Draft Technical Memorandum:

PacifiCorp

Montague to Weed

Idle Line Study

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ELECTRANIX

SPECIALISTS IN POWER SYSTEM STUDIES

Background

Electranix is undertaking a study to identify possible wildfire hazards resulting from the magnetic and electric field induction coupling between energized and idle transmission or distribution powerlines. Simulations are being performed to determine the maximum possible fault currents on the idle lines. The results of these simulations may be used to assess the fire probability as well as to validate and optimize the identification and prioritization process.

Modeling

For the analysis of the deenergized idle line from Montague to Weed Junction, we used PSCAD frequency-dependent line models to represent the lines considered for this study. Figure 1 shows an example line topology used for frequency-dependent line model development. A portion of the line between Montague and Weed Junction (STR 5/24) is shown and is modeled as 9 segments. One segment from Montague to STR 24/22 was modeled using Ibis, 397.5 ACSR, for 0.0838 mi and the remaining 1.46621 mi to STR 5/24 was modelled with #2 AWG bare solid copper in 8 segments that are each 0.1833 mi long.

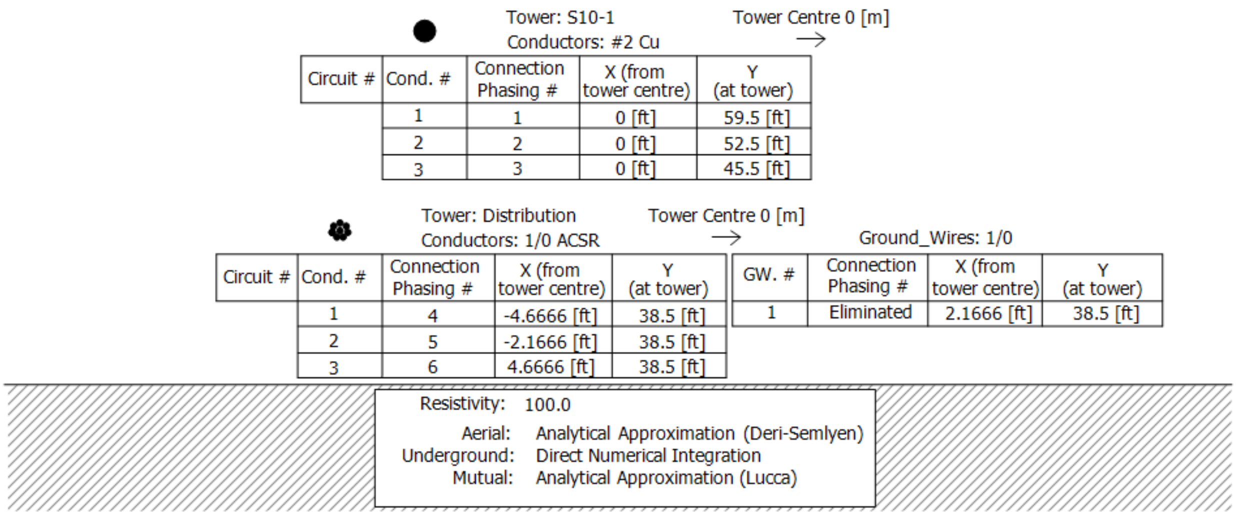


Figure 1 Frequency dependent line model

Validation of the line model: The 60 Hz equivalent impedance R, X and B value given by the PSCAD line models are compared against the Access database parameters values as seen in Table 1. The equivalent impedance R, X and B values from PSCAD are reasonably close to the Access parameters so the line models should be considered an acceptable representation of the lines. The PSCAD models were developed based on provided conductor and tower data.

Table 1 PSCAD line model validation for Montague to Weed Junction (STR 5/24), S10-1

Montague to Weed Junction, S10-1, 69 kV		R1 (pu)	X1 (pu)	B1 (pu)
PSCAD frequency dependent line constants calculation	Montague to STR 24/22	4.04E-04	1.27E-03	2.45E-05
	STR 24/22 to STR 5/24	2.64E-02	2.59E-02	3.56E-04
	Total PSCAD	2.68E-02	2.72E-02	3.81E-04
Access impedance		2.93E-02	2.61E-02	3.90E-04
Error Percent		9%	-4%	2%

Methodology

Simulations were performed with the following conditions:

1. Maximum realistic powerflow on the energized line (210 A, 12.97kV)
2. Faults applied to the energized line sharing the ROW such that the currents parallel to the idle line are maximized (LG and 3LG faults were performed) (2970A for 0.4s)

With the idle line split into 9 segments, we varied the following parameters:

1. Fault location on the idle line (10 locations, including both ends of the lines)
2. Fault type on the idle line (4 combinations)
    a. Phase A-to-Ground fault
    b. Phase B-to-Ground fault
    c. Phase C-to-Ground fault
    d. Three Phases-to-Ground fault
3. Fault location and fault type on the ends of the distribution line (9 combinations)
    a. Neither end faulted
    b. Phase A-to-Ground fault on either end of the line
    c. Phase B-to-Ground fault on either end of the line
    d. Phase C-to-Ground fault on either end of the line
    e. Three Phases-to-Ground fault on either end of the line
4. Grounding of idle line (4 combinations)
    a. No ground at either end
    b. 1 ground at Montague, STR 5/24 line end left open
    c. 1 ground at STR 5/24, Montague line end left open
    d. Both ends grounded
5. Fault resistance and ground resistance (5 combinations)
    a. Ideal ($R = 1x10^{-6}\ \Omega$)
    b. 1 Ω
    c. 5 Ω
    d. 25 Ω
    e. 100 Ω

Results

The results with the maximums for all 1440 combinations for each of the different fault and ground resistances for the Montague to Weed Junction line can be seen in Table 2.

