Case Simulation Study Ground Interrupt Device on INL 138kV Loop from MHD/GIC Drive

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Case Study Objectives/Questions

Background

- Phase IVB E3 Tests (2012) utilized two configurations of ground interrupt
  - "Global" and "Local"
- Higher DC drives in the "local" case were curtailed b/c diverted current effects elsewhere on INL grid were unknown
- **Objective: Simulate ground-interrupt on INL grid and address questions (right)**

Key Questions

1. "Net" GIC/MHC currents reduced by ground interrupt—how much?
2. Redirection of currents changes drive on transformers—how much?
3. GIC/MHD "bunches" on ends of ESP drive—numbers?

Case Simulation Study
INL Loop – 10V/km Overhead EW Field

ATRC Substation #3
43.588924ºN
112.961656ºW
- 8T3-1: Δ-Y, 5MVA
- 8T3-2: Δ-Y, 5MVA
- 8T3-5: Δ-Y, 12MVA
- 8T3-6: Δ-Y, 12MVA

Note: All Δ HV

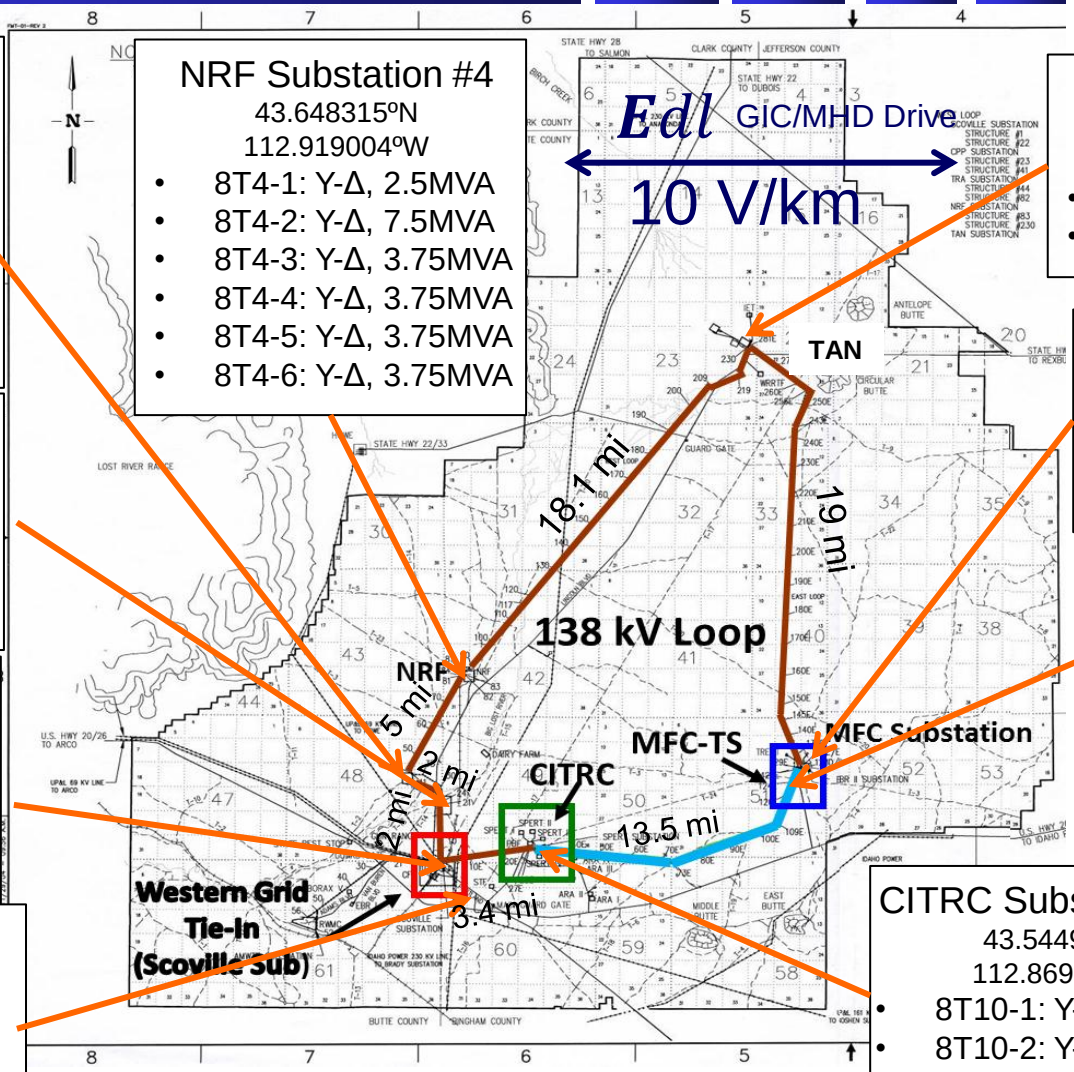
INTEC Substation #2
43.568584ºN
112.938831ºW
- 8T2-1: Δ-Y, 20MVA
- 8T2-2: Δ-Y, 20MVA

Note: All Δ HV

Scoville Substation #1
43.537272ºN
112.936803ºW
- 8T1-1: Y-Δ, 7.5MVA
- 8T1-2: Y-Δ, 7.5MVA
- RMP: A-A, 40MVA

Antelope Substation
43.533663ºN
112.926391ºW
- S1: A-A, 55MVA
- S2: A-A, 55MVA
- A1: A-A, 150MVA

NRF Substation #4
43.648315ºN
112.919004ºW
- 8T4-1: Y-Δ, 2.5MVA
- 8T4-2: Y-Δ, 7.5MVA
- 8T4-3: Y-Δ, 3.75MVA
- 8T4-4: Y-Δ, 3.75MVA
- 8T4-5: Y-Δ, 3.75MVA
- 8T4-6: Y-Δ, 3.75MVA



TAN Substation #5
43.846374ºN
112.703354ºW
- 8T5-1: Y-Δ, 7.5MVA
- 8T5-2: Y-Δ, 7.5MVA

MFC Substation #11
43.59441ºN
112.658272ºW
- 8T11-1: Y-Δ, 12MVA
- 8T11-2: Y-Δ, 12MVA

