Analysis of Multiple Misoperations following an External Fault

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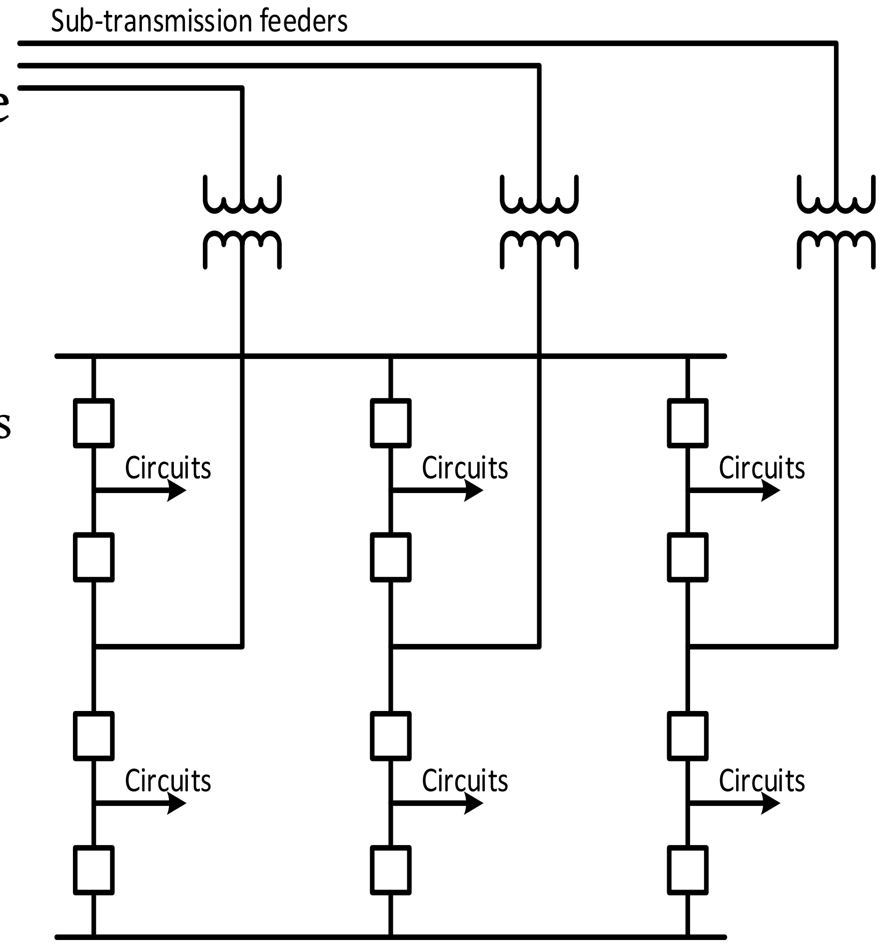
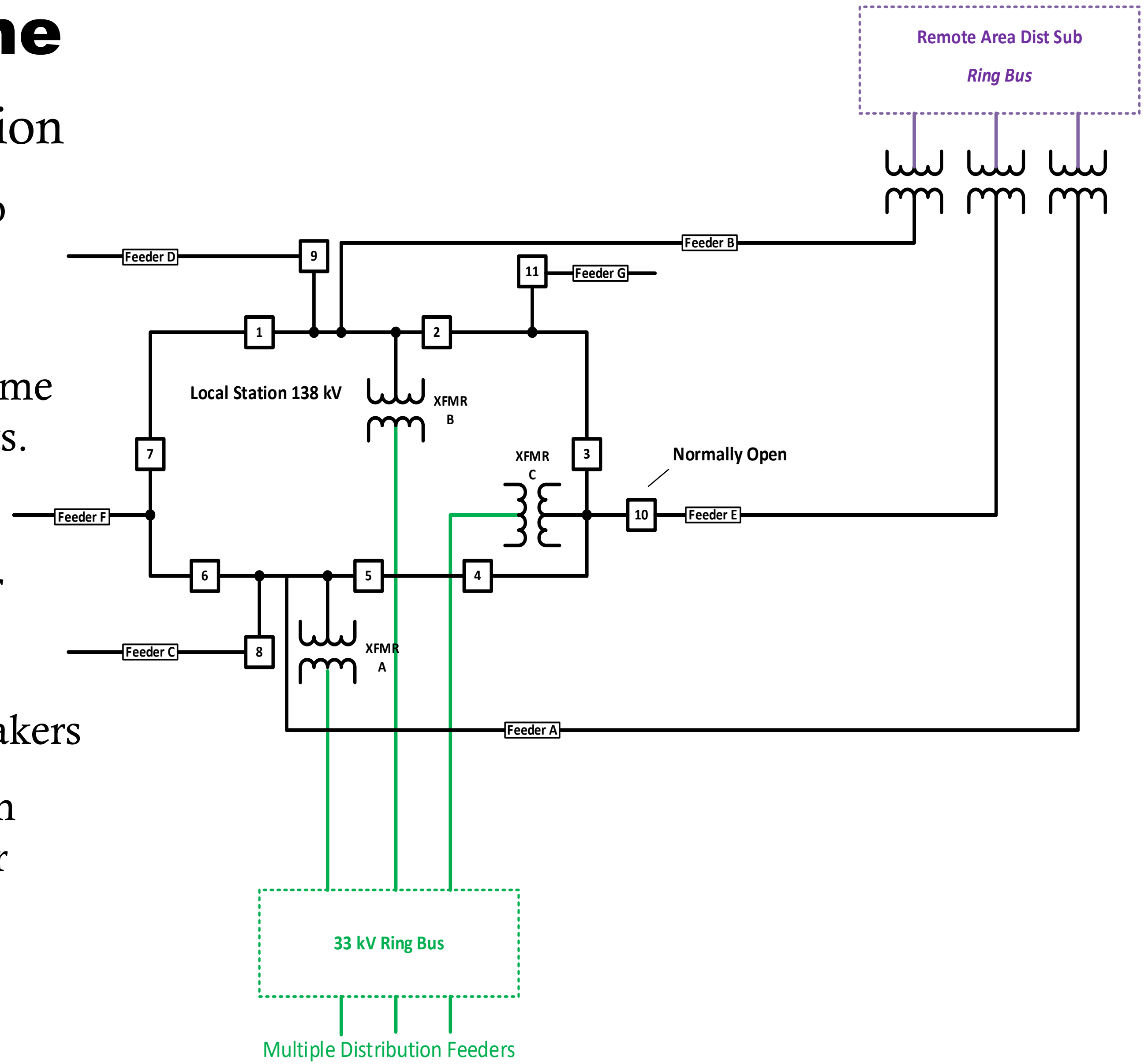
Introduction

- Consolidated Edison Company of New York, Inc. (Con Edison) is one of the largest investor-owned utilities in the world.
  - Established in 1823
  - Provides electric, gas and steam services to 9 million people
  - Owns 94,000 miles of underground cable and 34,000 miles of overhead conductors.
- Distribution system at three different voltage levels: 33kV, 27kV and 13kV.