For the base case with nominal current (210 A) on the 12.47 kV distribution line, the worst current condition is when one of the ends of the line is ideally grounded (R = $1x10^{-6}$ Ω) at STR 5/24 and a tree with an ideal resistance touches Phase-A on the idle line close to the opposite end of the line (0.0838 mi from Montague), producing an RMS current of 3.08 A into the tree as seen in Figure 2.

The worst case with fault currents (2970 A) on the 12.47 kV distribution line, the worst current condition is when one of the ends is ideally grounded at STR 5/24 and a tree with an ideal resistance touches Phase-C on the idle line close to the opposite end of the line (0.0838 mi from Montague), producing a RMS current of 649.2 A into the tree as seen in Figure 3.

Table 2 Results for Montague to Weed Junction Idle Line Study

Fault and Ground Resistance	Intentional Grounds on Idle Line	With Nominal Current on Underbuild			With Fault Current on Underbuild			
		Idle Line Fault Current			Idle Line Fault Current		Idle Line Fault Voltage	
		Ave (A, RMS)	Peak (A, inst)	Peak (V, inst) Tree Fault Vlg	Ave (A, RMS)	Peak (A, inst)	Peak (V, inst) Distribution Fault Induced Vlg	Peak (V, inst) Tree Fault Vlg
Ideal (R = $1x10^{-6}$ Ω)	No grounds	0.00	0.07	30.81	0.02	4.12	3213.40	2589.72
	One Ground	3.08	6.09	8.85	649.20	1331.57	7821.09	1760.55
	Two Grounds	2.20	3.13	0.14	475.17	694.87	1555.31	32.76
1 Ω	No grounds	0.00	0.07	30.81	0.01	2.26	3174.61	1414.24
	One Ground	1.60	2.28	8.85	183.31	261.77	7742.62	1001.78
	Two Grounds	1.16	1.64	4.14	140.86	199.71	1546.92	518.01
5 Ω	No grounds	0.00	0.07	30.81	0.00	0.59	3025.63	413.21
	One Ground	0.54	0.76	8.85	16.03	22.76	7439.36	266.67
	Two Grounds	0.33	0.46	5.44	10.42	14.78	1513.29	174.48
25 Ω	No grounds	0.00	0.07	30.81	0.00	0.13	2826.58	92.50
	One Ground	0.12	0.17	8.85	0.79	1.12	6144.24	58.14
	Two Grounds	0.07	0.10	5.89	0.51	0.72	1365.19	43.27
100 Ω	No grounds	0.00	0.05	30.80	0.00	0.06	2310.96	39.24
	One Ground	0.03	0.04	8.87	0.07	0.10	3335.84	20.17
	Two Grounds	0.02	0.03	5.98	0.05	0.06	991.45	15.37

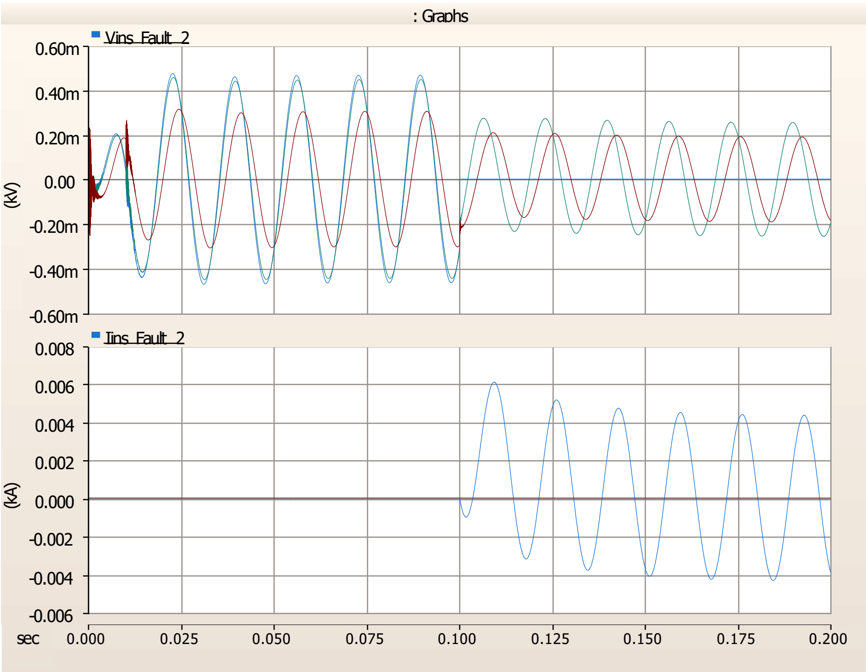


Figure 2 Instantaneous fault voltage and currents on the idle line worst case with nominal currents on the energized line

