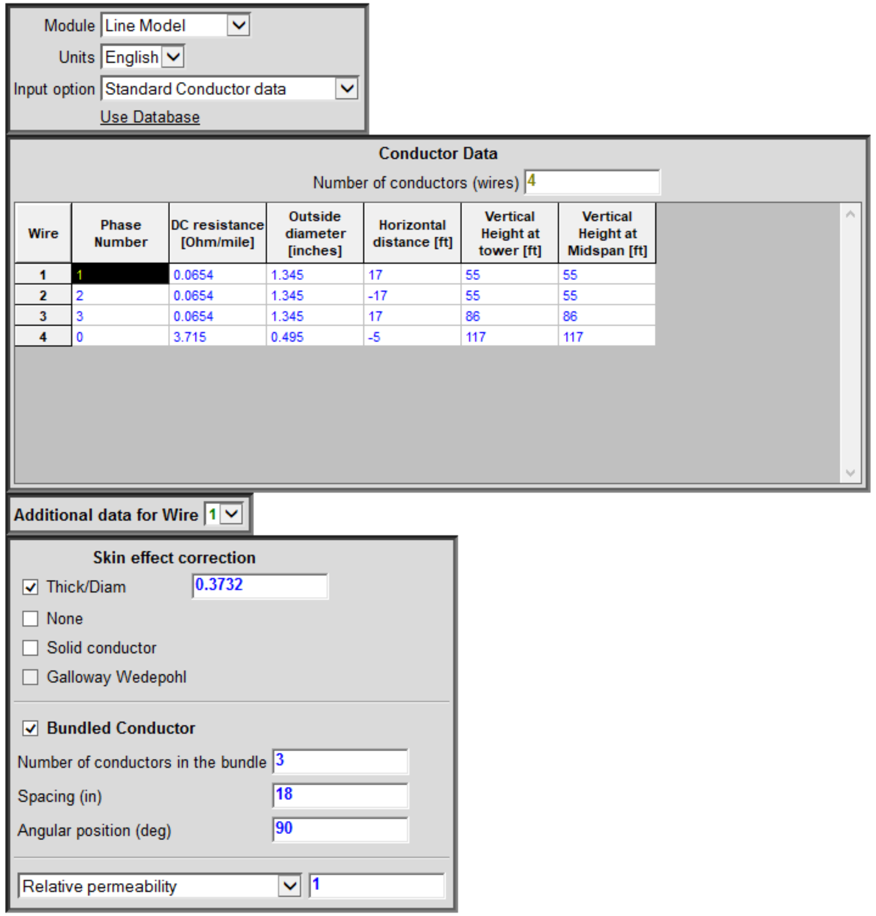


Figure 8: Archived Tower Geometry and EMTP's Line Data Tool

Line Modeling Using EMTP's Line Rebuild Tool.

					section length (miles)
	Enter ASPEN data in per unit, 100 MVA base:				
sec 1	R1 =	0.00001	X1 =	0.00023	1.192
	R0 =	0.00018	X0 =	0.00086	
sec 2	R1 =	0.00074	X1 =	0.01675	87.247
	R0 =	0.01311	X0 =	0.06276	
sec 3	R1 =	0.00019	X1 =	0.00452	22.703
	R0 =	0.00415	X0 =	0.01476	
sec 4	R1 =	0.00003	X1 =	0.00060	3.026
	R0 =	0.00058	X0 =	0.00182	
sec 5	R1 =		X1 =		
	R0 =		X0 =		
TOTAL	R1 =	0.00097	X1 =	0.02210	114.168
	R0 =	0.01802	X0 =	0.08020	

	p.u. per mile at each end			
B1 =	1.3366E-03	B2 =	1.3366E-03	(Y/2)
B10 =	8.8300E-04	B20 =	8.8300E-04	(Y/2)
	p.u. total at each end			
B1 =	1.5260E-01	B2 =	1.5260E-01	(Y/2)
B10 =	1.0081E-01	B20 =	1.0081E-01	(Y/2)

calculated primary values in ohms			
R1 =	2.67356	X1 =	60.91313
R0 =	49.66763	X0 =	221.05125
calculated primary values in ohms/mile			
R1 =	2.24292	X1 =	51.10161
R0 =	41.66747	X0 =	185.44568
calculated ohms/mile and mH/mile at 60 Hz			
	Ω/mile		mH/mile
R0 =	41.66747	X0 =	491.90994
R1 =	2.24292	X1 =	135.55124
line length =	114.168		

Conductor Data	
Number of Phases	3
R zero sequence [Ohm/mile]	41.66747
L zero sequence [mH/mile]	491.90994
G zero sequence [S/mile]	0
C zero sequence [microF/mile]	1.6278E-01
R positive sequence [Ohm/mile]	2.24292
L positive sequence [mH/mile]	135.55124
G positive sequence [S/mile]	0
C positive sequence [microF/mile	2.4641E-01
Frequency [Hz]	60
DC resistance [Ohms/mile]	0.0000

records for tweaking

tweak		1.0000	1.0000
	ASPEN	EMTP	% error
R1	**2.674**	2.81	5.10
X1	**60.913**	61.45	0.88
R0	**49.668**	35.93	27.66
X0	**221.051**	237.87	7.61
total % error			41.25

shunt admittance in per unit (Y/2)					
B10 =	1.0081E-01	B20 =	1.0081E-01		
B1 =	1.5260E-01	B2 =	1.5260E-01		
calculated primary values in Siemens (mhos)					
B10 =	3.6575E-05	B20 =	3.6575E-05		
B1 =	5.5365E-05	B2 =	5.5365E-05		
Siemens (mhos)/mile					
B10 =	3.0684E-05	B20 =	3.0684E-05		
B1 =	4.6447E-05	B2 =	4.6447E-05		
calculated values in uF/mile					
B10 =	8.1391E-02	B20 =	8.1391E-02		
B1 =	1.2321E-01	B2 =	1.2321E-01		
calculated values in uF/mile				I0 charge	amp/mile
B10 total =	1.6278E-01			22.1724	18.6010
B1 total =	2.4641E-01				
				I1 charge	amp/mile
				33.5633	28.1571

