Influence of CT Saturation on Protection Schemes

Basics of CT

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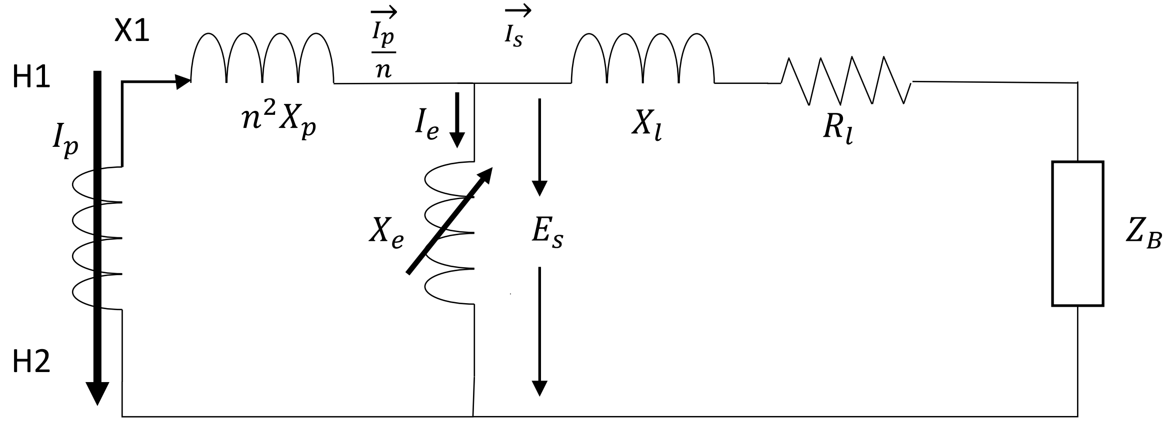
Current Transformer equivalent Circuit



E_s: Excitation Voltage

I_e:Excitation Current

X_e: Excitation Impedance

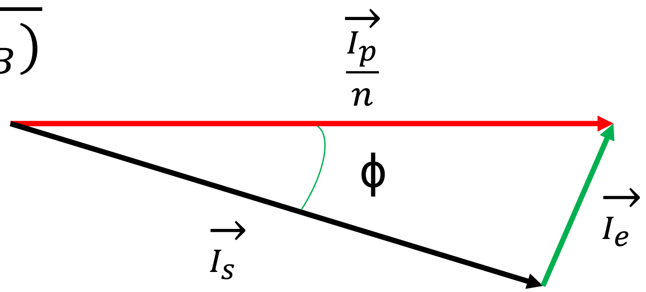
I_s: Secondary Current.

Z_B: Secondary Burden.

Real CT

$$Ip\ /(Is+Ie) = Ns/Np$$

$$I_e = \frac{\frac{I_s}{n}(R_i + jX_i + Z_B)}{X_e + (R_i + jX_i + Z_B)}$$



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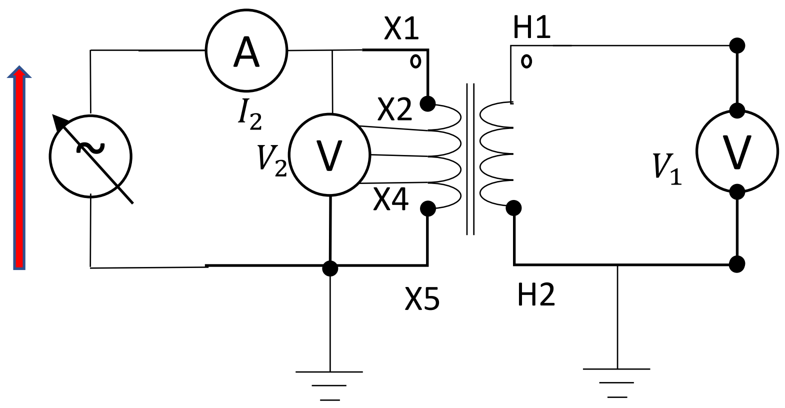
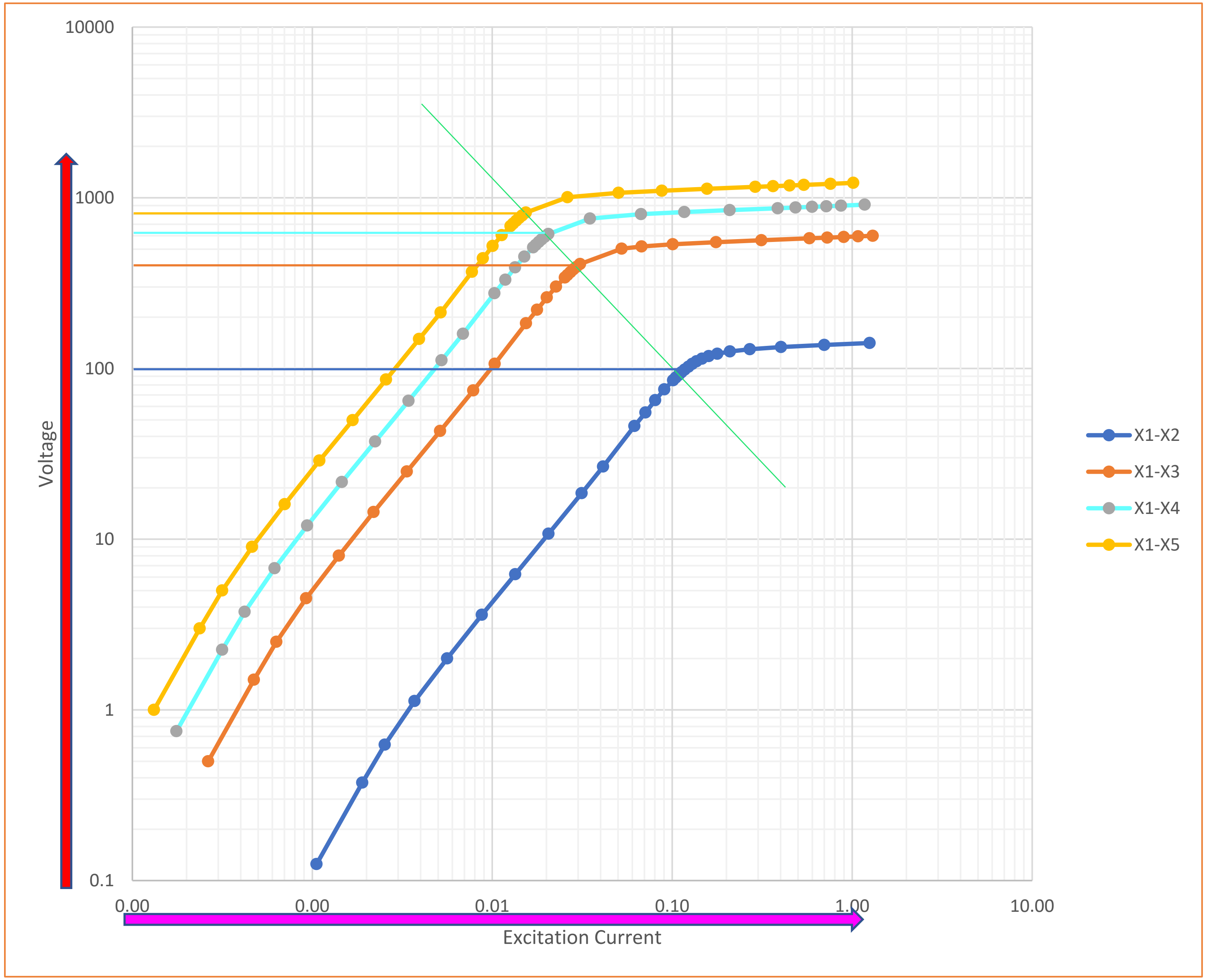
CT Saturation