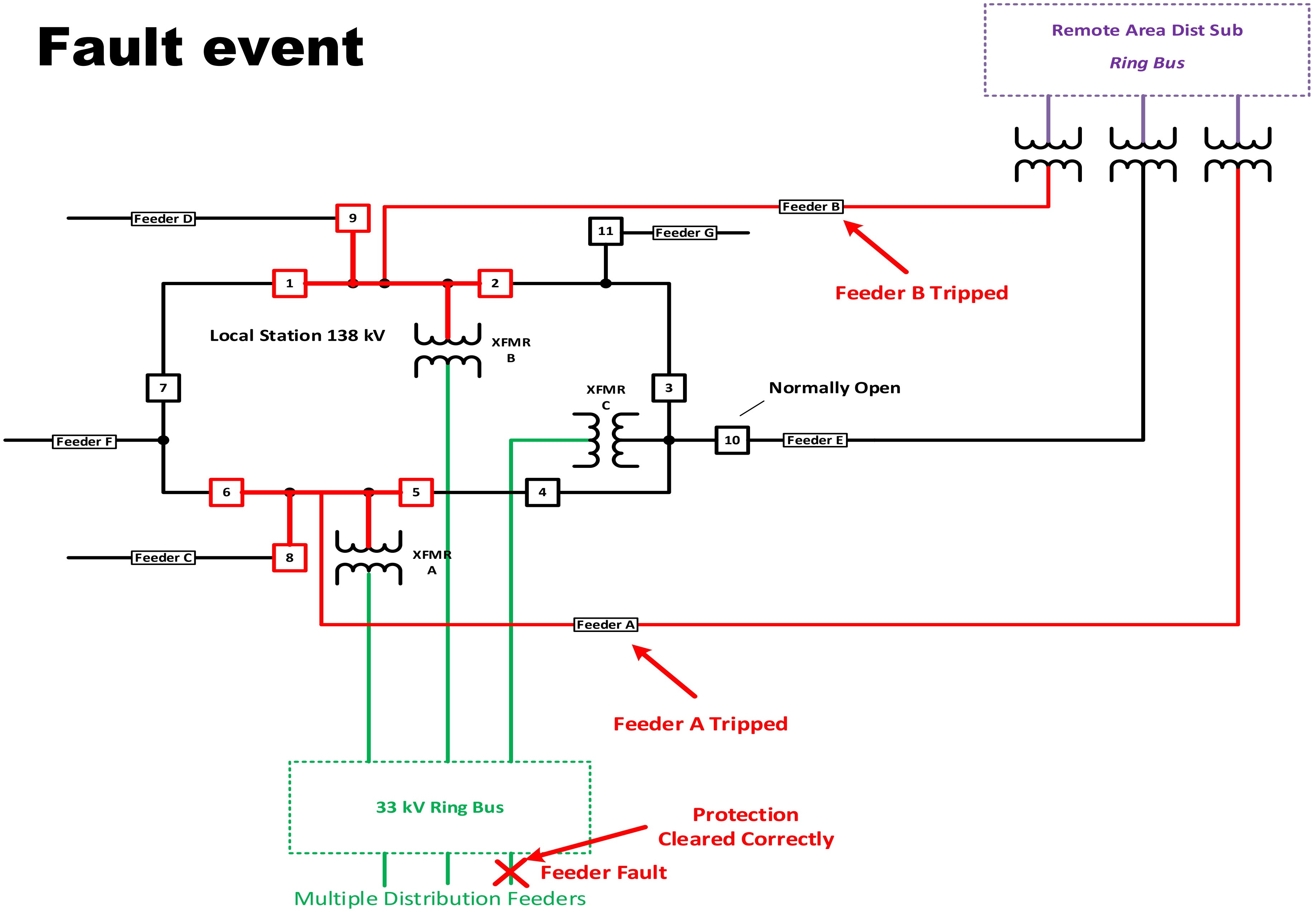


Event Scheme

- 33kV Feeder Protection
  - Protected by Phase to Phase and Phase to Ground relays.
  - Instantaneous and Time over Current elements.
- 138kV Ring Bus and Transmission Feeder Protection
  - Dedicated Local Breakers
  - Connected to the high side delta transformer windings.
  - Protected by Line Differential relays.