Figure 9: Excel Spread Sheet to go from ASPEN OneLiner to EMTP Line Rebuild

Line Modeling Using Line Rebuild Tool (Cont.):

Module: Line Model
Units: English
Input option: Conductor data for Line Rebuild

Conductor Data

Number of Phases	3
R zero sequence [Ohm/mile]	41.667
L zero sequence [mH/mile]	491.90994
G zero sequence [S/mile]	0
C zero sequence [microF/mile]	1.6278E-0
R positive sequence [Ohm/mile]	2.24292
L positive sequence [mH/mile]	135.55121
G positive sequence [S/mile]	0
C positive sequence [microF/mile]	2.4641E-0
Frequency [Hz]	60
DC resistance [Ohm/mile]	0.0

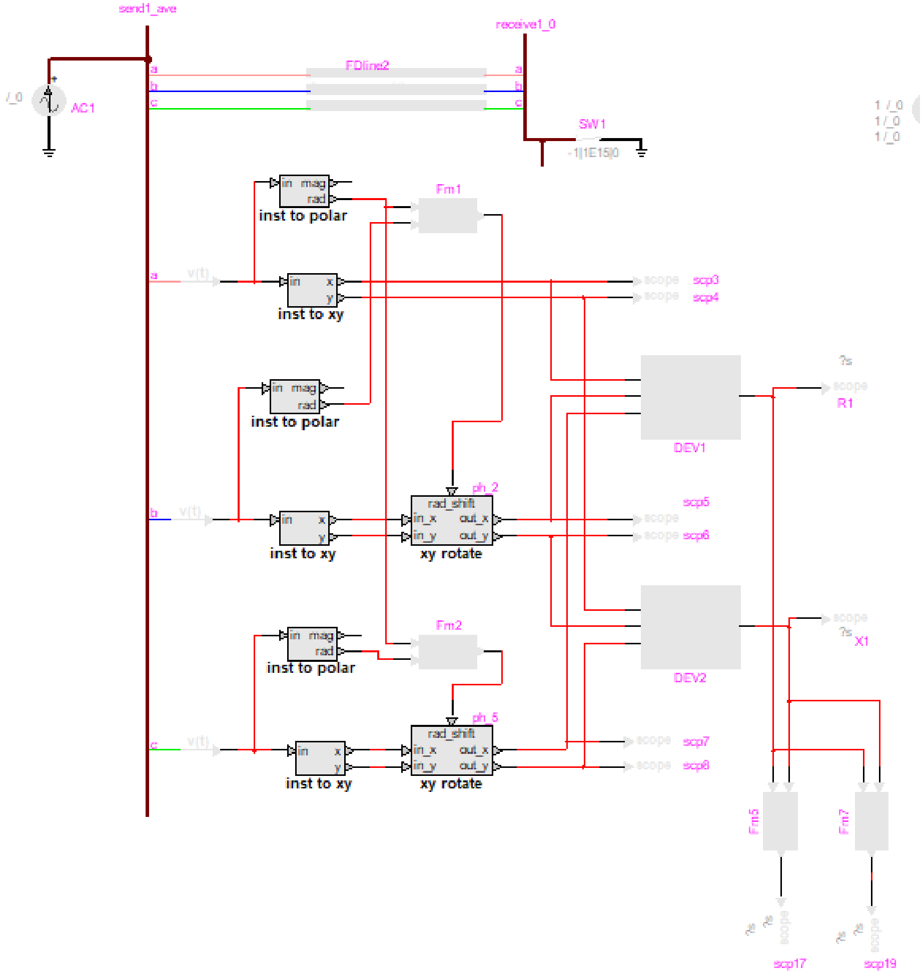


Figure 10: Line Rebuild input and WAPA's test circuit

MOV Energy dissipation:

Below is the method for obtaining the duty cycle and maximum continuous operating voltage of a surge arrester that will withstand a continuous voltage corresponding to the 4,300 Amps 30 minute rating of the capacitor bank:

$I_{E\_TCY\_1} := 4300\ A$ Emergency Rating of Tracy Segment 1 Capacitor Bank

$V_{TCY\_1\_MCOV} := I_{E\_TCY\_1} \cdot 9\ \Omega = \left(38.7 \cdot 10^3\right)\ V$

The corresponding MCOV at 38.7-kV from Table 1 of ANSI C62.11 is 39-kV with a duty cycle of 48-kV. This rating matches the existing MOV, therefore the existing MOV VI curve provided by GE was used as a starting point in the EMTP simulation to find the energy dissipated during various faults. The main 2 faults of concern are an internal line fault and and external line fault. If the fault occurs within the section of transmission line where the series cap is located, it is referred to as an internal fault. Anywhere the fault occurs outside of that is an external fault. An internal fault would result in fast or instantaneous clearing time and an external fault in COTP’s case will also have high-speed tripping 5 cycles.

External 3 phase to ground fault 5 cycles (83 ms) on Tracy - Maxwell 525-kV transmission line. Bypass breaker logic disabled. The case simulated is an external fault on the Line side of the Tracy series capacitor bank. All COTP series caps are included and the COTP reactor banks are excluded.