MFC-TS
43.59441ºN
112.658272ºW
- PENN: Y-Δ, 15MVA
- WEST: Y-Δ, 3.75MVA

CITRC Substation #10
43.544967ºN
112.869372ºW
- 8T10-1: Y-Δ, 5MVA
- 8T10-2: Y-Δ, 5MVA

Substation Separation Calculation

- Substation to substation separations calculated from Lat-Long coordinates
- MHD/GIC potentials added to each line
  - V=Ed/
  - Negative to Positive = West to East

	West-to-East Distance in km							
	ATRC	INTEC	Scoville	Antelope	NRF	CITRC	TAN	MFC
ATRC	x	1.837	2.001	2.84	3.431	7.43	20.745	24.417
INTEC	-1.837	x	0.164	1.003	1.594	5.593	18.908	22.58
Scoville	-2.001	-0.164	x	0.839	1.43	5.429	18.744	22.416
Antelope	-2.84	-1.003	-0.839	x	0.591	4.59	17.905	21.577
NRF	-3.431	-1.594	-1.43	-0.591	x	3.999	17.314	20.986
CITRC	-7.43	-5.593	-5.429	-4.59	-3.999	x	13.315	16.987
TAN	-20.745	-18.908	-18.744	-17.905	-17.314	-13.315	x	3.672
MFC	-24.417	-22.58	-22.416	-21.577	-20.986	-16.987	-3.672	x

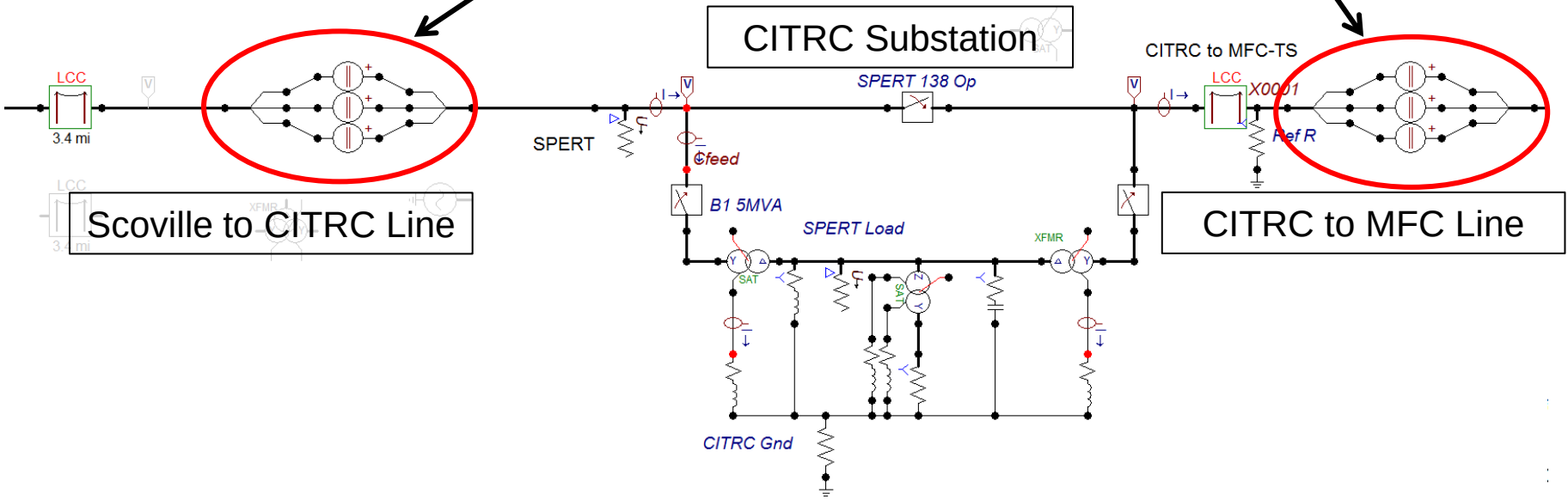
Calculated distance matrix

	10V/km
Negative to Positive	**V line**
Scoville to Antelope	8.39
CITRC to MFC	169.87
Scoville to CITRC	54.29
INTEC to Scoville	1.64
ATRC to INTEC	18.37
ATRC to NRF	34.31
NRF to TAN	173.14
TAN to MFC	36.72