Excitation curve





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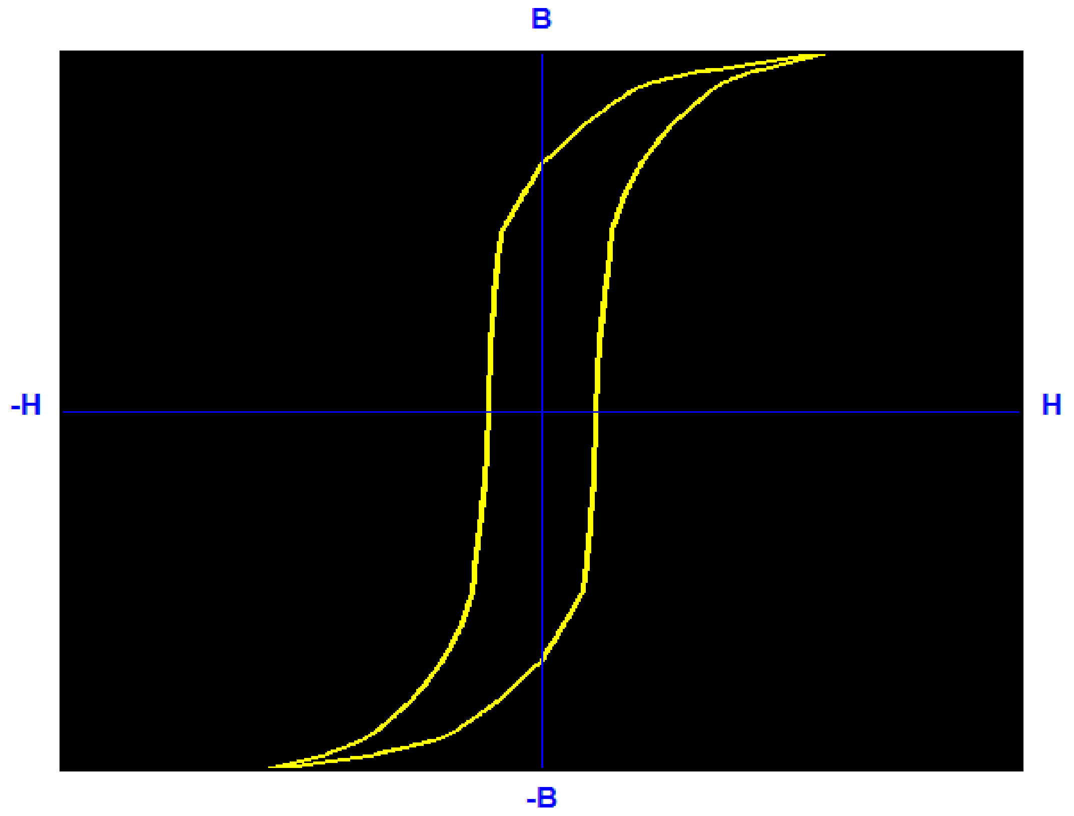
Hysteresis