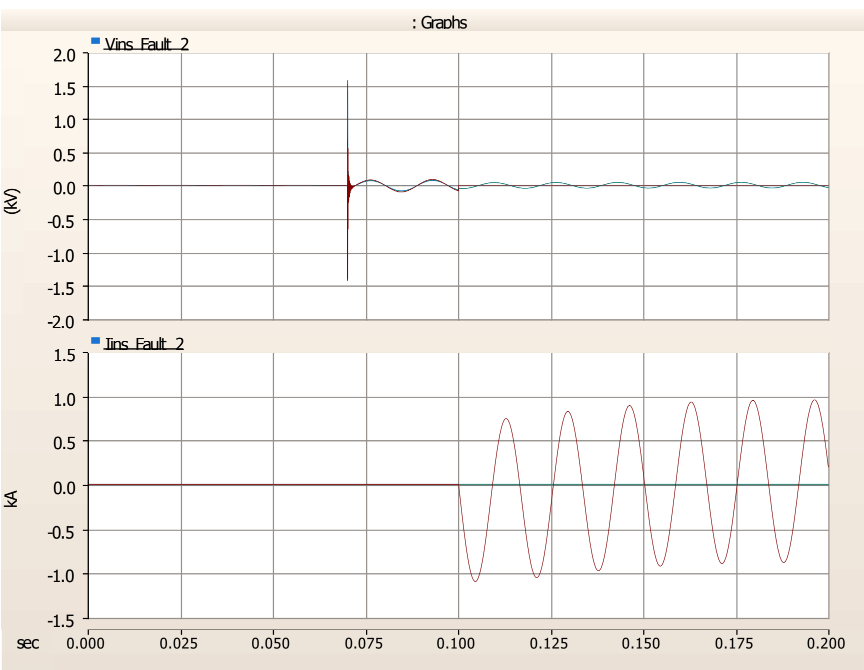


Figure 3 Instantaneous fault voltage and currents on the idle line worst case with fault currents on the energized line

When comparing the idle line fault current values to the probability of fire based on currents and species of vegetation, there are a few assumptions that dictate if there is a fire risk, including:

1. How the idle line is grounded
2. Fault and Ground Resistance
    a. The fault/ground resistance being lower increases the amount of fault current on the idle line and increases the risk of a fire.
3. If there is a fault on the energized line
    a. Higher current on the energized line induces more current on the idle line.

Parametric Analysis

To better understand which parameters effect the chance of fire, we compared the simulation with the actual line data with results from simulations that were repeated with varying the following parameters:

1. Length of the idle line
    a. 0.25x (0.3875 mi)
    b. 0.5x (0.775 mi)
    c. 1x (1.55 mi) – Actual length

2. Spacing of the idle line from the energized line with the original orientation
    a. 5 feet apart
    b. 7 feet apart – Actual spacing
    c. 9 feet apart
    d. 20 feet apart
    e. 30 feet apart
3. Orientation of the idle line and energized line
    a. Actual configuration

Tower: S10-1 Tower Centre 0 [m]
Conductors: Ibis

Circuit #	Cond. #	Connection Phasing #	X (from tower centre)	Y (at tower)
	1	1	0 [ft]	59.5 [ft]
	2	2	0 [ft]	52.5 [ft]
	3	3	0 [ft]	45.5 [ft]

Tower: Distribution Tower Centre 0 [m]
Conductors: 1/0 ACSR

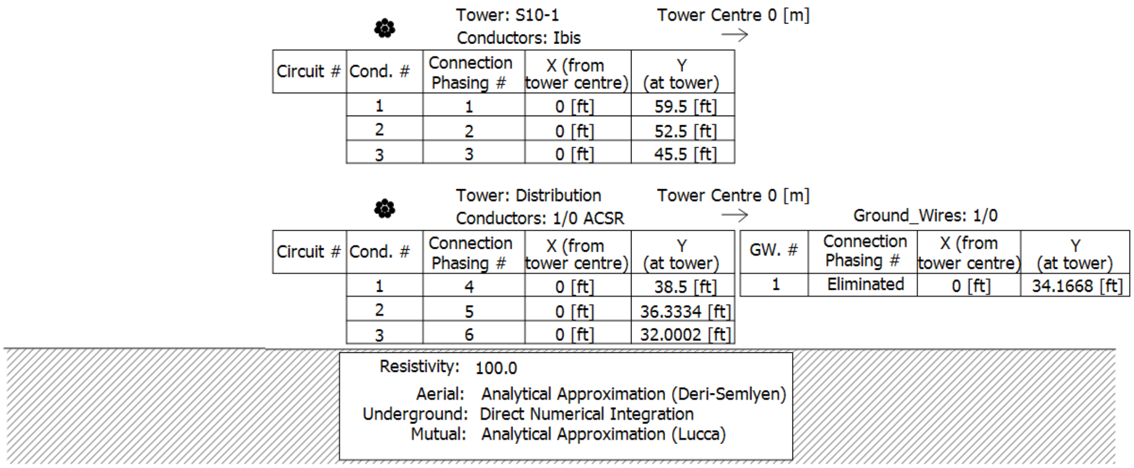
Circuit #	Cond. #	Connection Phasing #	X (from tower centre)	Y (at tower)
	1	4	-4.6666 [ft]	38.5 [ft]
	2	5	-2.1666 [ft]	38.5 [ft]
	3	6	4.6666 [ft]	38.5 [ft]