Voltages added to Lines

Addition of MHD/GIC Drive on Overhead Lines

Series DC Sources added to overhead lines

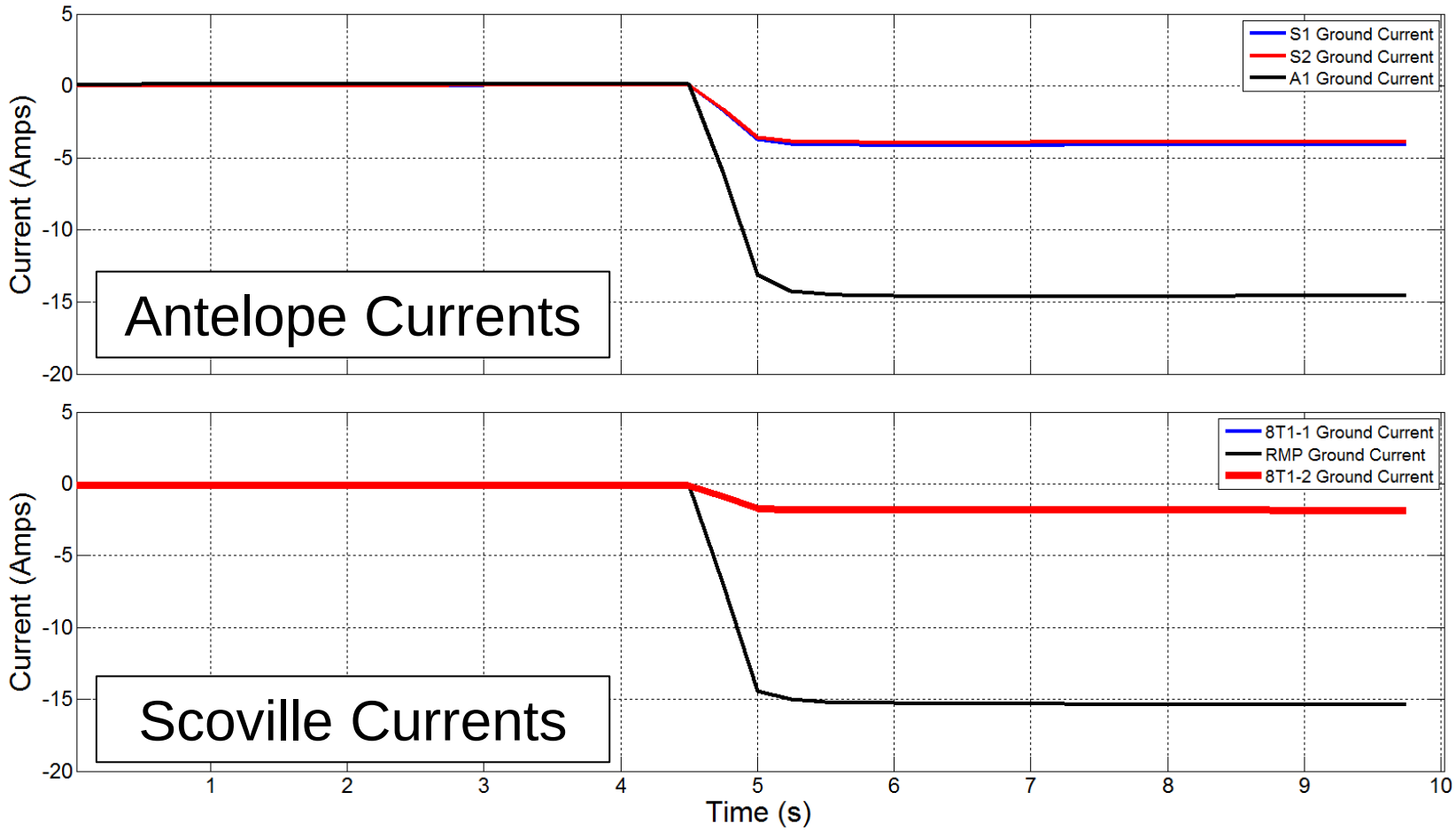


Baseline MHD/GIC Drive Results

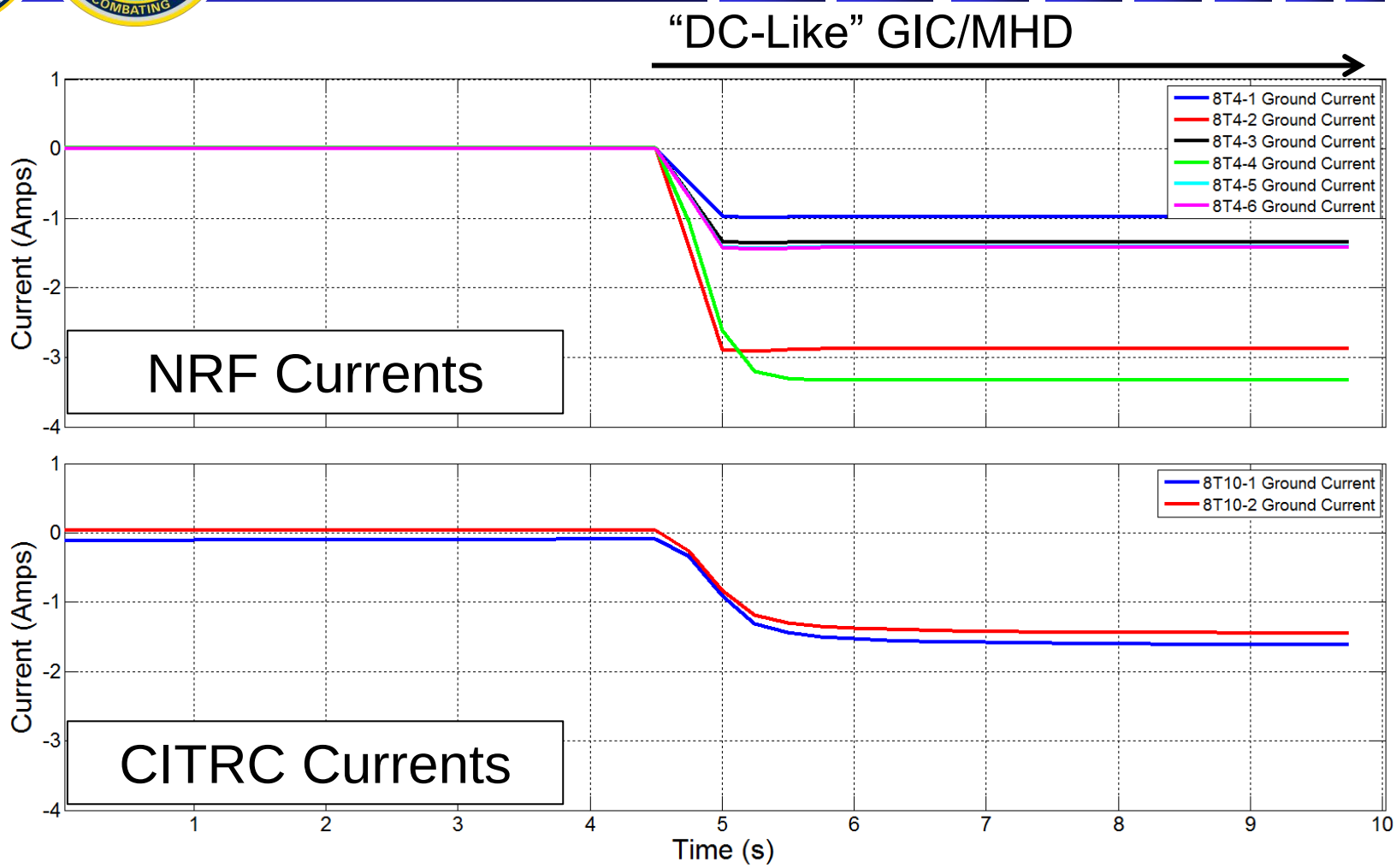
Antelope/Scoville Ground Currents

Baseline MHD/GIC – No Emprimus

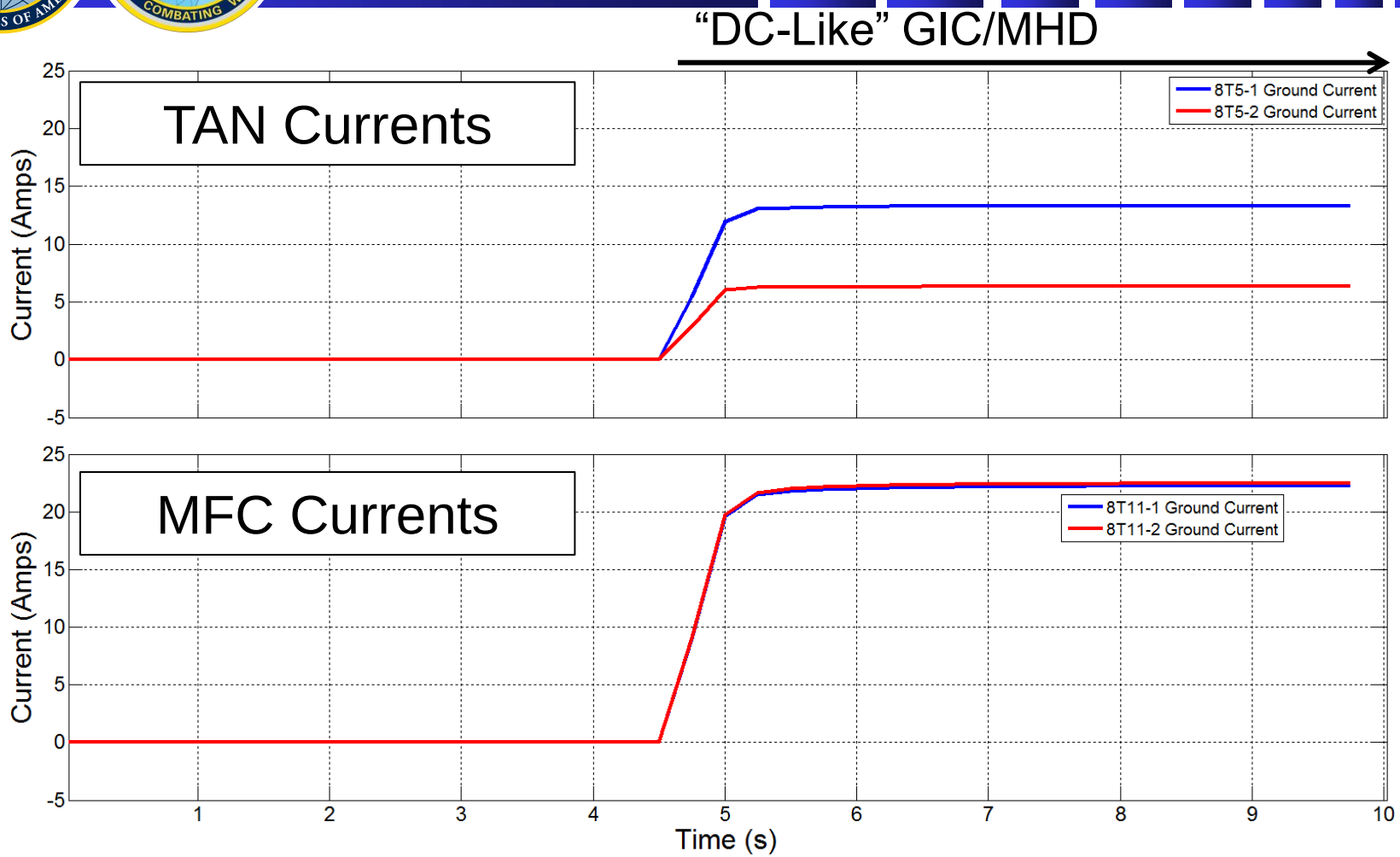
"DC-Like" GIC/MHD