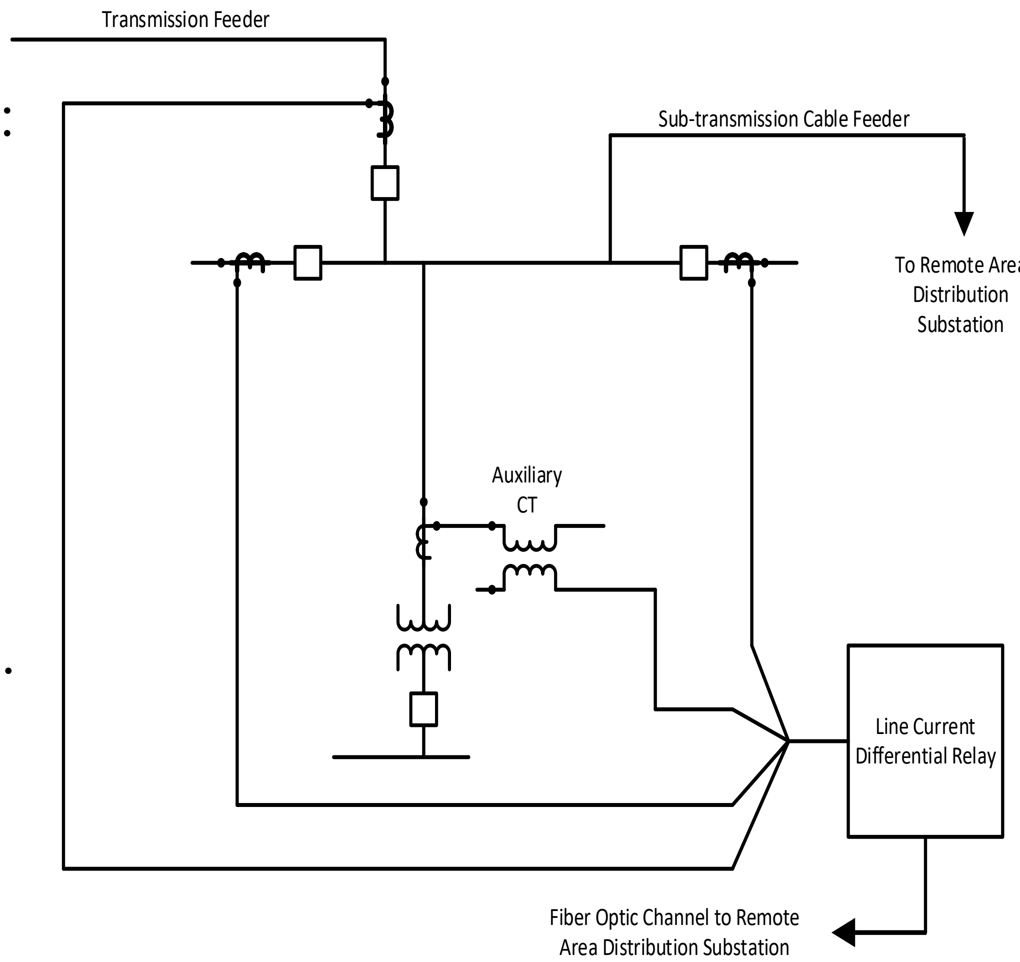


Fault event


Remote Area Dist Sub
Ring Bus
Feeder D
9
Feeder B
11
Feeder G
1
2
Feeder B Tripped
Local Station 138 kV
XFMR
B
XFMR
C
7
3
Normally Open
Feeder F
10
Feeder E
6
5
4
Feeder C
8
XFMR
A
Feeder A
Feeder A Tripped
33 kV Ring Bus
Protection
Cleared Correctly
Feeder Fault
Multiple Distribution Feeders

Event Scheme

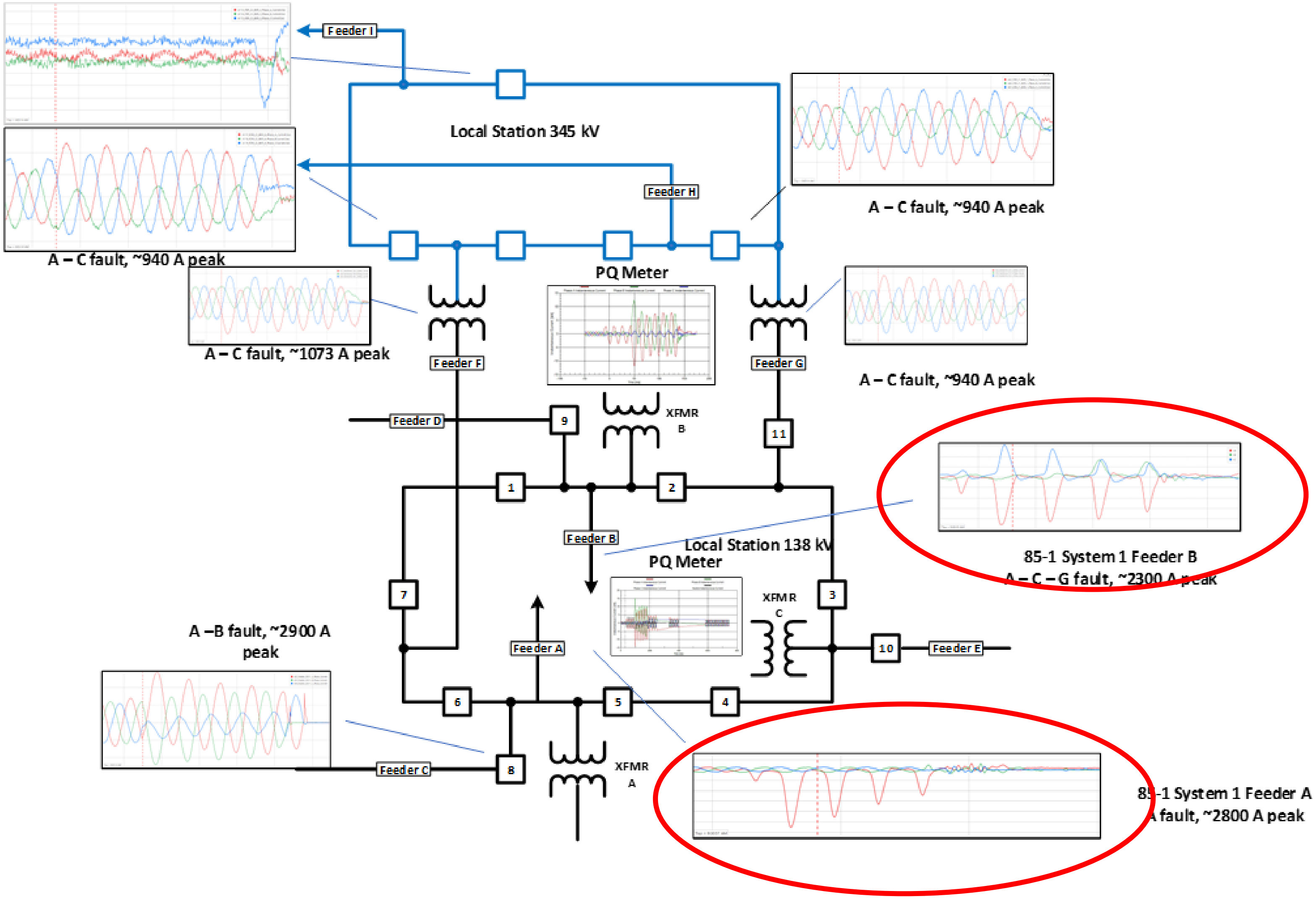
- Line Differential Protection
- External Summation of CTs:
  - Two (2) 138kV bus section breakers CTs
  - Transmission Feeder breaker CT
  - Transformer high side CT connected by Auxiliary CTs.
- Transfer trip to Remote End.
- Limited Relay CT inputs.