Ground_Wires: 1/0

GW. #	Connection Phasing #	X (from tower centre)	Y (at tower)
1	Eliminated	2.1666 [ft]	38.5 [ft]

Figure 4 Actual ROW spacing of idle line and energized line

b. Vertically Stacked



Tower: S10-1 — Conductors: Ibis — Tower Centre 0 [m]

Circuit #	Cond. #	Connection Phasing #	X (from tower centre)	Y (at tower)
	1	1	0 [ft]	59.5 [ft]
	2	2	0 [ft]	52.5 [ft]
	3	3	0 [ft]	45.5 [ft]

Tower: Distribution — Conductors: 1/0 ACSR — Tower Centre 0 [m]

Circuit #	Cond. #	Connection Phasing #	X (from tower centre)	Y (at tower)
	1	4	0 [ft]	38.5 [ft]
	2	5	0 [ft]	36.3334 [ft]
	3	6	0 [ft]	32.0002 [ft]

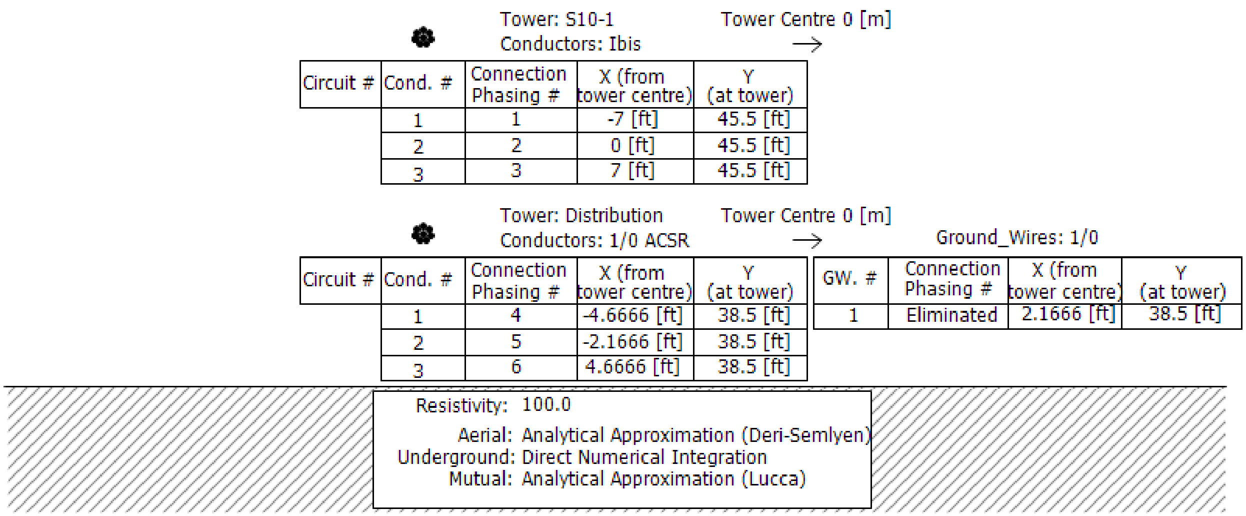
Ground_Wires: 1/0

GW. #	Connection Phasing #	X (from tower centre)	Y (at tower)
1	Eliminated	0 [ft]	34.1668 [ft]

Resistivity: 100.0
Aerial: Analytical Approximation (Deri-Semlyen)
Underground: Direct Numerical Integration
Mutual: Analytical Approximation (Lucca)

Figure 5 Vertically stacked ROW spacing of idle line and energized line used for parametric analysis

c. Horizontally Stacked



Tower: S10-1 — Conductors: Ibis — Tower Centre 0 [m]

Circuit #	Cond. #	Connection Phasing #	X (from tower centre)	Y (at tower)
	1	1	-7 [ft]	45.5 [ft]
	2	2	0 [ft]	45.5 [ft]
	3	3	7 [ft]	45.5 [ft]

Tower: Distribution — Conductors: 1/0 ACSR — Tower Centre 0 [m]

Circuit #	Cond. #	Connection Phasing #	X (from tower centre)	Y (at tower)
	1	4	-4.6666 [ft]	38.5 [ft]
	2	5	-2.1666 [ft]	38.5 [ft]
	3	6	4.6666 [ft]	38.5 [ft]