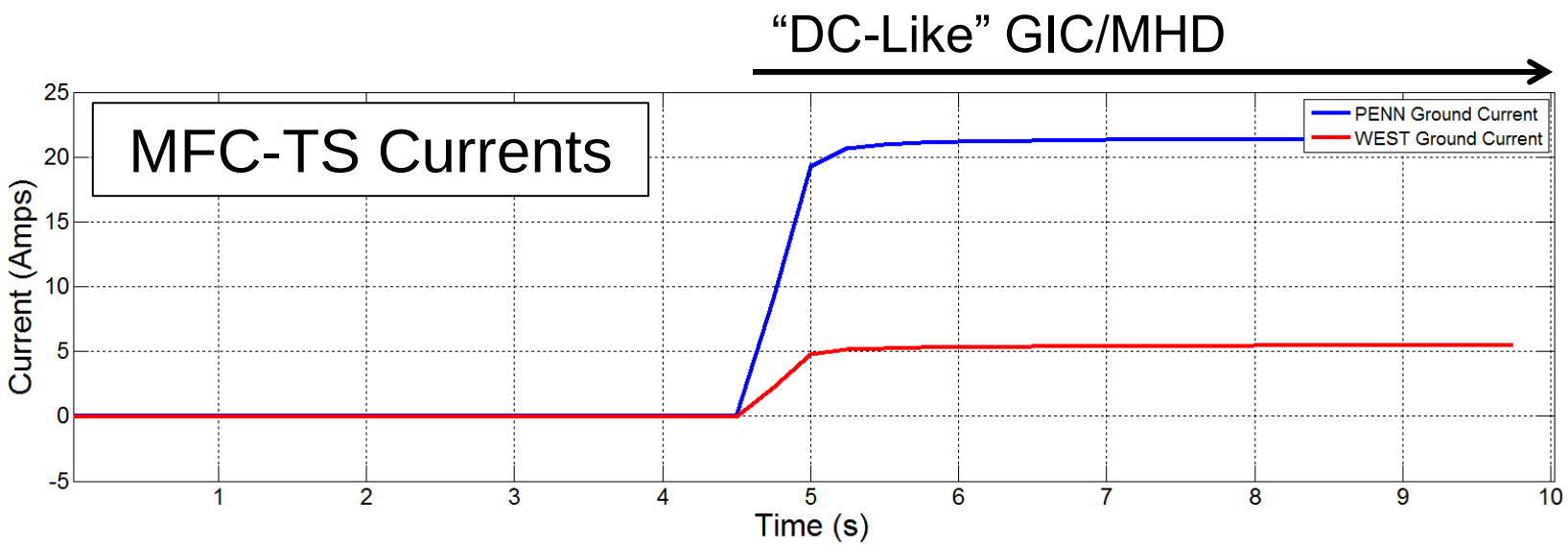
NRF/CITRC Ground Currents



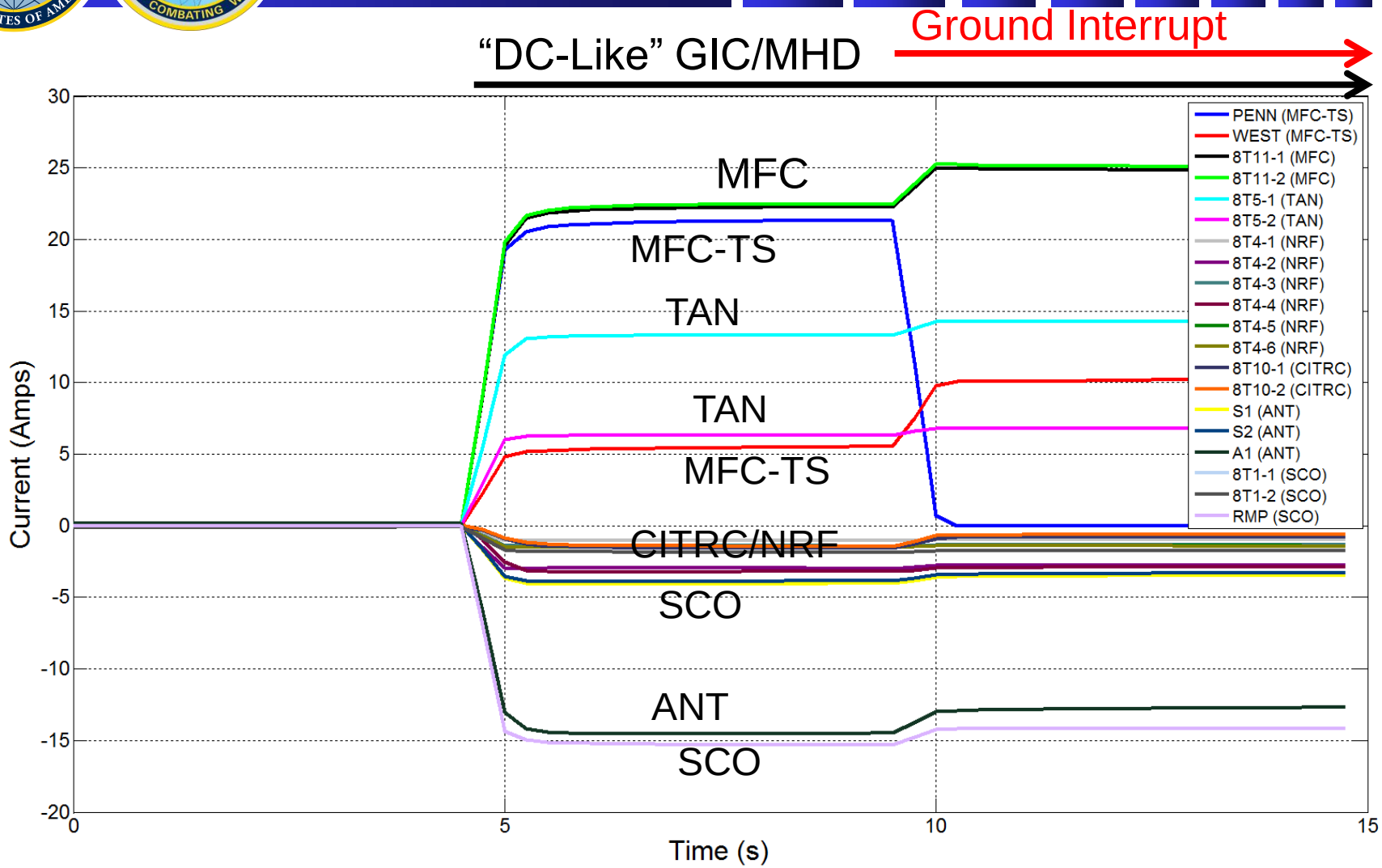
TAN/MFC Currents



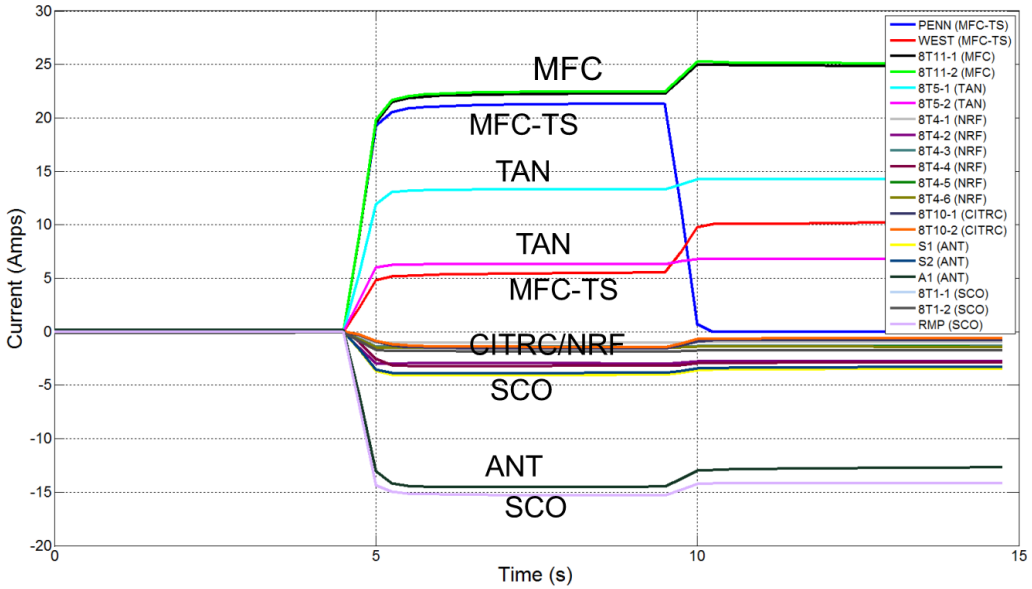
TAN/MFC Currents



Case: Gnd Interrupt on PENN @ MFC-TS



Case 1: Gnd Interrupt on PENN @ MFC-TS

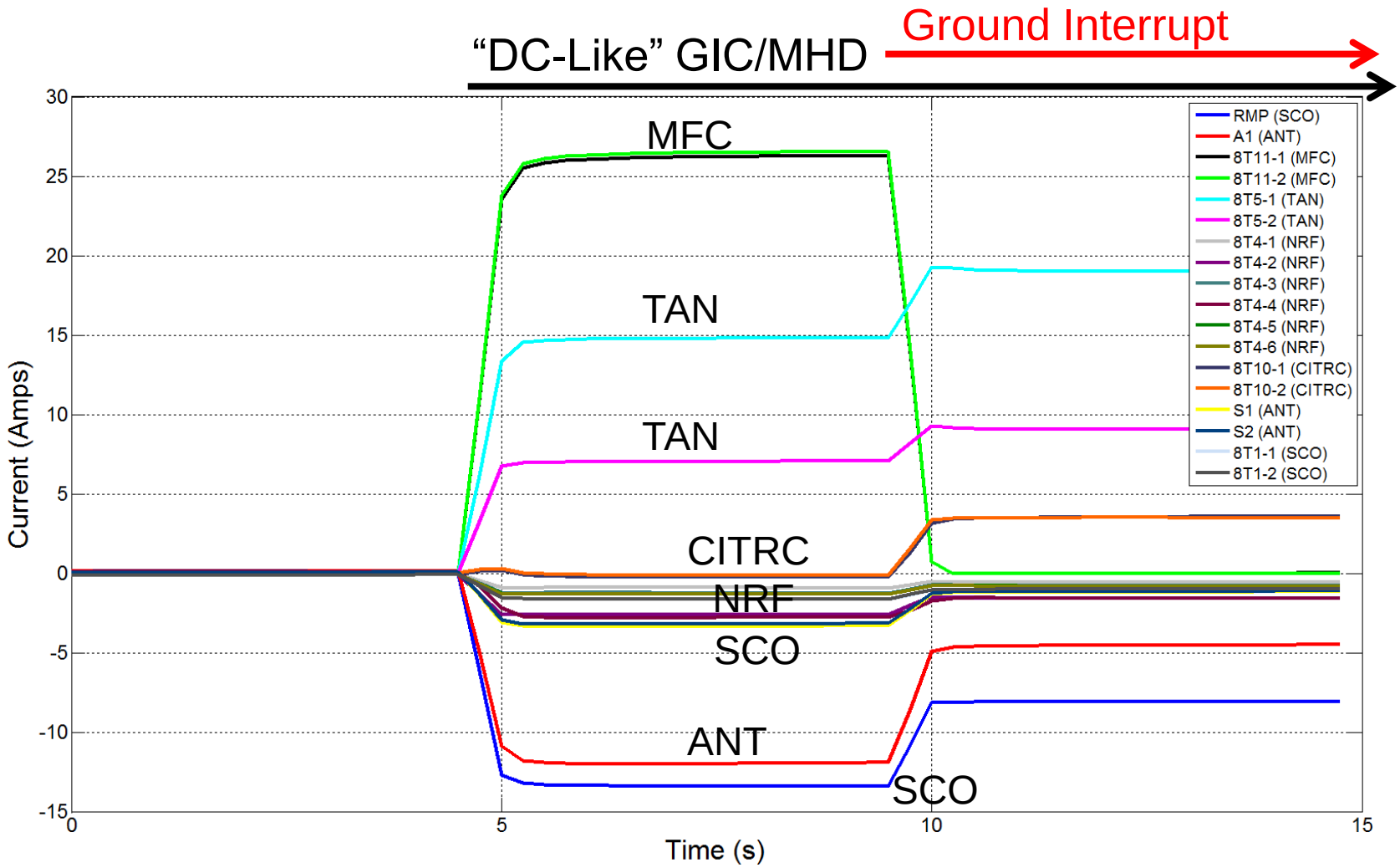


Xfmr	Pre	Post	Net +/-
8T11-1	22.247	24.905	11.95%
8T11-2	22.467	25.148	11.93%
PENN	21.311	0	-100.00%
WEST	5.428	10.103	86.13%
8T5-1	13.315	14.246	6.99%
8T5-2	6.34	6.784	7.00%
Sum East	***91.108***	***81.186***	***-10.89%***
8T4-1	-1.042	-0.983	-5.66%
8T4-2	-2.972	-2.765	-6.97%
8T4-3	-1.424	-1.327	-6.81%
8T4-4	-3.21	-2.916	-9.16%
8T4-5	-1.498	-1.399	-6.61%
8T4-6	-1.502	-1.407	-6.32%
8T10-1	-1.589	-0.786	-50.53%
8T10-2	-1.43	-0.64	-55.24%
S1	-4.047	-3.524	-12.92%
S2	-3.88	-3.368	-13.20%
A1	-14.535	-12.847	-11.61%
8T1-1	-1.851	-1.722	-6.97%
8T1-2	-1.848	-1.723	-6.76%
RMP	-15.322	-14.183	-7.43%
Sum West	***-56.15***	***-49.59***	***-11.68%***
Calc Rem	**34.958**	**31.596**	***-9.62%***
230 to World	35.112	31.545	***-10.16%***