Fault occurs at 100ms
Line Breakers clear the fault at 183ms

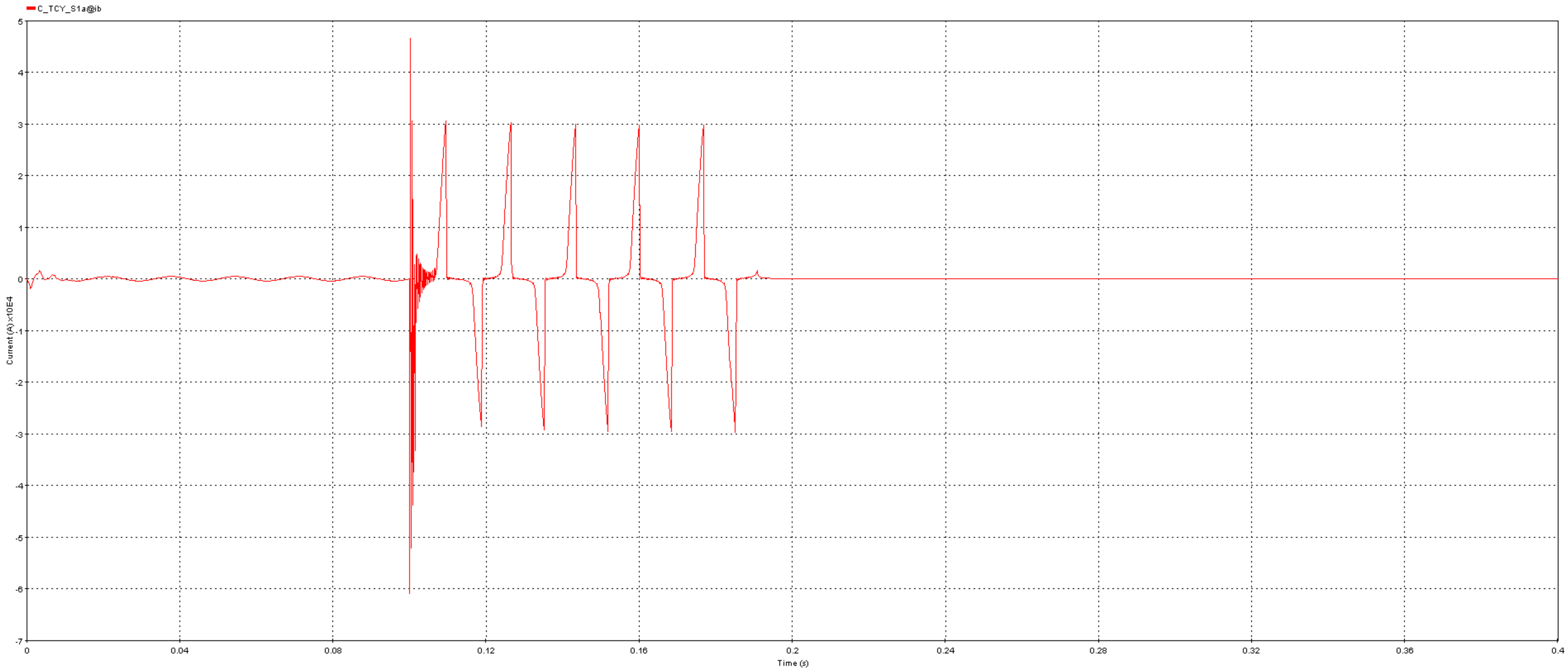


Figure 11: Phase A current through segment 1 of Tracy series capacitor bank

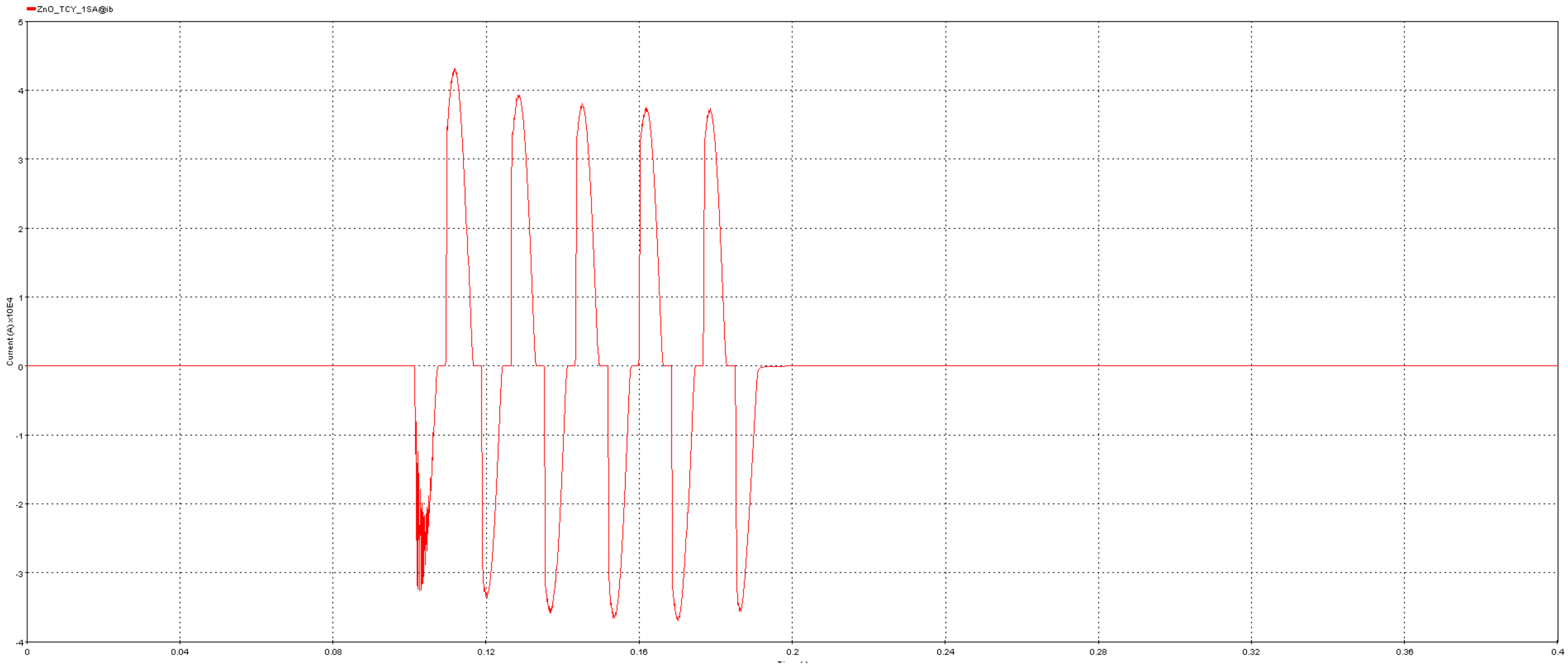


Figure 12: Phase A current through segment 1 of Tracy MOV

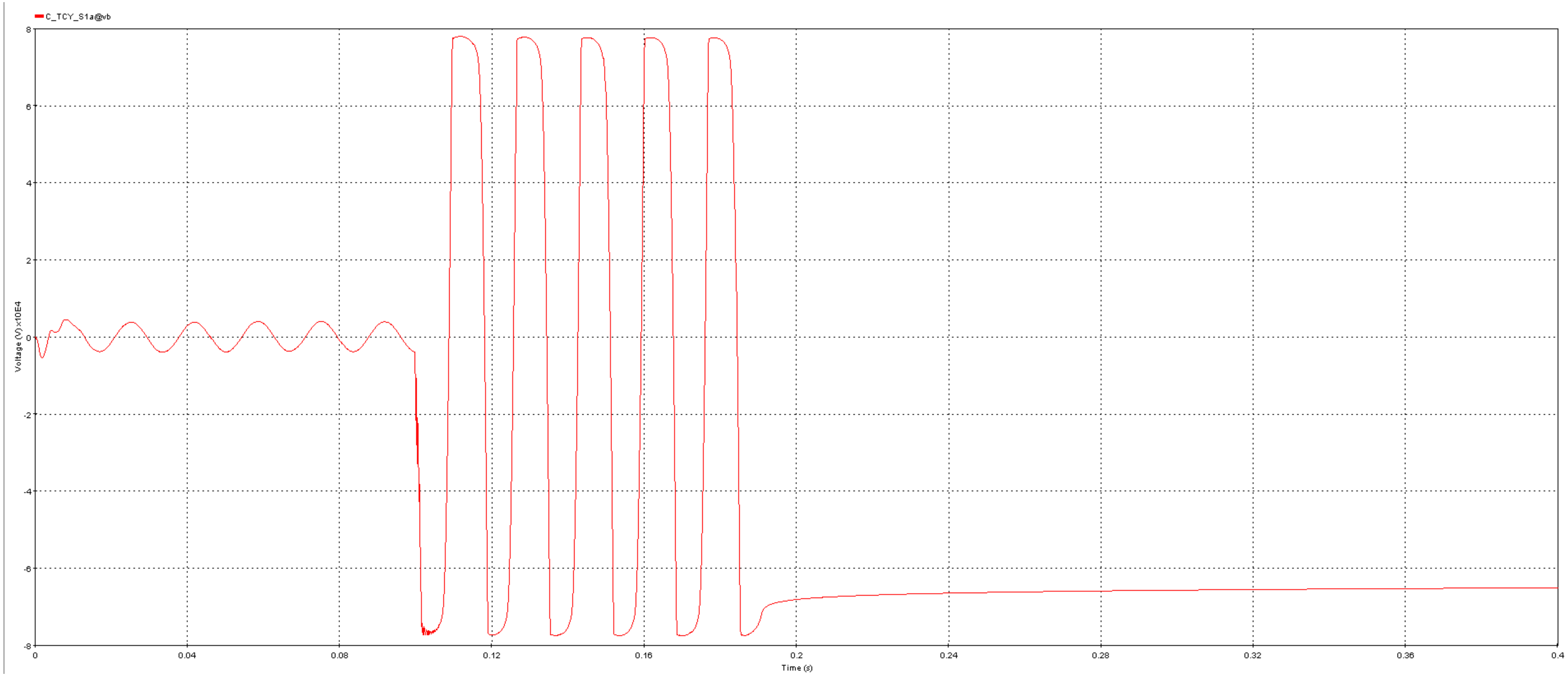