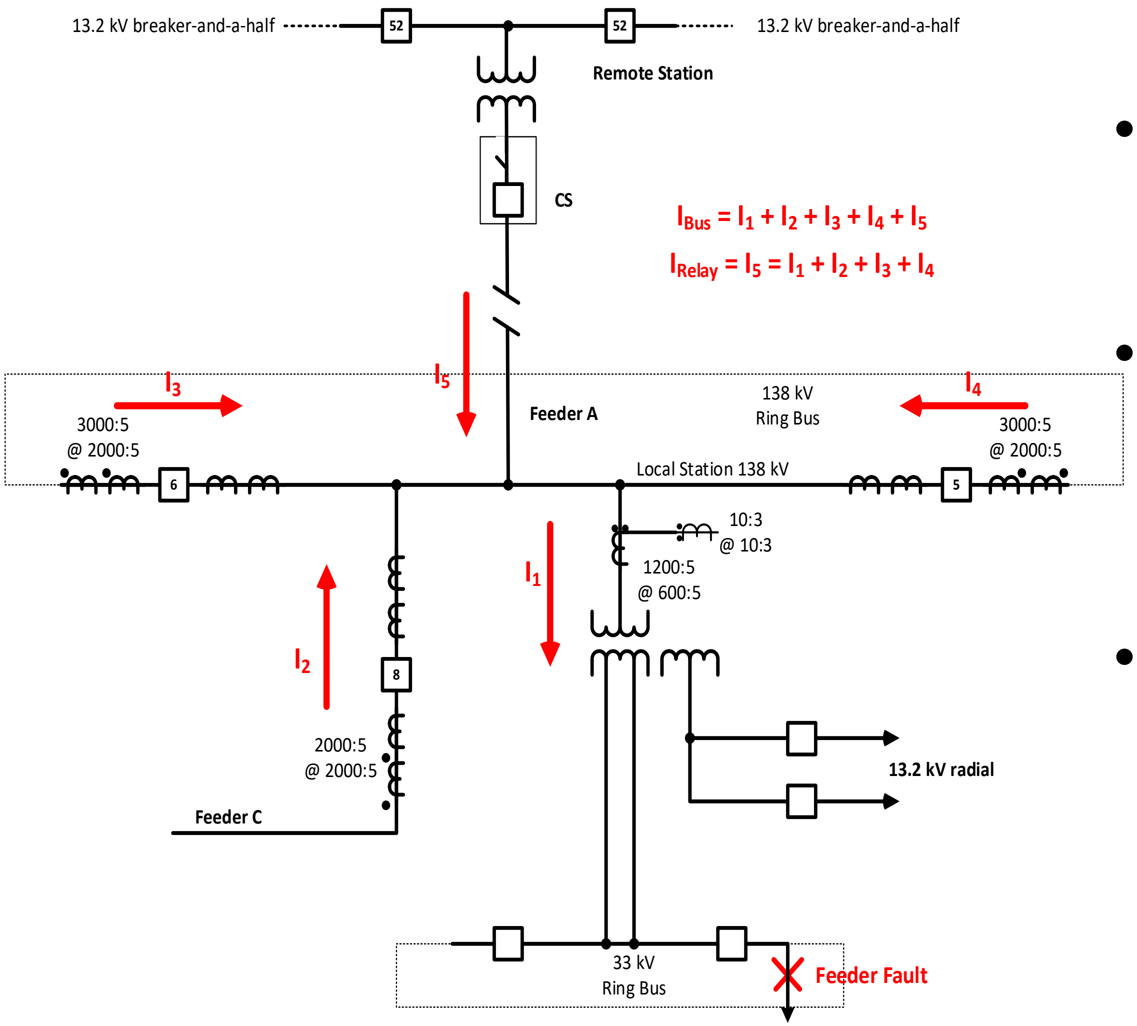
Steps to analyze this event

- Verify protection settings, coordination, short circuit model
- Field verify relay secondary circuits, connections
  - Emphasis on actual burden, CT performance
- Model relay circuits and analyze performance

What do we know about the fault?

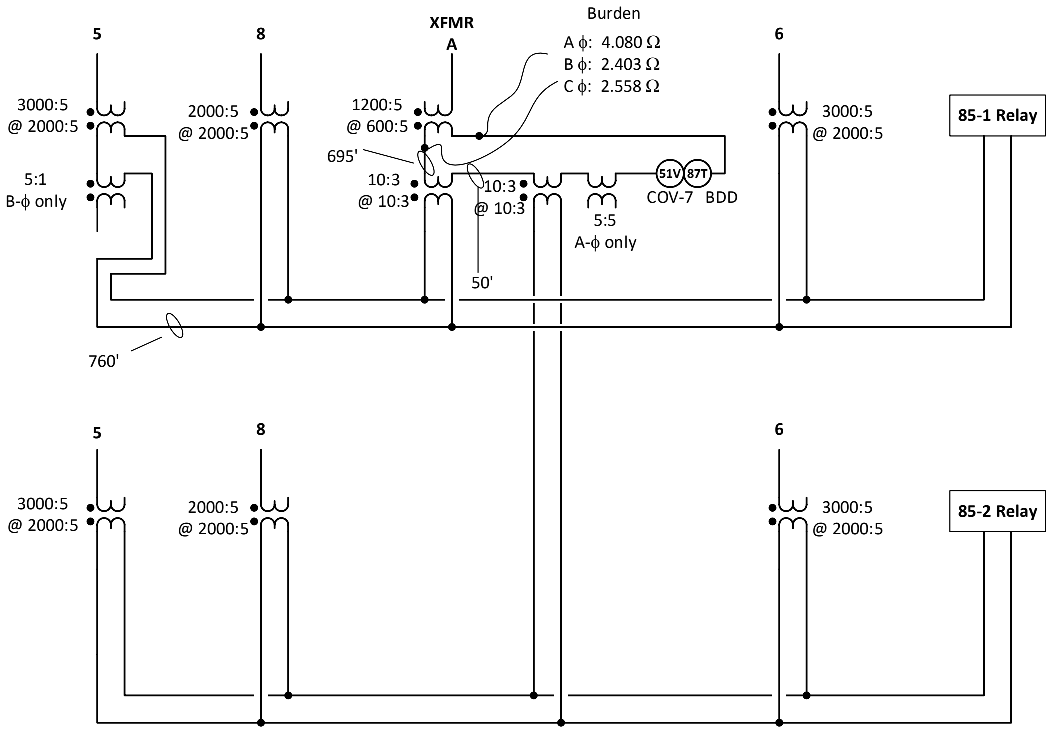


Feeder A arrangement



- Feeder A and Feeder B have the same functional arrangement
- Relay parallels 4 CTs as an input to the relay
  - Essentially measures an error current at all times
- How to determine if this was CT saturation
  - Not a typical waveform for a saturated CT for a fault

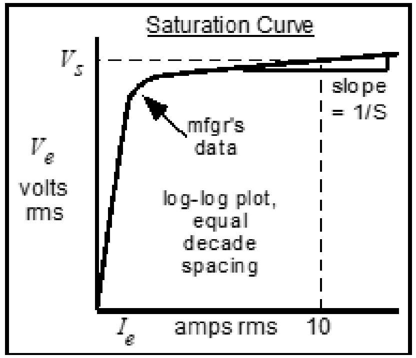
Feeder A CT secondary circuits



- One of these CTs is not like the others:
  - Transformer A has a 1200:5 bushing CT tapped to 600:5.
  - Uses an auxiliary CT for turns ratio correction
- Relatively high connected burdens on these CTs