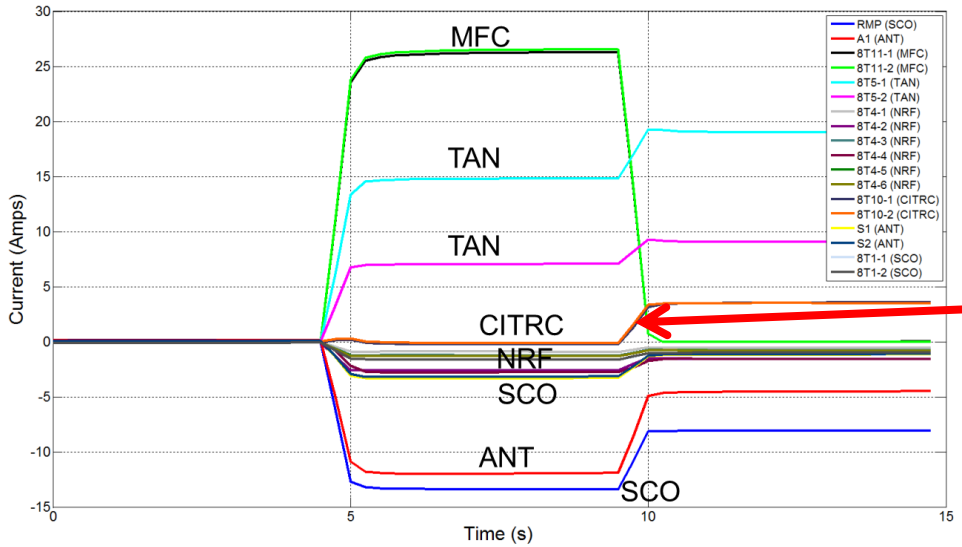
Observations:

- Largest currents belong to furthest E/W
- Gnd Interrupt on east side results in increase to all east side transformers; all west side decrease
- NET current overall decreases
- WECC interconnection current decreases

Case: Gnd Interrupt on MFC Substation (No MFC-TS; "Normal" INL Loop)



Case 2: Gnd Interrupt on MFC Substation (No MFC-TS; "Normal" INL Loop)

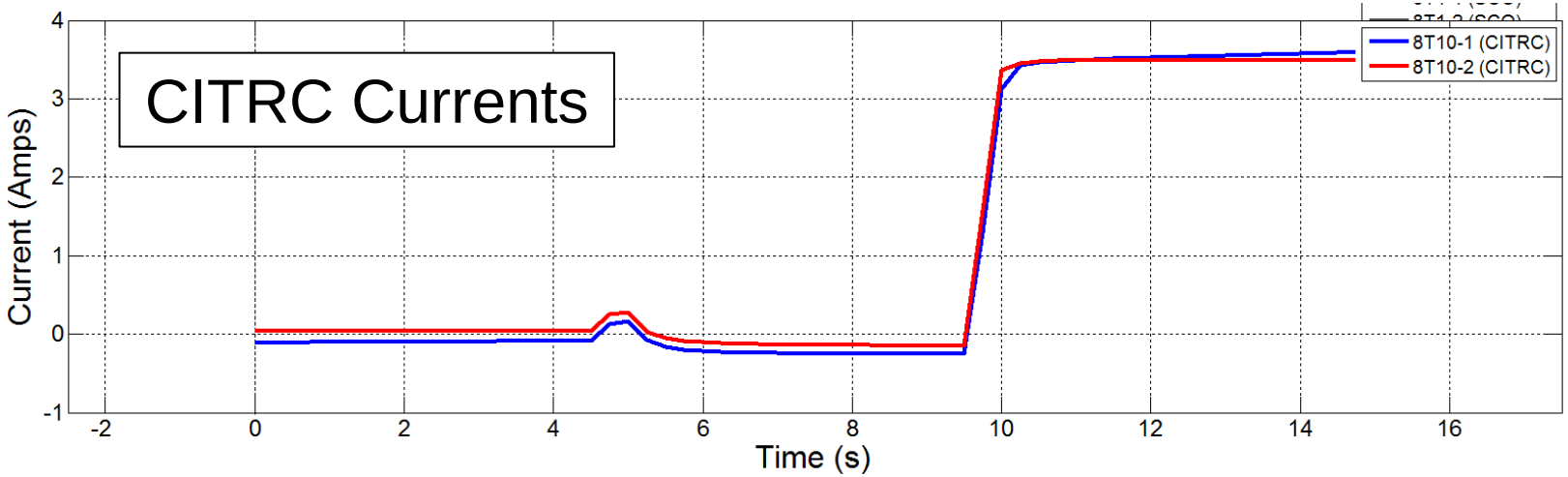


Xfmr	Pre	Post	Net
8T11-1	26.177	0	-100.00%
8T11-2	26.492	0	-100.00%
8T5-1	14.797	19.026	28.58%
8T5-2	7.037	9.054	28.66%
Sum East	***74.503***	***35.093***	***-52.90%***
8T10-1	-0.248	3.518	-1518.55%
8T10-2	-0.143	3.495	-2544.06%
8T4-1	-0.909	-0.57	-37.29%
8T4-2	-2.594	-1.572	-39.40%
8T4-3	-1.239	-0.769	-37.93%
8T4-4	-2.792	-1.563	-44.02%
8T4-5	-1.302	-0.808	-37.94%
8T4-6	-1.312	-0.812	-38.11%
S1	-3.36	-1.2	-64.29%
S2	-3.2	-1.148	-64.13%
A1	-11.991	-4.576	-61.84%
8T1-1	-1.631	-1.022	-37.34%
8T1-2	-1.632	-1.019	-37.56%
RMP	-13.427	-8.097	-39.70%
Sum West	***-45.78***	***-23.156***	***-49.42%***
Calc Rem	**28.723**	**11.937**	***-58.44%***
230 to World	28.943	11.936	***-58.76%***

Observations:

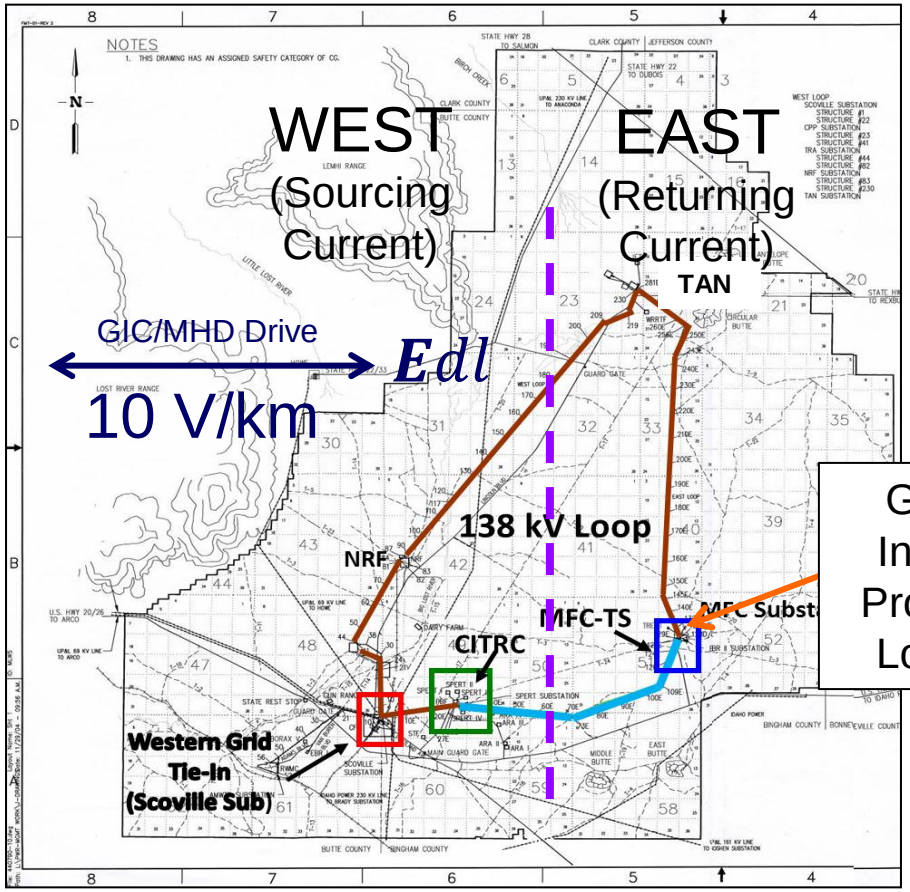
- MFC→0; TAN increases by ~28%
- "East-West" boundary changes with ground interrupt activation
- CITRC transformer currents change direction and increase by 15-25X
- NET current overall decreases
- WECC interconnection current decreases

Case: Gnd Interrupt on MFC Substation (No MFC-TS; "Normal" INL Loop)

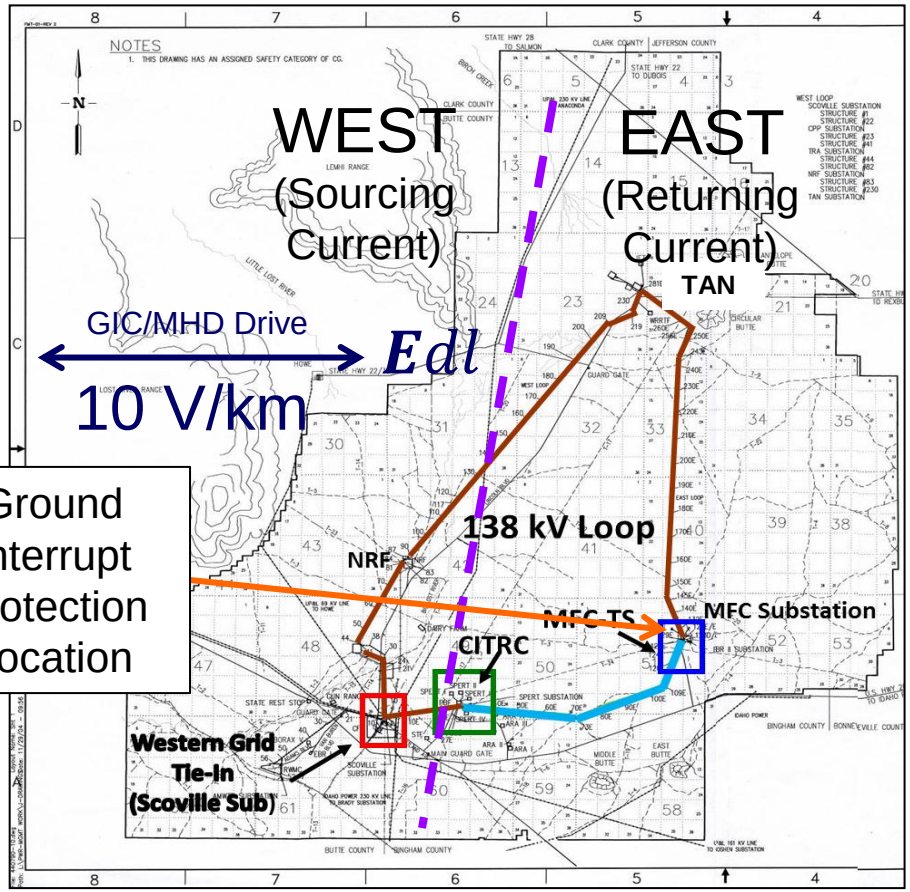


Case: Gnd Interrupt on MFC Substation (No MFC-TS; "Normal" INL Loop)

Before Activation of Protection



After Activation of Protection



Ground Interrupt Protection Location

Summary

- Both scenarios show an overall net-decrease in the amount of GIC/MHD current due to activation of ground interrupt
  - Case 1: Reduction by 10-11%
  - Case 2: Reduction by 50%
- Second scenario showed interesting result by which activation of the device altered the sourcing-returning profile
  - Some transformers reversed directions and increased by 15-25X
  - Redistribution is complex and dependent upon a number of factors; **may result in large increases at unexpected locations**
- Largest magnitude currents appeared at easternmost/westernmost locations when presented with purely E-W drive; transformers in middle experience lowest magnitude currents
  - Agrees with preliminary assumption that “transformers in the middle” receive little to no net-drive

Limitations of This Study

- INL loop is a “dead end” fed from one side and open circuited at the other end; E*dl* abruptly ends at Scoville
  - WECC “drive” not considered (i.e. current out to WECC only, no possibility for WECC→INL drive)
- E*dl* is simple and non-variant spatially and temporally
- Autotransformers; direction of drive need further development
  - Little direct data on benchmarking model to data for autotransformers
- This simulation **non-saturating**
  - Changes in currents could affect whether or not a transformer “saturates” and that saturation event can also change magnitudes/distributions of currents
  - **Magnitudes and distributions of currents can be even more complex than this study demonstrates**