Figure 13: Phase A voltage across segment 1 of Tracy series capacitor bank

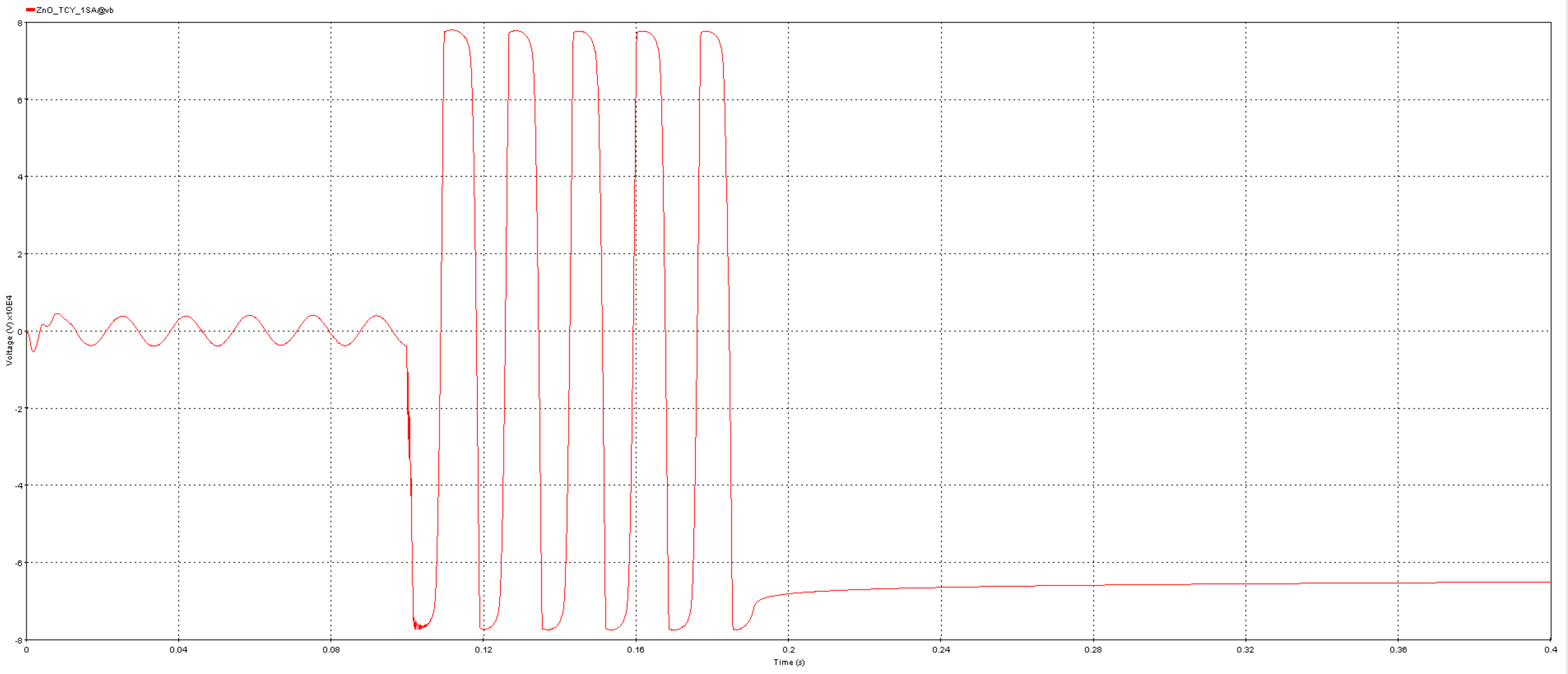


Figure 14: Phase A voltage across segment 1 of Tracy MOV

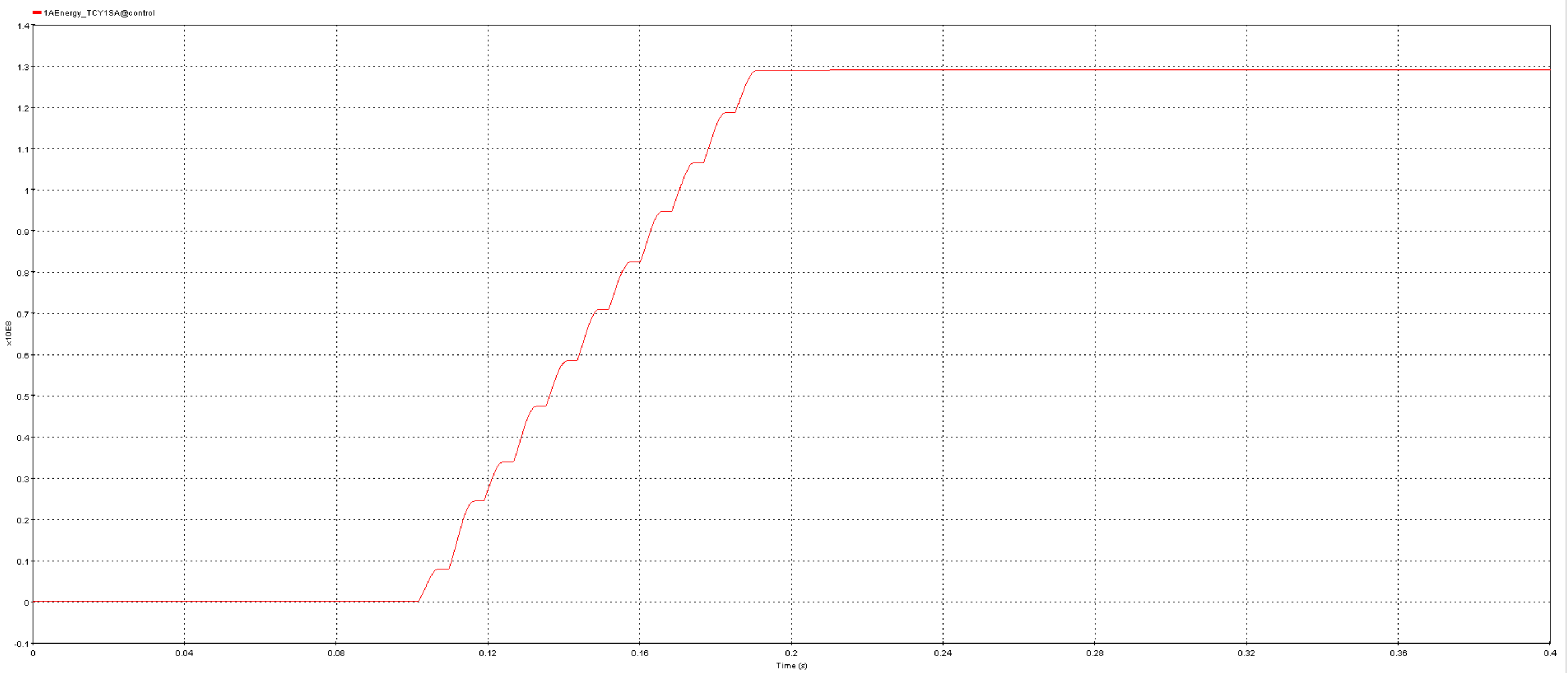
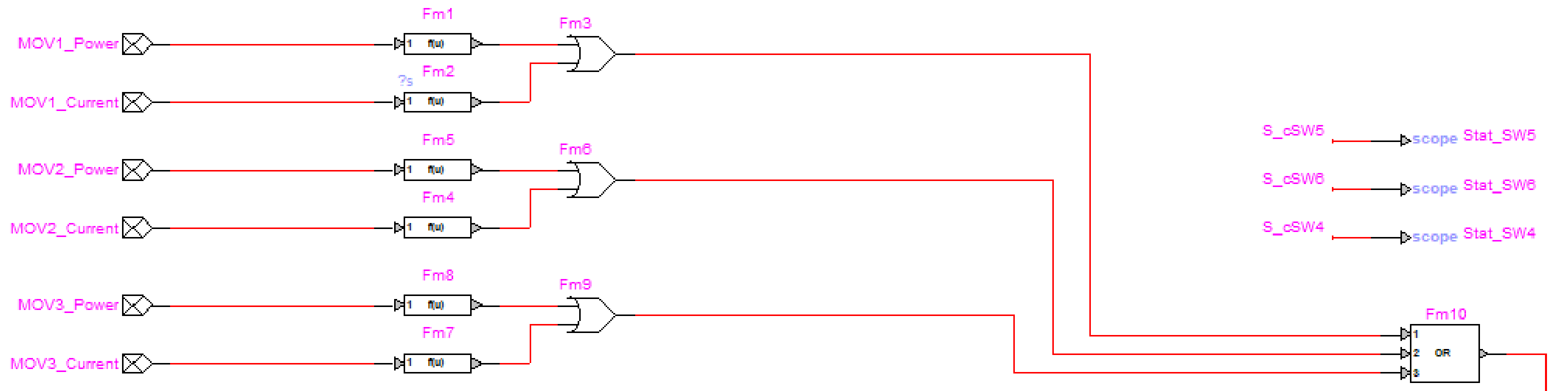


Figure 14: Energy dissipation of segment 1 Tracy MOV Approximately 129MJ

Simulation with Bypass logic enabled



Black box device with scripting

Use Global Data ☐ Update Global Data automatically ☐

Use input grid for Initial Parameters-Values ☑

Initial Parameters-Values: Grid mode input Insert row

	Parameter	Value	Definition/Comments
1	E_Thresh	6E6	Energy (J)
2	I_Thresh	14E3	Current (A)
3			
4			
5			