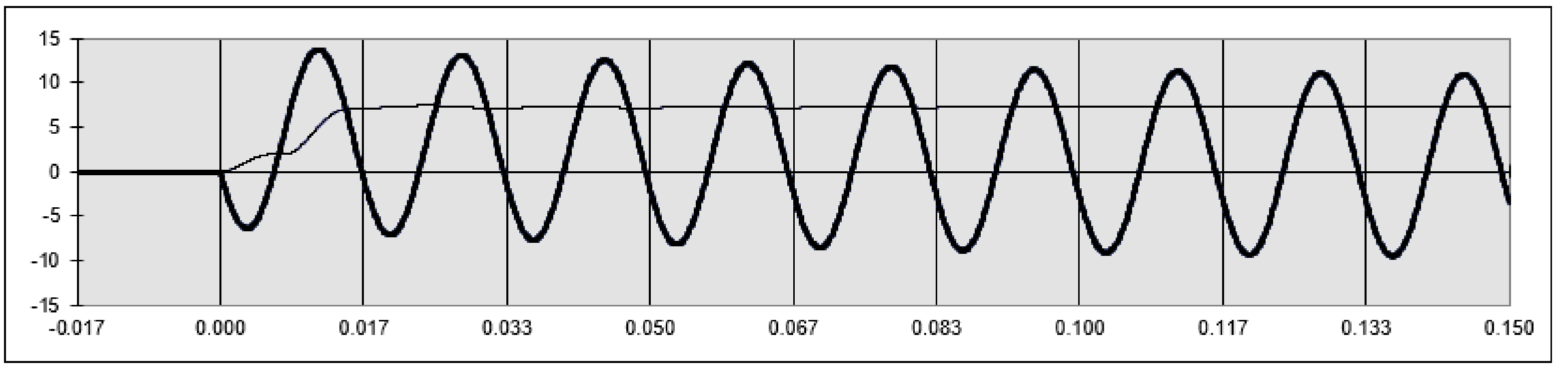
2000:5 CT Analysis

INPUT PARAMETERS:		ENTER:	
Inverse of sat. curve slope =	S =	20	---
RMS voltage at 10A exc. current =	Vs =	800	volts rms
Turns ratio = n2/1=	N =	400	---
Winding resistance =	Rw =	0.750	ohms
Burden resistance =	Rb =	1.558	ohms
Burden reactance =	Xb =	0.000	ohms
System X/R ratio =	XoverR =	30.0	---
Per unit offset in primary current =	Off =	0.39	-1<Off<1
Per unit remanence (based on Vs) =	λrem	0.00	---
Symmetrical primary fault current =	Ip =	2,900	amps rms



CALCULATED:			
Rt =	Total burden resistance = Rw + Rb =	2.308	ohms
pf =	Total burden power factor =	1.000	---
Zb =	Total burden impedance =	2.308	ohms
Tau1 =	System time constant =	0.080	seconds
Lamsat =	Peak flux-linkages corresponding to Vs	3.001	Wb-turns
ω =	Radian freq =	376.99	rad/s
RP =	Rms-to-peak ratio =	0.35408	
A =	Coefficient in instantaneous ie versus lambda curve: ie = A * l^S :	8.04E-09	---
dt =	Time step =	0.000083	seconds
Lb =	Burden inductance =	0.00000	henries

Thick lines: **Ideal (blue)** and **actual (black)** secondary current in amps vs time in seconds.
Thin lines: **Ideal (blue)** and **actual (black)** secondary current extracted fundamental rms value, using a simple DFT with a one-cycle window.

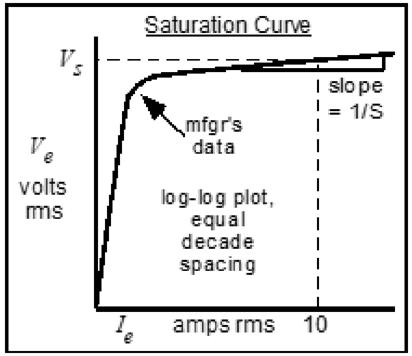


Used PSRC CT Saturation Calculator to model the Breaker 8 (I_2 current) CT that sees almost all the fault current

No saturation - none of the 2000:5 CTs will saturate for the available fault current, even fully offset

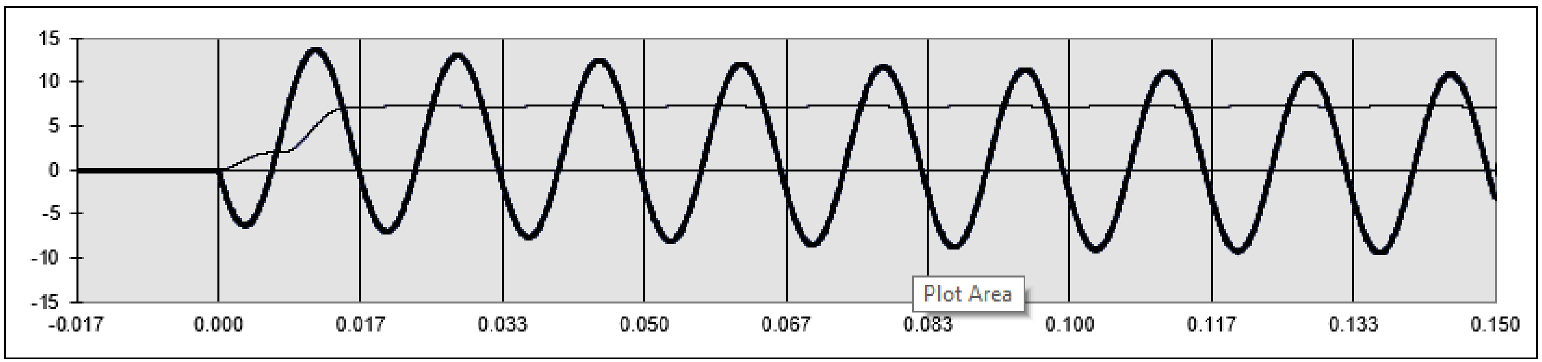
Auxiliary CT analysis

INPUT PARAMETERS:		ENTER:	
Inverse of sat. curve slope =	S =	20	---
RMS voltage at 10A exc. current =	Vs =	200	volts rms
Turns ratio = n2/1=	N =	3	---
Winding resistance =	Rw =	0.750	ohms
Burden resistance =	Rb =	0.110	ohms
Burden reactance =	Xb =	0.000	ohms
System X/R ratio =	XoverR =	30.0	---
Per unit offset in primary current =	Off =	0.39	-1<Off<1
Per unit remanence (based on Vs) =	λrem	0.00	---
Symmetrical primary fault current =	Ip =	24	amps rms