Ground_Wires: 1/0

GW. #	Connection Phasing #	X (from tower centre)	Y (at tower)
1	Eliminated	2.1666 [ft]	38.5 [ft]

Resistivity: 100.0
Aerial: Analytical Approximation (Deri-Semlyen)
Underground: Direct Numerical Integration
Mutual: Analytical Approximation (Lucca)

Figure 6 Horizontally stacked ROW spacing of idle line and energized line used for parametric analysis

4. Operating the energized line with nominal voltage but no current.

5. Adding additional grounds at 10 different points on the line

Results of Parametric Analysis

When varying the length for which the lines are parallel, the simulations show a correlation of higher currents being induced on the idle line for shorter lines only for the case with zero-resistance grounds, as seen in Table 3. When a more realistic ground resistance is modeled (25 Ohms in this case) there is a correlation between shorter coupled line segments and lower induced currents.

When varying the spacing between the idle line and energized line, the currents trended down with a larger spacing, although this trend was more evident for the cases with fault current on the energized line, as seen in Table 4.

When the orientation is changed from the actual configuration of the right of way, as seen in Figure 4, to a stacked orientation, as seen in Figure 5 and Figure 6, we see higher currents. The as-built configuration shows the least amount of induced current, and the other two configurations show a significant increase in current on the idle line for nominal current scenarios, as seen in Table 5. The impact of the orientation is reduced for fault scenarios when only the inductive coupling from a single faulted phase is inducing current onto the idle circuit.

Table 6 shows the results for a test ran with voltage but no current on the energized line to see how much of the coupling from the energized line to the idle line is capacitive induction. The results show that for the actual configuration of the Right of Way, the current is mainly from inductive coupling.

The final test ran was to run the actual configuration case when a ground is placed at each segment (every 0.18 mi) and at each end of the line. The results in Table 7 show that the grounds along the line don’t have much effect on the current on the idle line and have comparable results to the two grounds at the ends of the line results. In Figure 7, the voltages along the line and fault currents are plotted for the case that produces the maximum average current on the idle line. The voltage on the line is almost zero in the middle of the line and is the highest at the ends. The coupling from the energized line and the grounds along the idle line create smaller current loops that have a “push” and a “pull” of current on both ends. The results for this same test with fault currents on the energized line can be seen in Figure 8.

Table 3 Results for Montague to Weed Junction Idle Line with varied length

Line Length Multiplier	Fault and Ground Resistance	Intentional Grounds on Idle Line	With Nominal Current on Underbuild			With Fault Current on Underbuild			
			Idle Line Fault Current			Idle Line Fault Current		Idle Line Fault Voltage	
			Ave (A, RMS)	Peak (A, inst)	Peak (V, inst) Tree Fault Vlg	Ave (A, RMS)	Peak (A, inst)	Peak (V, inst) Distribution Fault Induced Vlg	Peak (V, inst) Tree Fault Vlg
0.25x	Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	0.02	8.46	0.01	1.46	3414.27	1066.98
		One Ground	6.10	9.86	4.37	1235.86	2195.91	7772.11	791.12
		Two Grounds	3.94	6.00	0.08	1226.87	1791.26	743.08	13.24
	25 Ω	No grounds	0.00	0.02	8.07	0.00	0.07	3224.31	48.94
		One Ground	0.06	0.08	4.05	0.49	0.70	5828.52	35.07
		Two Grounds	0.04	0.05	3.08	0.30	0.43	567.18	25.80
0.5x	Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	0.04	16.31	0.01	2.32	3012.28	1659.07
		One Ground	4.47	7.02	6.31	862.72	1759.98	8156.47	1164.42
		Two Grounds	3.24	4.63	0.10	573.64	857.33	675.29	19.24
	25 Ω	No grounds	0.00	0.04	16.31	0.00	0.10	2825.74	81.88
		One Ground	0.09	0.12	6.48	0.78	1.11	6333.31	56.19
		Two Grounds	0.06	0.08	4.86	0.49	0.69	525.80	41.29
1x	Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	0.07	30.81	0.02	4.12	3213.40	2589.72
		One Ground	3.08	6.09	8.85	649.20	1331.57	7821.09	1760.55
		Two Grounds	2.20	3.13	0.14	475.17	694.87	1555.31	32.76
	25 Ω	No grounds	0.00	0.07	30.81	0.00	0.13	2826.58	92.50
		One Ground	0.12	0.17	8.85	0.79	1.12	6144.24	58.14
		Two Grounds	0.07	0.10	5.89	0.51	0.72	1365.19	43.27

Table 4 Results for Montague to Weed Junction Idle Line with varied spacing between Idle Line and Energized Line