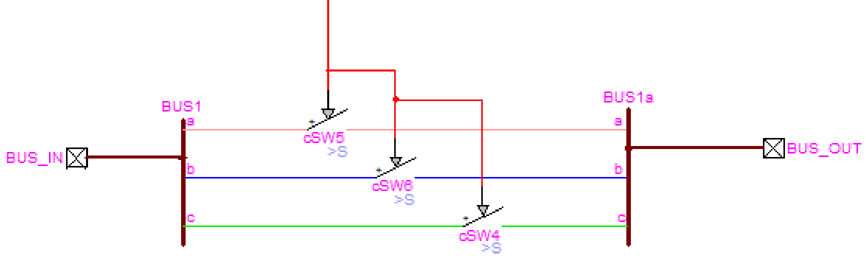


Figure 15: Existing Tracy series capacitor bank protection for triggered air gap & bypass logic

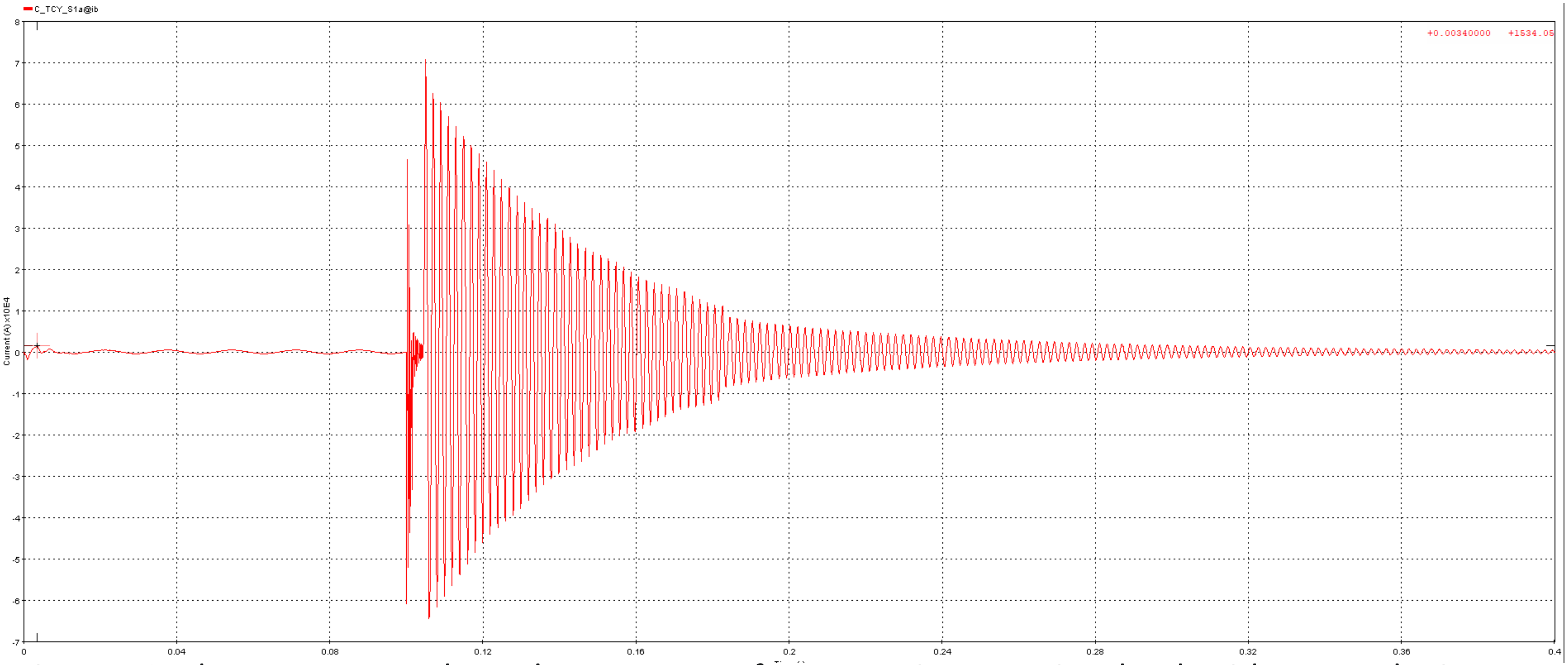


Figure 16: Phase A current through segment 1 of Tracy series capacitor bank with Bypass logic enabled