CALCULATED:			
Rt =	Total burden resistance = Rw + Rb =	0.860	ohms
pf =	Total burden power factor =	1.000	---
Zb =	Total burden impedance =	0.860	ohms
Tau1 =	System time constant =	0.080	seconds
Lamsat =	Peak flux-linkages corresponding to Vs	0.750	Wb-turns
ω =	Radian freq =	376.99	rad/s
RP =	Rms-to-peak ratio =	0.35408	
A =	Coefficient in instantaneous ie versus lambda curve: ie = A * l^S :	8.84E+03	---
dt =	Time step =	0.000083	seconds
Lb =	Burden inductance =	0.00000	henries

Thick lines: Ideal (blue) and **actual (black)** secondary current in amps vs time in seconds.
Thin lines: Ideal (blue) and **actual (black)** secondary current extracted fundamental rms value, using a simple DFT with a one-cycle window.

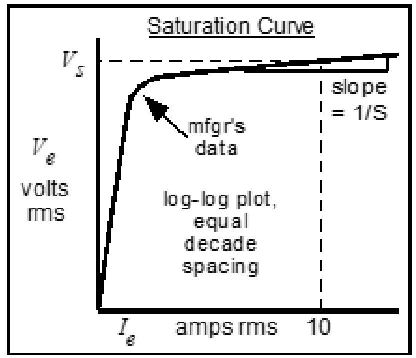


No saturation for this fault event – will faithfully reproduce the output of the bushing CT.

Transformer A bushing CT analysis

INPUT PARAMETERS:

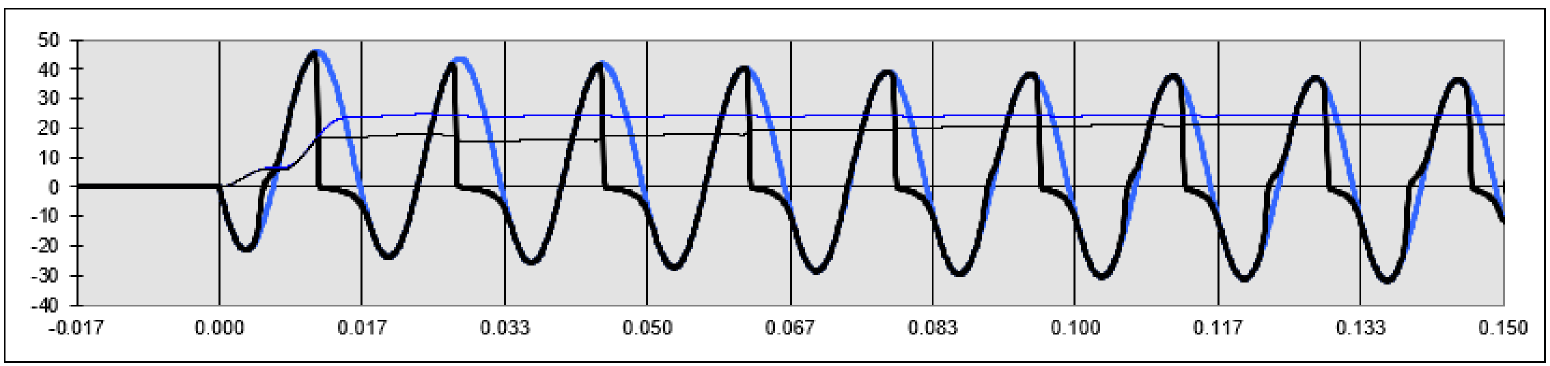
		ENTER:	
Inverse of sat. curve slope =	S =	20	---
RMS voltage at 10A exc. current =	Vs =	100	volts rms
Turns ratio = n2/1=	N =	120	---
Winding resistance =	Rw =	0.750	ohms
Burden resistance =	Rb =	4.080	ohms
Burden reactance =	Xb =	0.000	ohms
System X/R ratio =	XoverR =	30.0	---
Per unit offset in primary current =	Off =	0.39	-1<Off<1
Per unit remanence (based on Vs) =	λrem	0.00	---
Symmetrical primary fault current =	Ip =	2,900	amps rms



CALCULATED:

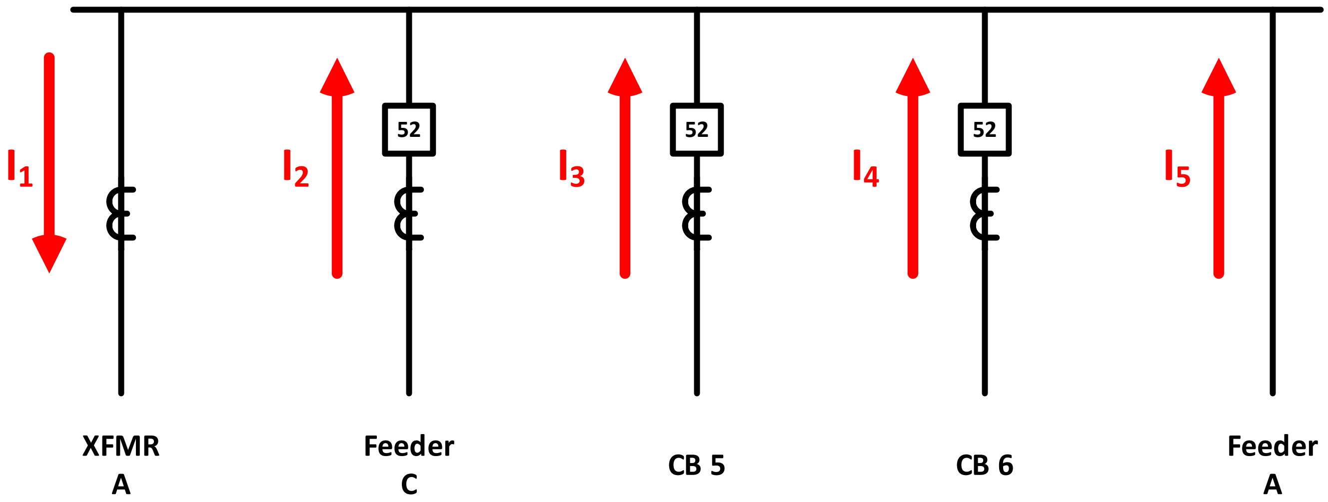
Rt =	Total burden resistance = Rw + Rb =	4.830	ohms
pf =	Total burden power factor =	1.000	---
Zb =	Total burden impedance =	4.830	ohms
Tau1 =	System time constant =	0.080	seconds
Lamsat =	Peak flux-linkages corresponding to Vs	0.375	Wb-turns
ω =	Radian freq =	376.99	rad/s
RP =	Rms-to-peak ratio =	0.35408	
A =	Coefficient in instantaneous ie versus lambda curve: ie = A * l^S :	9.27E+09	---
dt =	Time step =	0.000083	seconds
Lb =	Burden inductance =	0.00000	henries

Thick lines: Ideal (blue) and **actual (black)** secondary current in amps vs time in seconds.
Thin lines: Ideal (blue) and **actual (black)** secondary current extracted fundamental rms value, using a simple DFT with a one-cycle window.