Spacing between Idle Line and Energized Line	Fault and Ground Resistance	Intentional Grounds on Idle Line	With Nominal Current on Underbuild			With Fault Current on Underbuild			
			Idle Line Fault Current		Peak (V, inst) Tree Fault Vlg	Idle Line Fault Current		Idle Line Fault Voltage	
			Ave (A, RMS)	Peak (A, inst)		Ave (A, RMS)	Peak (A, inst)	Peak (V, inst) Distribution Fault Induced Vlg	Peak (V, inst) Tree Fault Vlg
5 ft	Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	0.22	64.09	0.02	4.53	3432.27	2842.13
		One Ground	3.20	6.21	8.98	710.95	1371.99	8299.28	1894.84
		Two Grounds	2.05	3.38	0.19	509.23	755.25	1516.81	35.11
	25 Ω	No grounds	0.00	0.19	64.09	0.00	0.29	2928.86	131.45
		One Ground	0.15	0.21	8.99	0.80	1.12	6499.60	58.89
		Two Grounds	0.06	0.09	5.16	0.51	0.73	1319.02	43.67
7 ft	Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	0.07	30.81	0.02	4.12	3213.40	2589.72
		One Ground	3.08	6.09	8.85	649.20	1331.57	7821.09	1760.55
		Two Grounds	2.20	3.13	0.14	475.17	694.87	1555.31	32.76
	25 Ω	No grounds	0.00	0.07	30.81	0.00	0.13	2826.58	92.50
		One Ground	0.12	0.17	8.85	0.79	1.12	6144.24	58.14
		Two Grounds	0.07	0.10	5.89	0.51	0.72	1365.19	43.27
9 ft	Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	0.10	33.03	0.01	3.86	2985.74	2491.58
		One Ground	3.06	6.01	9.00	626.38	1292.43	7339.29	1696.57
		Two Grounds	2.31	3.30	0.13	454.55	675.91	1591.73	29.66
	25 Ω	No grounds	0.00	0.09	33.03	0.00	0.16	2745.47	90.84
		One Ground	0.12	0.17	9.01	0.79	1.12	5773.94	57.58
		Two Grounds	0.08	0.11	6.49	0.51	0.72	1407.58	42.93
20 ft	Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	0.12	37.78	0.01	2.80	2467.54	2037.31
		One Ground	3.12	6.11	9.02	522.10	1099.74	5790.39	1473.49
		Two Grounds	2.27	3.24	0.13	367.99	552.07	1622.20	23.02
	25 Ω	No grounds	0.00	0.11	37.78	0.00	0.16	2368.23	92.29
		One Ground	0.12	0.17	9.04	0.71	1.01	4142.10	51.94
		Two Grounds	0.08	0.12	6.91	0.46	0.65	1466.32	38.97
30 ft	Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	0.10	33.61	0.01	2.41	2434.27	1863.49
		One Ground	2.96	5.88	8.78	476.02	1011.09	5630.85	1369.09
		Two Grounds	2.12	3.03	0.12	330.97	498.48	1562.92	20.63
	25 Ω	No grounds	0.00	0.09	33.61	0.00	0.14	2370.59	85.04
		One Ground	0.12	0.17	8.80	0.66	0.94	3745.42	48.49
		Two Grounds	0.08	0.11	6.69	0.43	0.61	1422.03	36.68

Table 5 Results for Montague to Weed Junction Idle Line with different orientations between Idle Line and Energized Line

Orentation	Fault and Ground Resistance	Intentional Grounds on Idle Line	With Nominal Current on Underbuild			With Fault Current on Underbuild			
			Idle Line Fault Current			Idle Line Fault Current		Idle Line Fault Voltage	
			Ave (A, RMS)	Peak (A, inst)	Peak (V, inst) Tree Fault Vlg	Ave (A, RMS)	Peak (A, inst)	Peak (V, inst) Distribution Fault Induced Vlg	Peak (V, inst) Tree Fault Vlg
1	Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	0.07	30.81	0.02	4.12	3213.40	2589.72
		One Ground	3.08	6.09	8.85	649.20	1331.57	7821.09	1760.55
		Two Grounds	2.20	3.13	0.14	475.17	694.87	1555.31	32.76
	25 Ω	No grounds	0.00	0.07	30.81	0.00	0.13	2826.58	92.50
		One Ground	0.12	0.17	8.85	0.79	1.12	6144.24	58.14
		Two Grounds	0.07	0.10	5.89	0.51	0.72	1365.19	43.27
2	Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	1.02	327.74	0.02	4.31	3476.39	2515.39
		One Ground	12.77	19.90	32.53	715.03	1476.04	8459.12	1831.41
		Two Grounds	7.03	9.95	0.81	471.35	671.88	1558.65	34.63
	25 Ω	No grounds	0.00	0.91	327.74	0.01	0.98	3257.80	317.35
		One Ground	0.41	0.58	30.42	1.15	1.63	6637.48	86.29
		Two Grounds	0.21	0.29	17.51	0.65	0.93	1356.23	55.27
3	Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	0.22	58.01	0.02	4.43	3320.25	2823.12
		One Ground	17.25	29.46	9.56	703.90	1450.89	8226.86	1856.37
		Two Grounds	19.28	32.95	2.32	507.41	752.67	1882.88	40.38
	25 Ω	No grounds	0.00	0.18	57.77	0.00	0.28	2992.57	125.48
		One Ground	0.14	0.19	9.58	0.77	1.10	6347.10	57.25
		Two Grounds	0.07	0.11	5.77	0.52	0.73	1639.97	43.76