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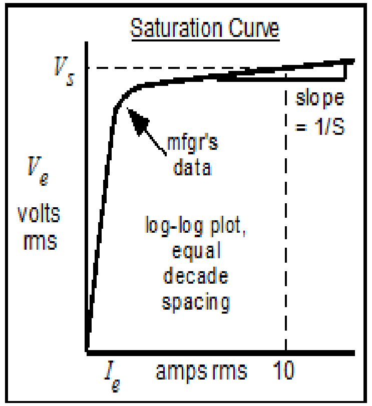
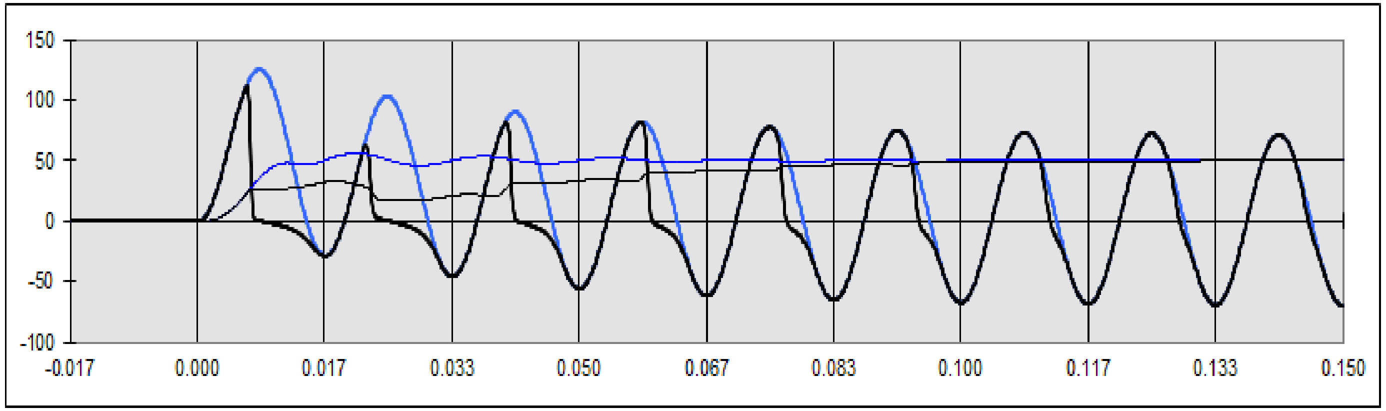
PSRC model

INPUT PARAMETERS:		ENTER:	
Inverse of sat. curve slope =	S =	22	---
RMS voltage at 10A exc. current =	Vs =	400	volts rms
Turns ratio = n2/1=	N =	300	---
Winding resistance =	Rw =	0.500	ohms
Burden resistance =	Rb =	4.000	ohms
Burden reactance =	Xb =	0.000	ohms
System X/R ratio =	XoverR =	12.0	---
Per unit offset in primary current =	Off =	1.00	-1<Off<1
Per unit remanence (based on Vs) =	λrem	0.00	---
Symmetrical primary fault current =	Ip =	15,000	amps rms



CALCULATED:			
Rt =	Total burden resistance = Rw + Rb =	4.500	ohms
pf =	Total burden power factor =	1.000	---
Zb =	Total burden impedance =	4.500	ohms
Tau1 =	System time constant =	0.032	seconds
Lamsat =	Peak flux-linkages corresponding to Vs	1.501	Wb-turns
ω =	Radian freq =	376.99	rad/s
RP =	Rms-to-peak ratio =	0.34584	
A =	Coefficient in instantaneous ie versus lambda curve: ie = A * l^S :	3.83E-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.



How does saturation affect Protection

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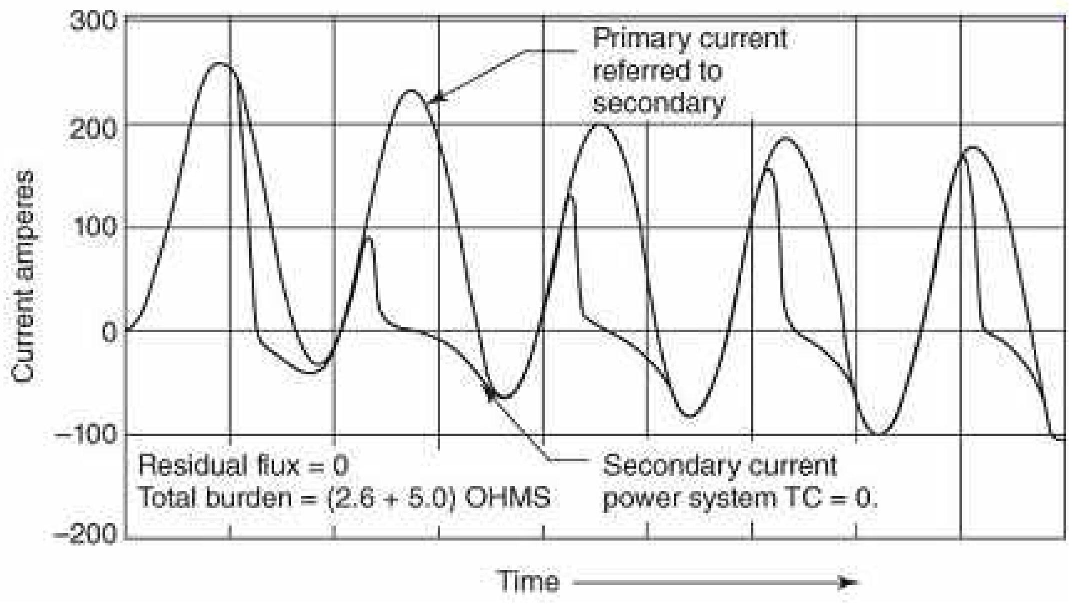
CT Saturation

- Once CT saturation occurs, ratio error increases and secondary current is no more linear to primary current
- AC Saturation (AC components):
  - High symmetrical faults
  - Contains only odd harmonics
- DC Saturation (DC + AC):
  - Asymmetrical faults
  - Motor starting
  - Generator synchronization
  - Contains both odd and even harmonics