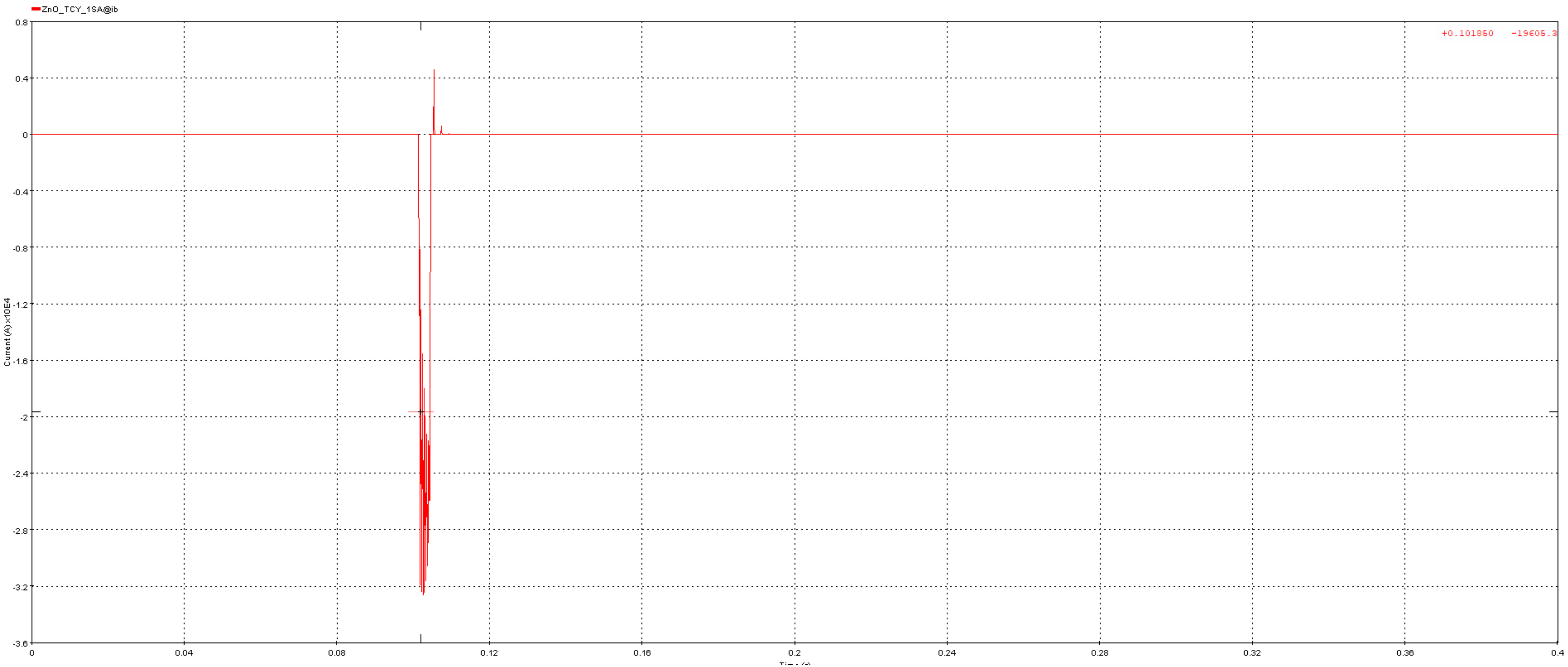


Figure 17: Phase A current through segment 1 of Tracy MOV with Bypass logic enabled

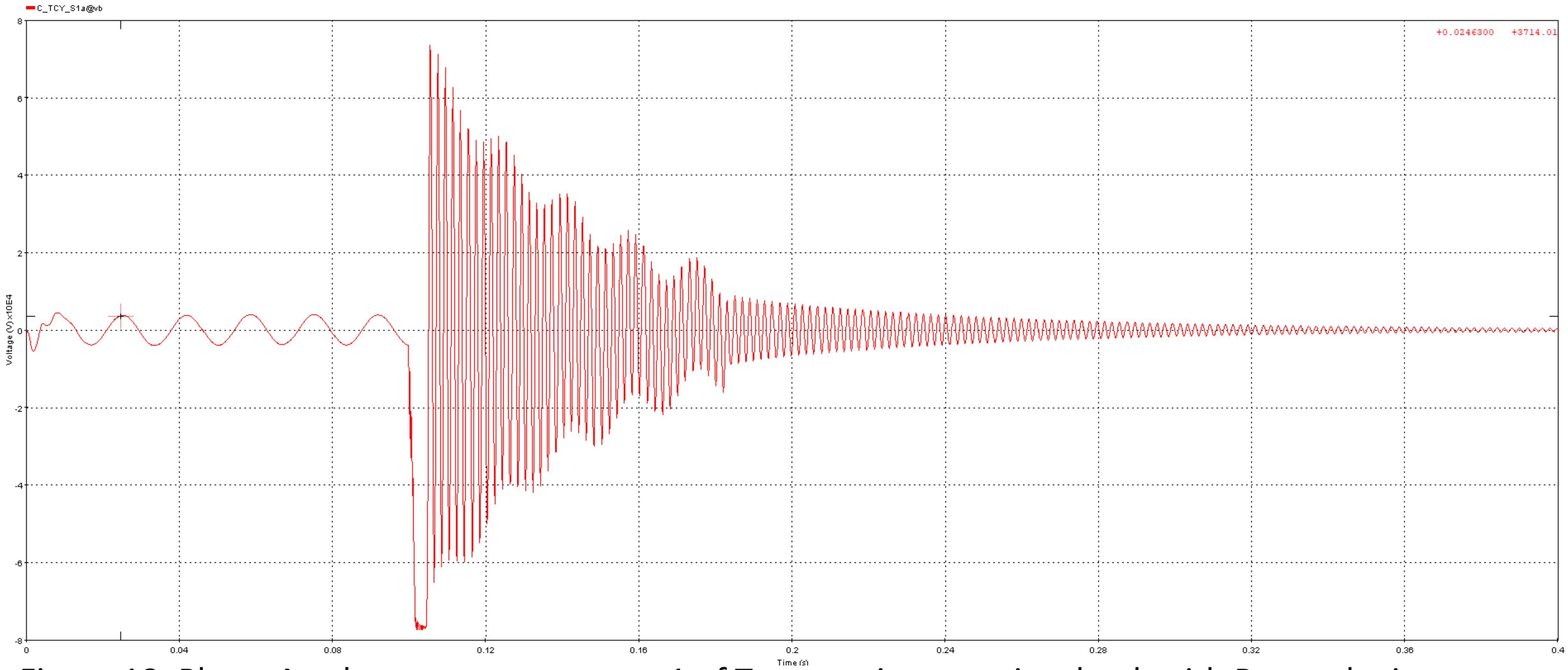


Figure 18: Phase A voltage across segment 1 of Tracy series capacitor bank with Bypass logic enabled