Table 6 Results for Montague to Weed Junction Idle Line with No Current on Underbuild Distribution Line

Fault and Ground Resistance	Intentional Grounds on Idle Line	With Nominal Current on Underbuild			With No Current on Underbuild		
		Idle Line Fault Current			Idle Line Fault Current		
		Ave (A, RMS)	Peak (A, inst)	Peak (V, inst) Tree Fault Vlg	Ave (A, RMS)	Peak (A, inst)	Peak (V, inst) Tree Fault Vlg
Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	0.07	30.81	0.00	0.06	25.50
	One Ground	3.08	6.09	8.85	0.00	0.00	0.00
	Two Grounds	2.20	3.13	0.14	0.00	0.00	0.00
25 Ω	No grounds	0.00	0.07	30.81	0.00	0.05	25.49
	One Ground	0.12	0.17	8.85	0.00	0.00	0.01
	Two Grounds	0.07	0.10	5.89	0.00	0.00	0.00

Table 7 Results for Montague to Weed Junction Idle Line with Grounds at every fault location

Fault and Ground Resistance	Intentional Grounds on Idle Line	With Nominal Current on Underbuild			With Fault Current on Underbuild			
		Idle Line Fault Current			Idle Line Fault Current		Idle Line Fault Voltage	
		Ave (A, RMS)	Peak (A, inst)	Peak (V, inst) Tree Fault Vlg	Ave (A, RMS)	Peak (A, inst)	Peak (V, inst) Distribution Fault Induced Vlg	Peak (V, inst) Tree Fault Vlg
Ideal (R = 1x10^{-6} Ω)	No grounds	0.00	0.07	30.81	0.02	4.12	3213.40	2589.72
	One Ground	3.08	6.09	8.85	649.20	1331.57	7821.09	1760.55
	Two Grounds	2.20	3.13	0.14	475.17	694.87	1555.31	32.76
	All Grounds	2.07	2.94	0.00	446.55	650.13	0.00	0.00
25 Ω	No grounds	0.00	0.07	30.81	0.00	0.13	2826.58	92.50
	One Ground	0.12	0.17	8.85	0.79	1.12	6144.24	58.14
	Two Grounds	0.07	0.10	5.89	0.51	0.72	1365.19	43.27
	All Grounds	0.09	0.13	4.46	0.70	0.99	337.58	33.23