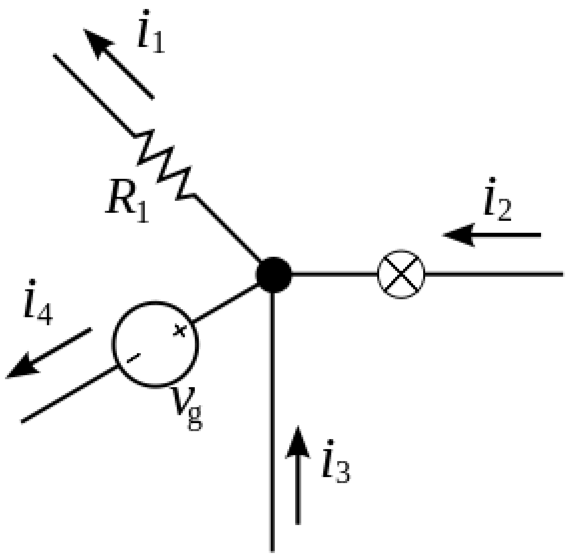


Differential

Current Differential (87)

- Kirchhoff's Current Law: The sum of the currents into a point must equal zero

- What goes in, must come out



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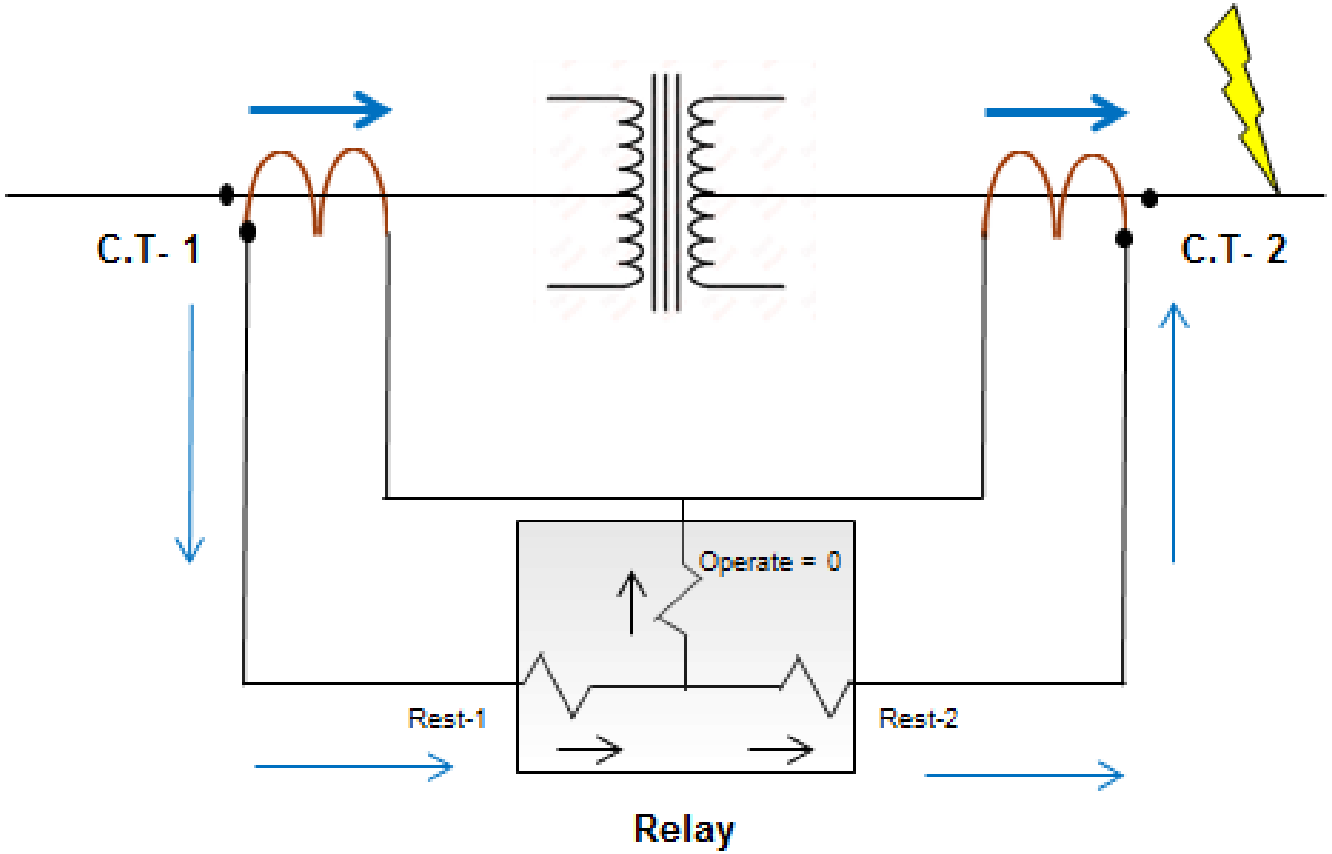
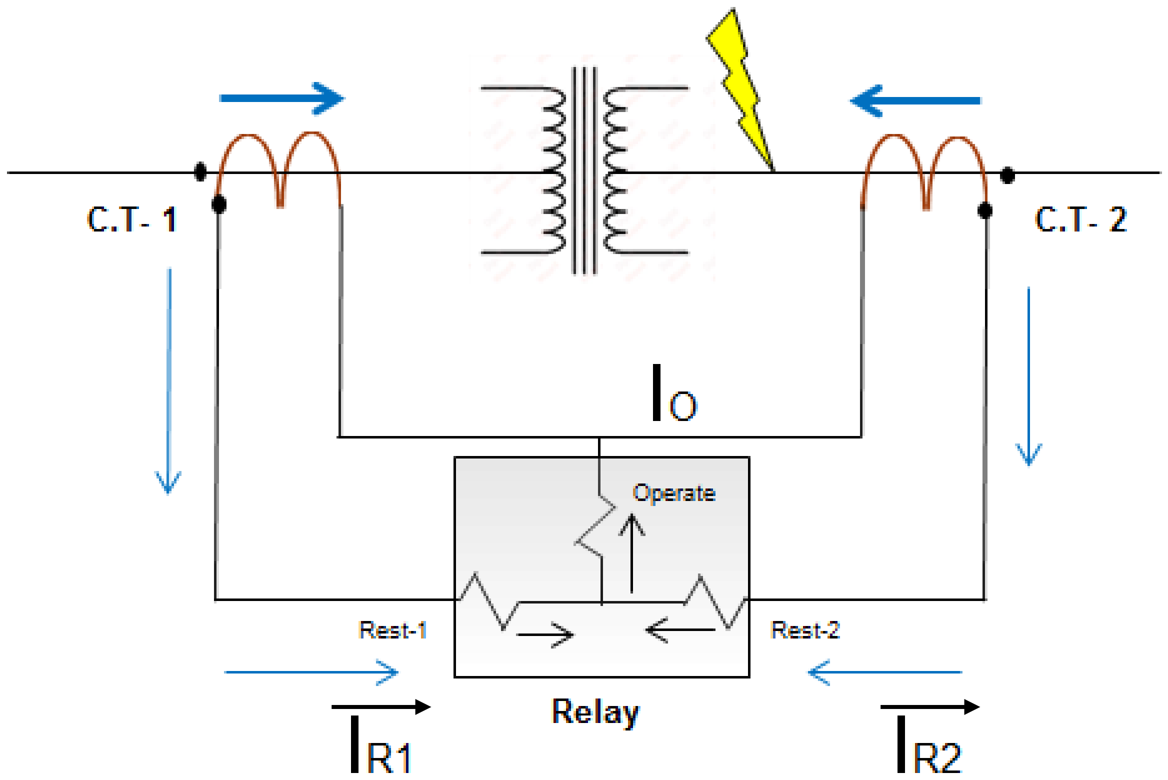
Differential Principle: External Fault