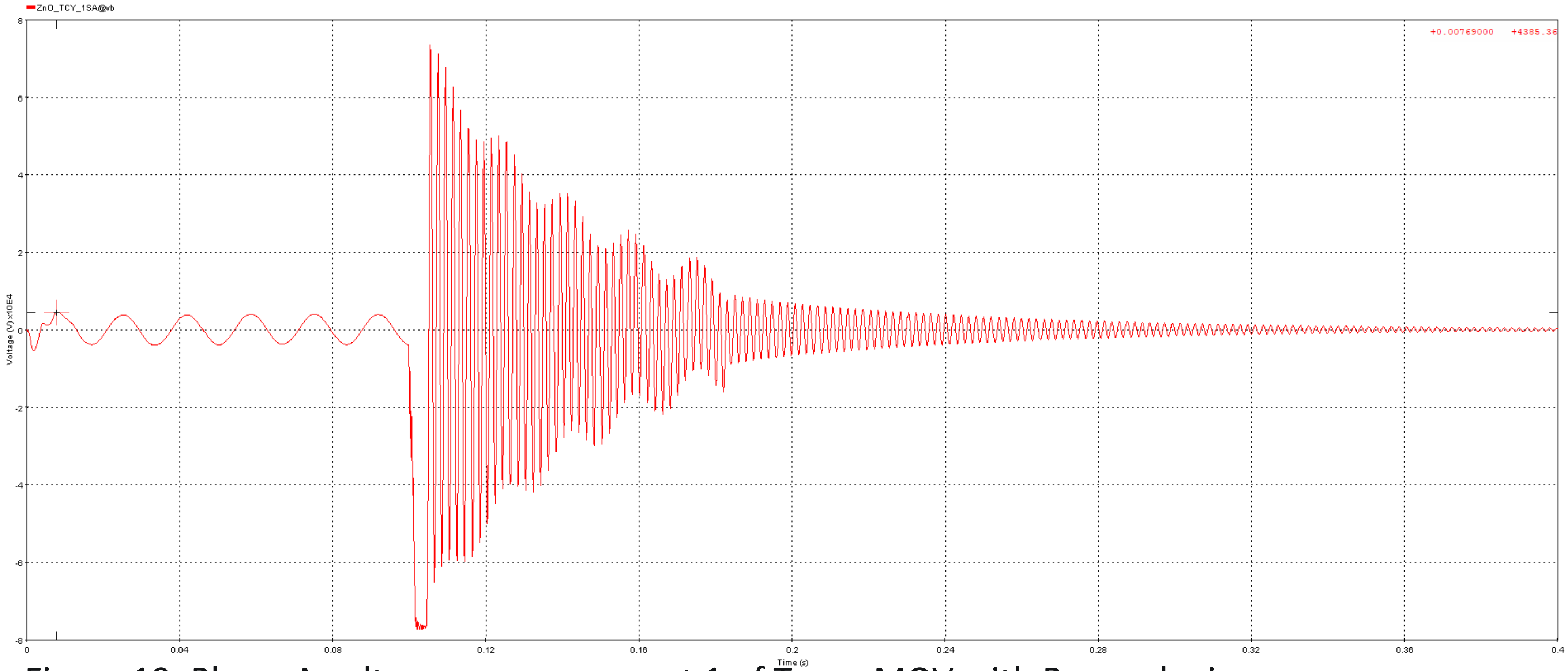


Figure 19: Phase A voltage across segment 1 of Tracy MOV with Bypass logic enabled

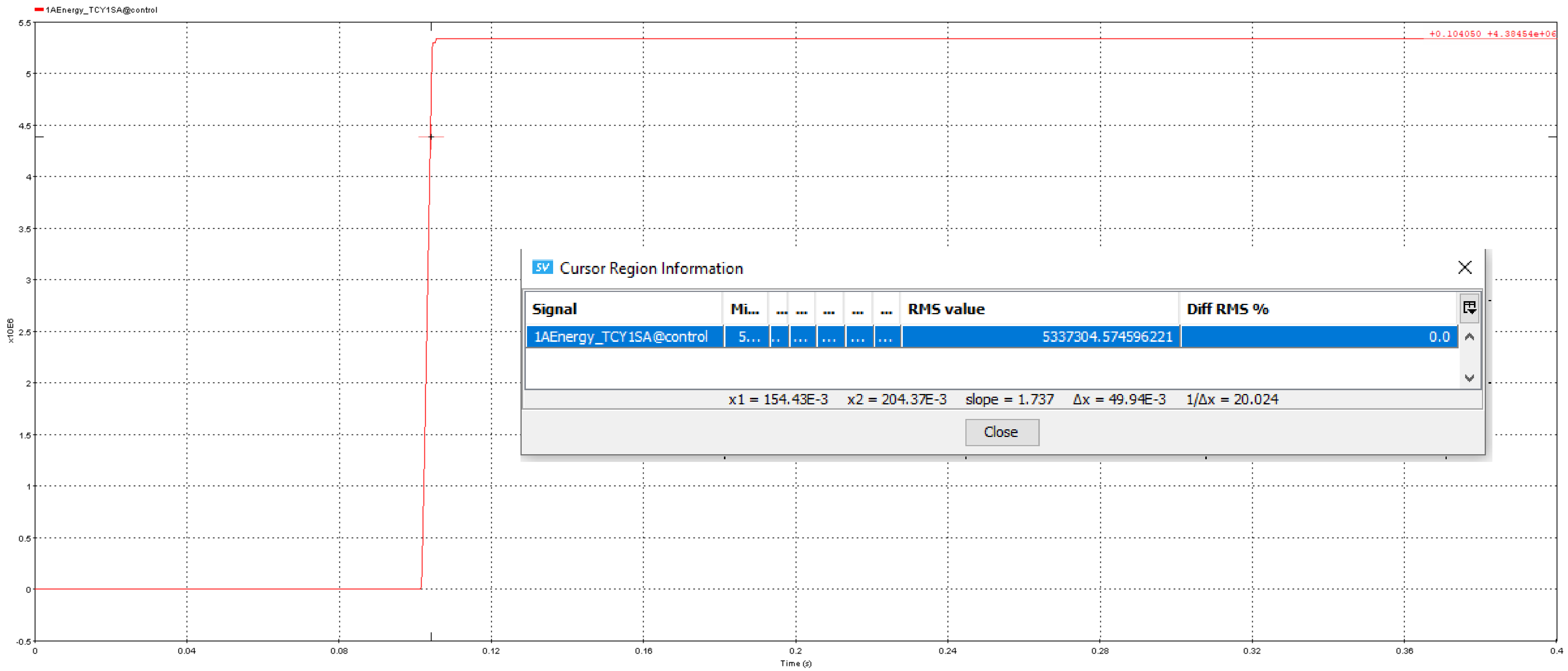


Figure 20: Energy dissipation of segment 1 Tracy MOV Approximately 5.3MJ with bypass logic enabled.

Summary:

- The methods and model presented will be used to evaluate the MOV energy dissipation at the other 3 substation in the WAPA COTP corridor.
- The data obtained will be provided to the manufacture to provide the best fitting MOV and Series CAP protection.

Questions?

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