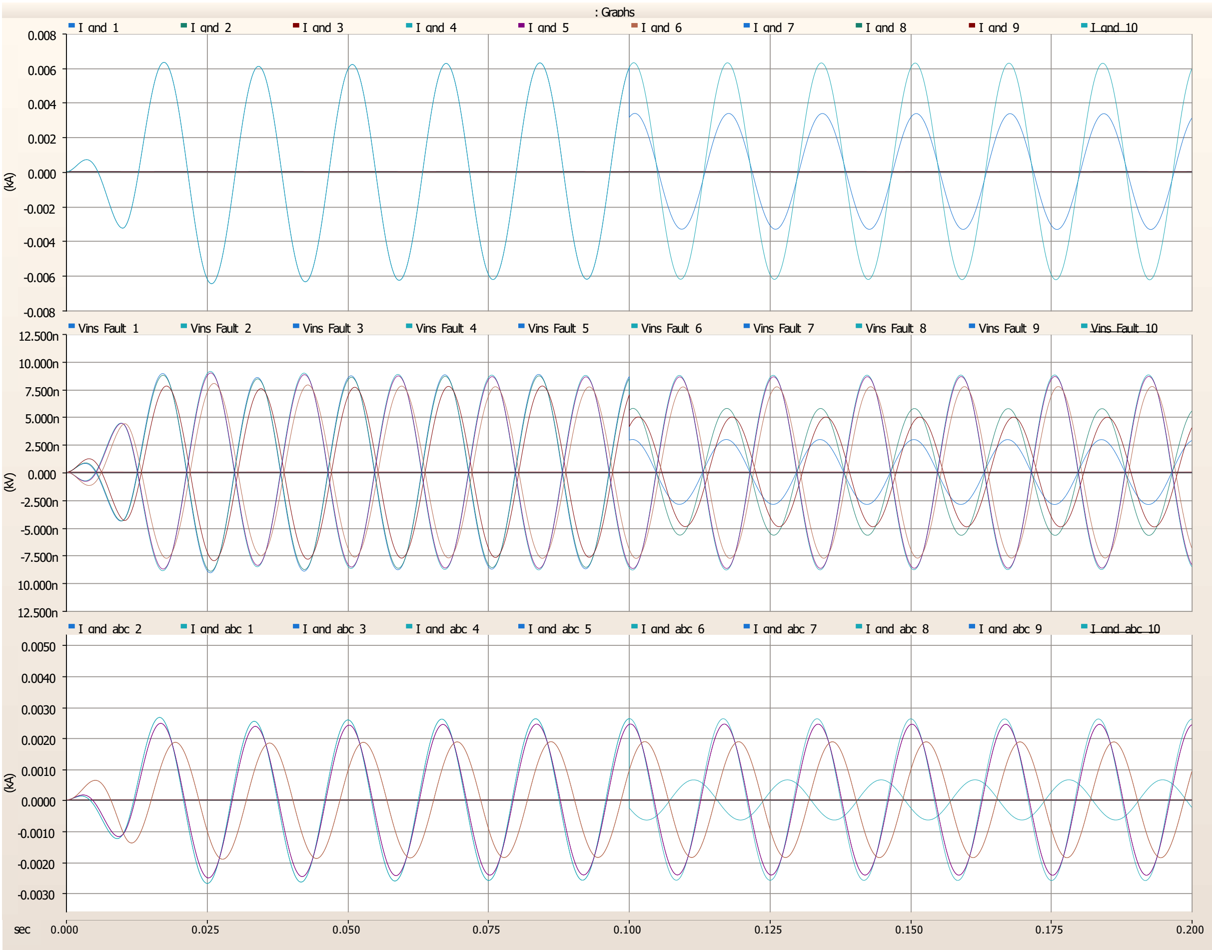


Figure 7 All grounds case for nominal current on energized line with a Phase-A to Ground fault at STR 5/24

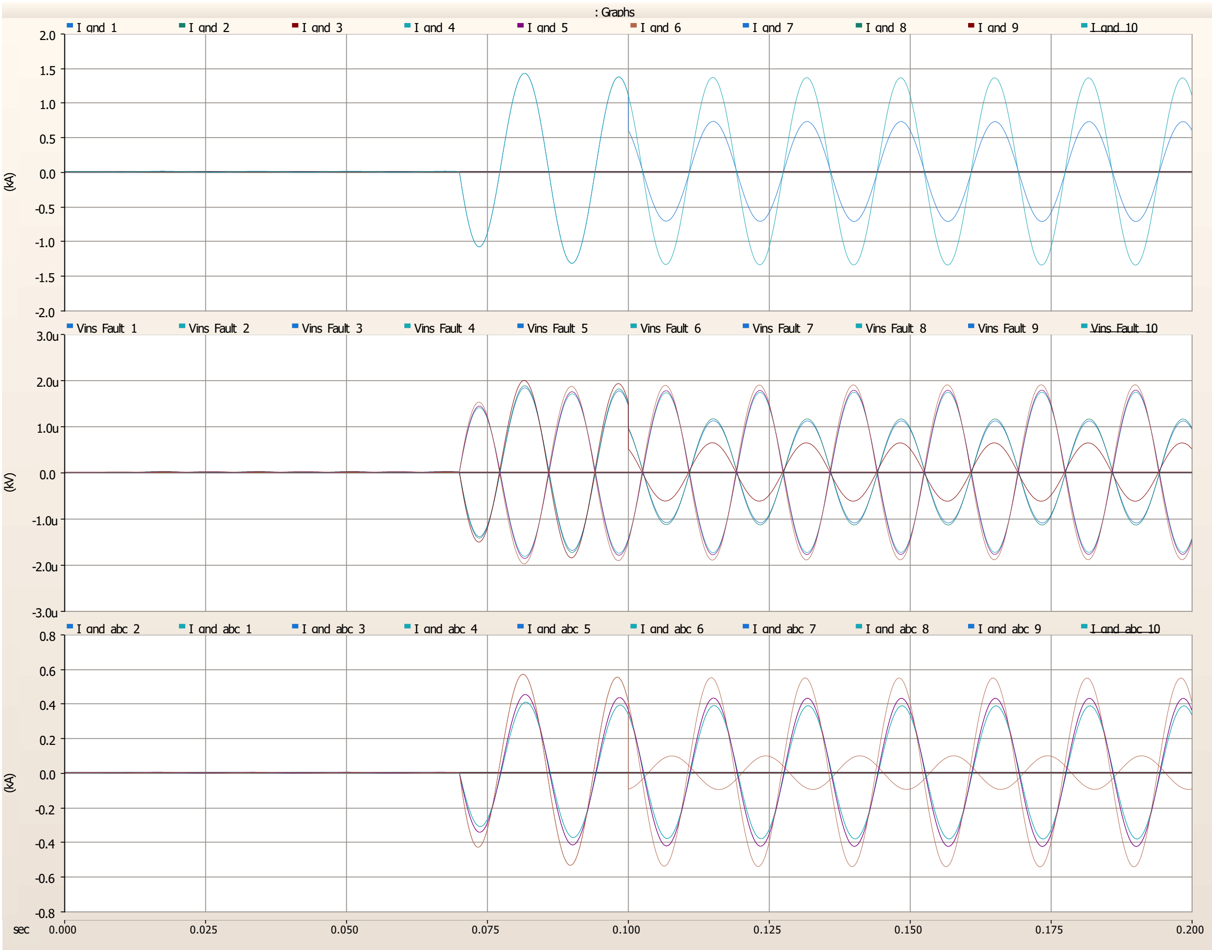


Figure 8 All grounds case for fault current on energized line with a Phase-A to Ground fault at Montague