- **Ideally**, no current in operating coil for external faults

Differential Principle: Internal Fault



Operate when

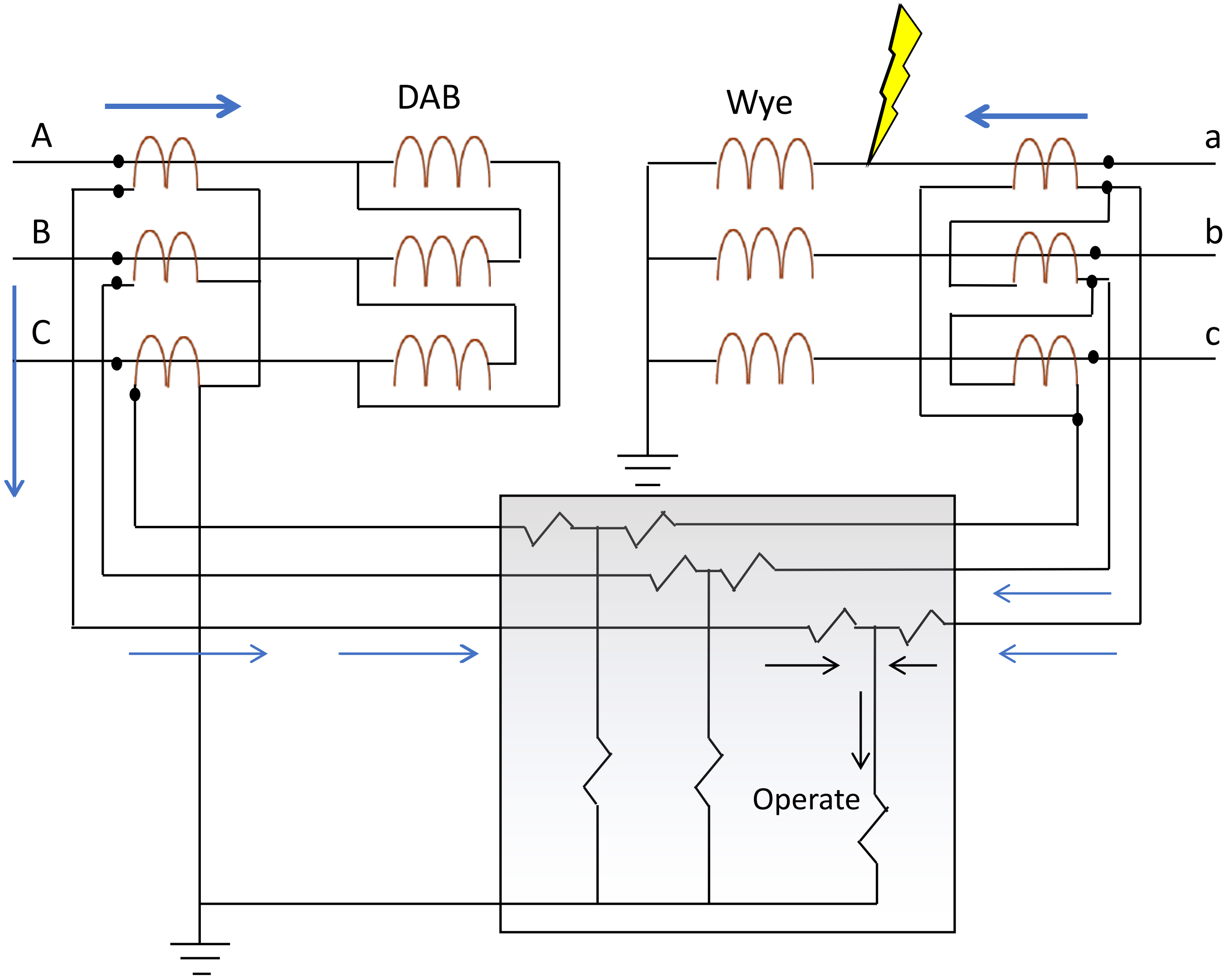
$I_{Operate} > k \times I_{Restrain}$