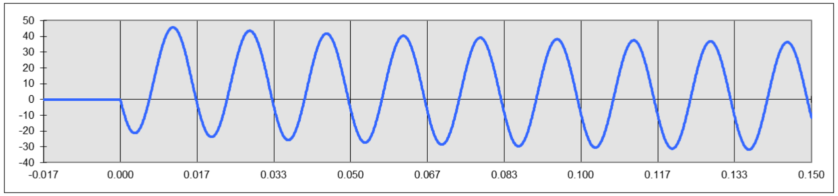


C200 tapped down to 50% winding (effectively a C100), high connected burden

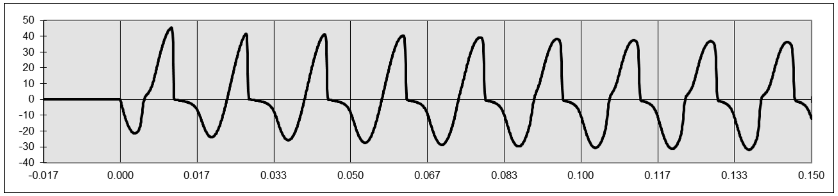
What does the relay see



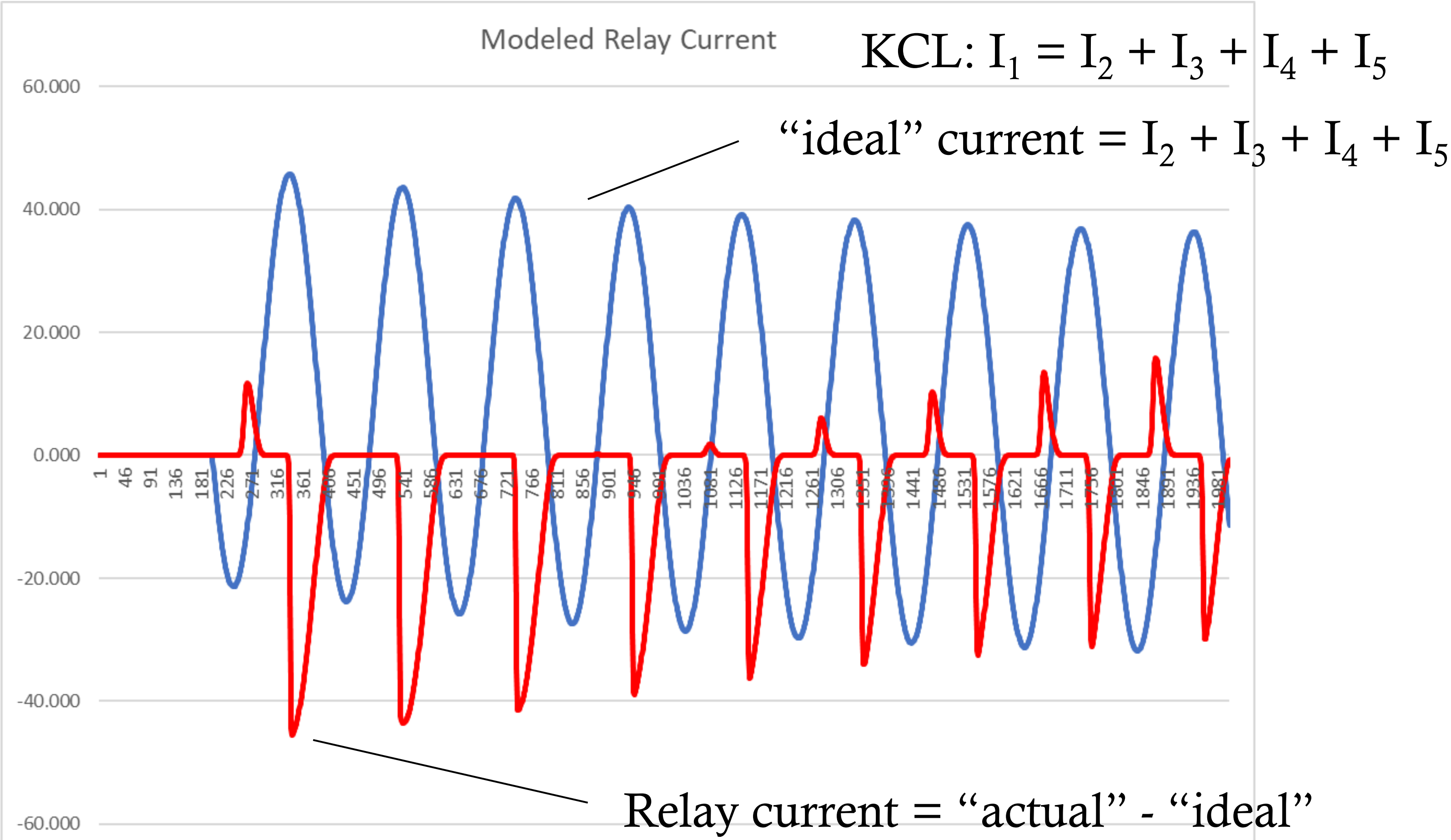
$I_2 + I_3 + I_4 =$



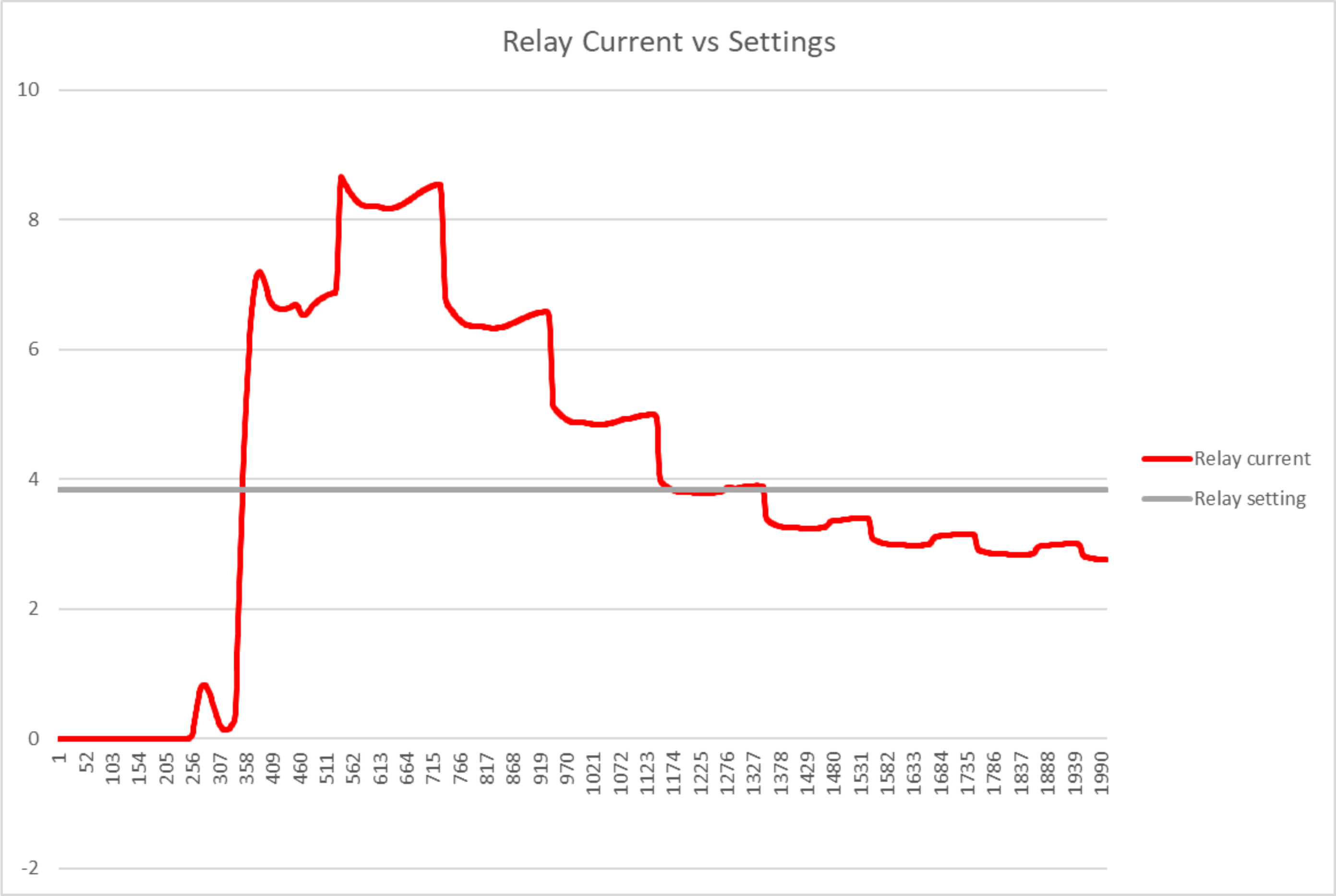
$I_1 =$



Relay error current

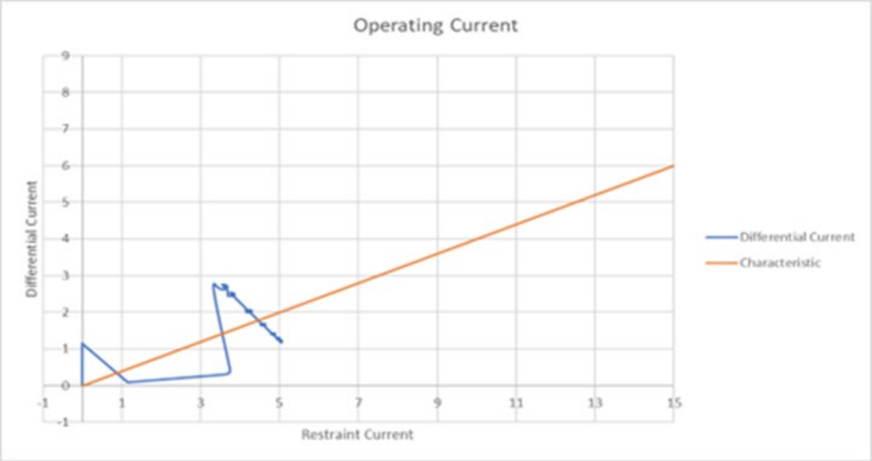


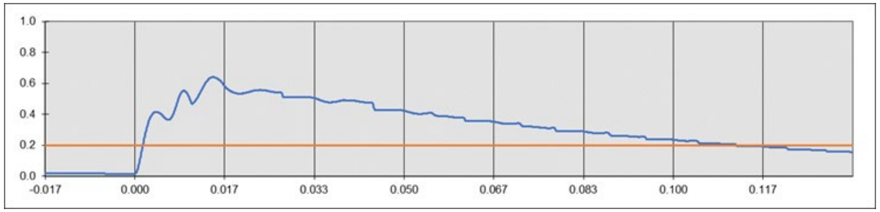
Differential relay operation



Used a 1-cycle DFT to calculate a phasor quantity for the CT error current

Why didn't the transformer differential operate?





- Modeled characteristic in CT Saturation Calculator
  - Saturated high-side CT
  - Unsaturated low-side CT
  - Enough differential current to operate
- Answer: 2nd harmonic restraint
  - Calculated 2nd harmonic of saturated CT in CT Saturation Calculator

Event Testing and Results

- Secondary Circuit Burden Test
  - Full circuit burden test.
  - The A Phase had a high burden of 4 ohms.
- Current Transformer Excitation Test
  - All nameplate values were confirmed.
  - The 600/5 Transformer CTs saturated at an unacceptable level.
- Current Transformer and Second Circuit Insulation Resistance Tests
  - All insulation resistance testing results were satisfactory.

Corrective Action Plan

- Corrective Action Recommendations:
  - In order to address the under dimensioned CT concerns, the differential relay setting was increased in order to reduce the likelihood of undesirable operations for similar fault events.
- Fault studies confirmed that de-sensitizing the relays did not impact protection dependability.

Lessons Learned

- Avoid wired parallel connections of CTs.
- Install or retrofit CTs of appropriate accuracy class and ratio.
- Assess CT accuracy and performance during the design phase.
- Establish standard CT application categories.
- Specify standard CTs including accuracy class, use of full tap, etc.
- Confirm CT and scheme performance at the extreme fault scenarios to reduce CT saturations and misoperations.
- Check wiring conditions, insulation performance, and circuit grounding during commissioning.
- Develop standard relay setting criteria, especially for differential relays.


OPERATE
ANALYZE
IMPROVE
CONTINUOUS IMPROVEMENT