$I_O = \overrightarrow{I_{R1}} + \overrightarrow{I_{R2}}$

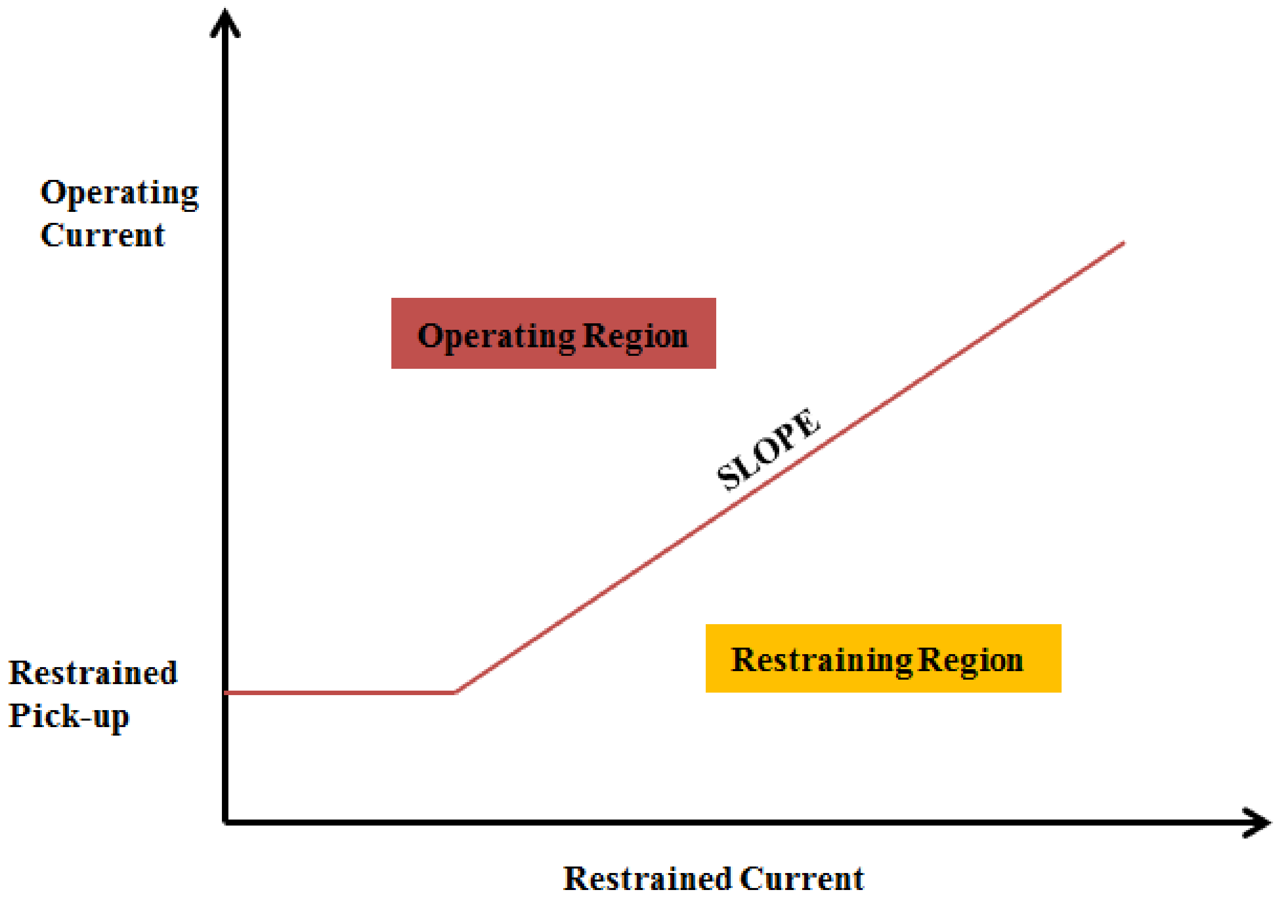
$I_R = (\overrightarrow{I_{R1}} + \overrightarrow{I_{R2}})/2$

- Any fault within the zone CT-1 and CT-2 is internal fault

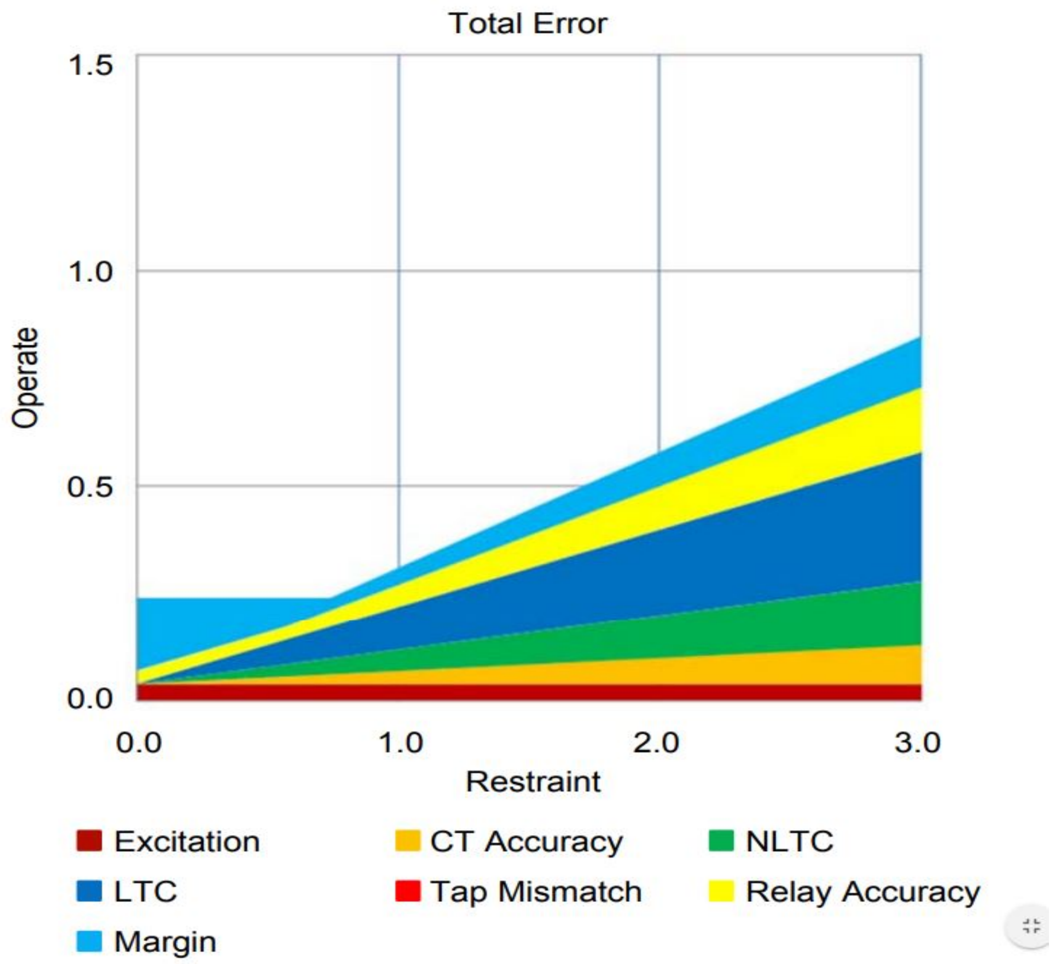
Differential Principle: Three Phase



Differential



Differential Slope : Steady State Errors



- Michael Thompson, "Percentage Restrained Differential, Percentage of What?", originally presented at the proceedings of 37th Annual Western Protective Relay Conference, Spokane, WA, October 2010

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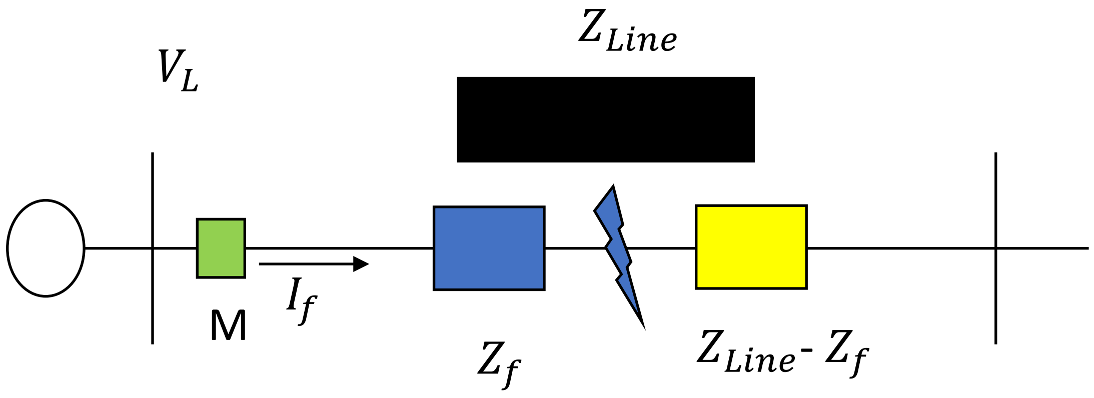
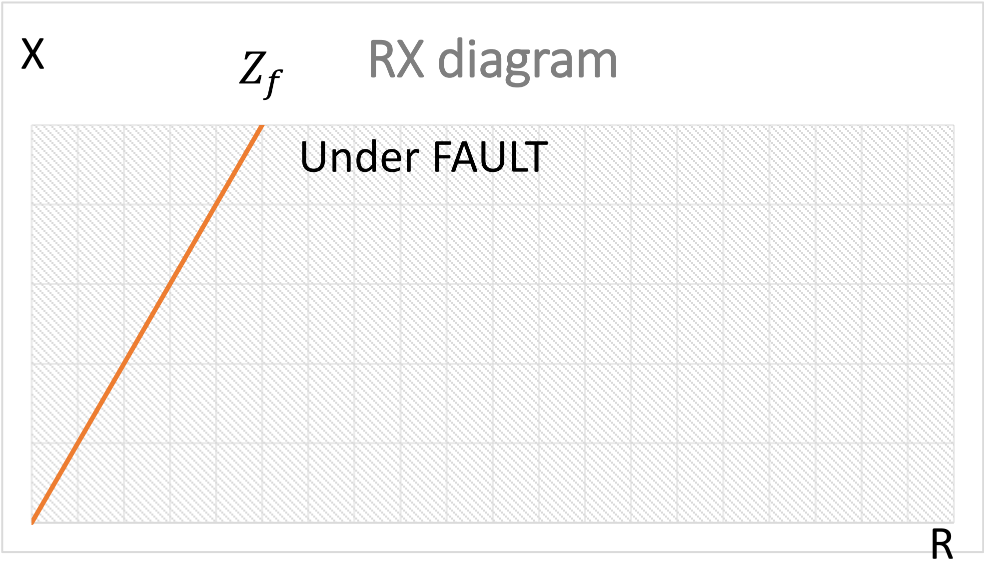
Distance

Distance



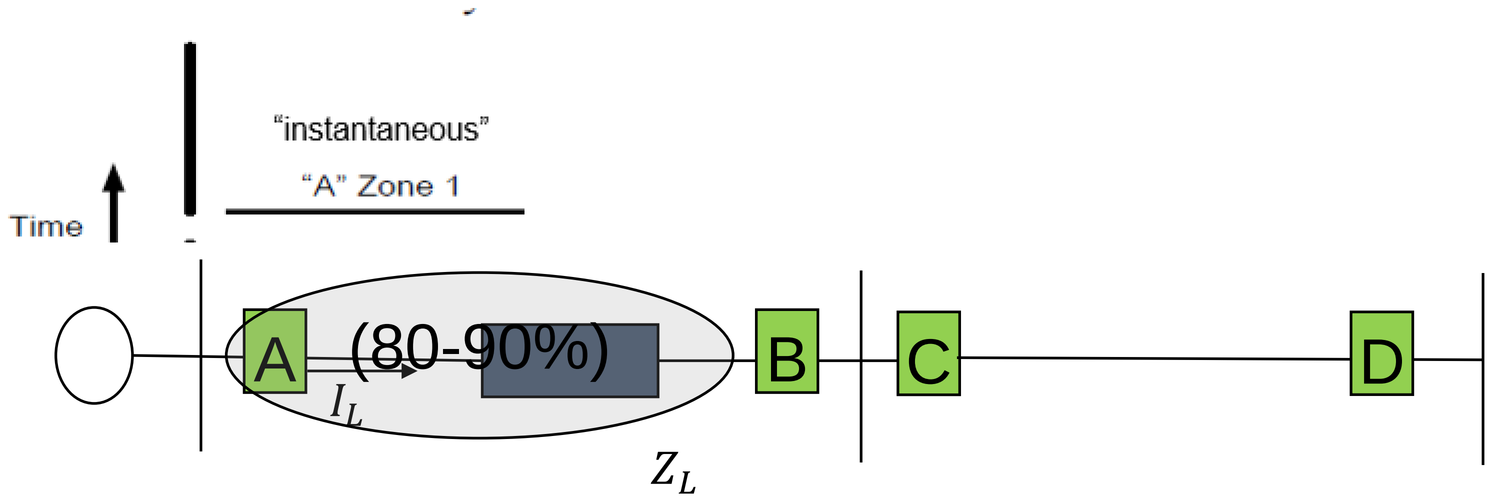
$Z_f = \frac{V_L}{I_f}$

$I_f >> I_{Load}$



Zones of Protection

Zone 1



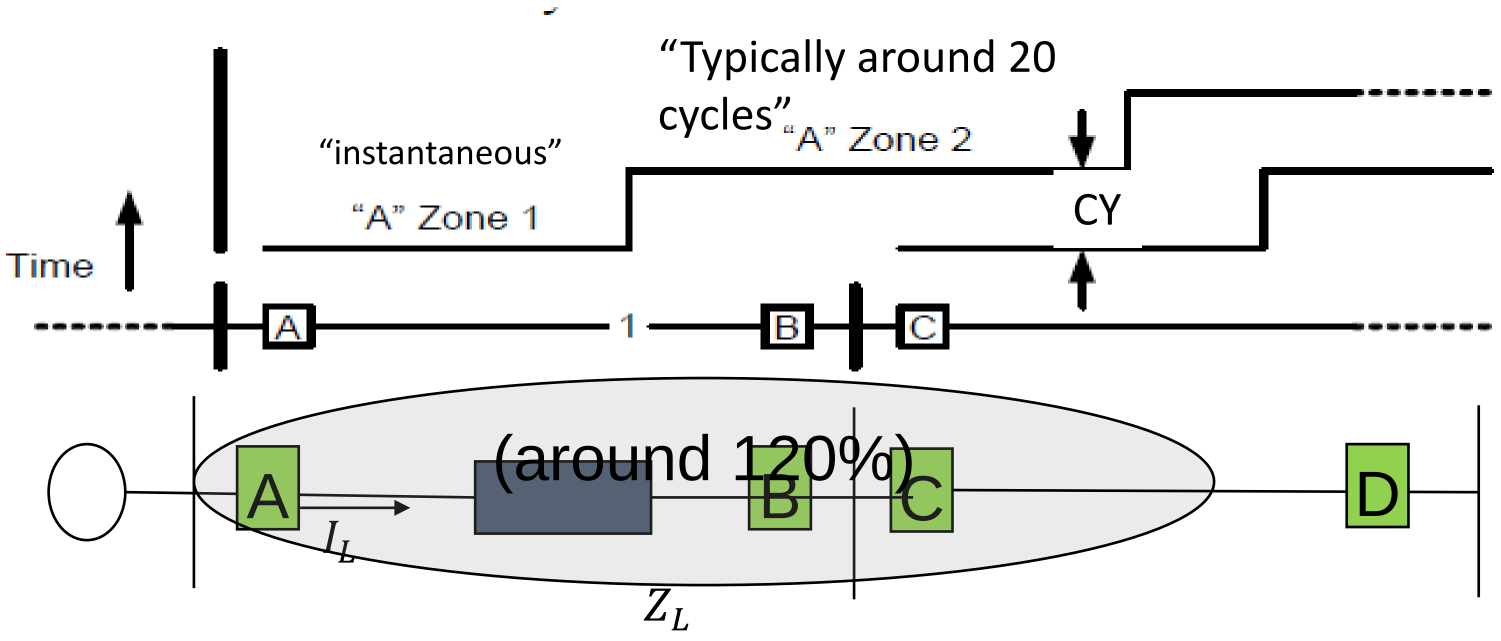
- Zone 1 should not reach beyond remote bus
- Use 10 to 20% as safety factor

Inaccuracies

- Relay measurement accuracies
- Current and potential transformers errors and transient behaviour
- Line impedances values are approximations.
- CVT transients

Zones of Protection

Zone 2



It is not instantaneous.

Time should provide enough time for the operation of zone 1 protection and breaker on B to operate.

Should not reach beyond D

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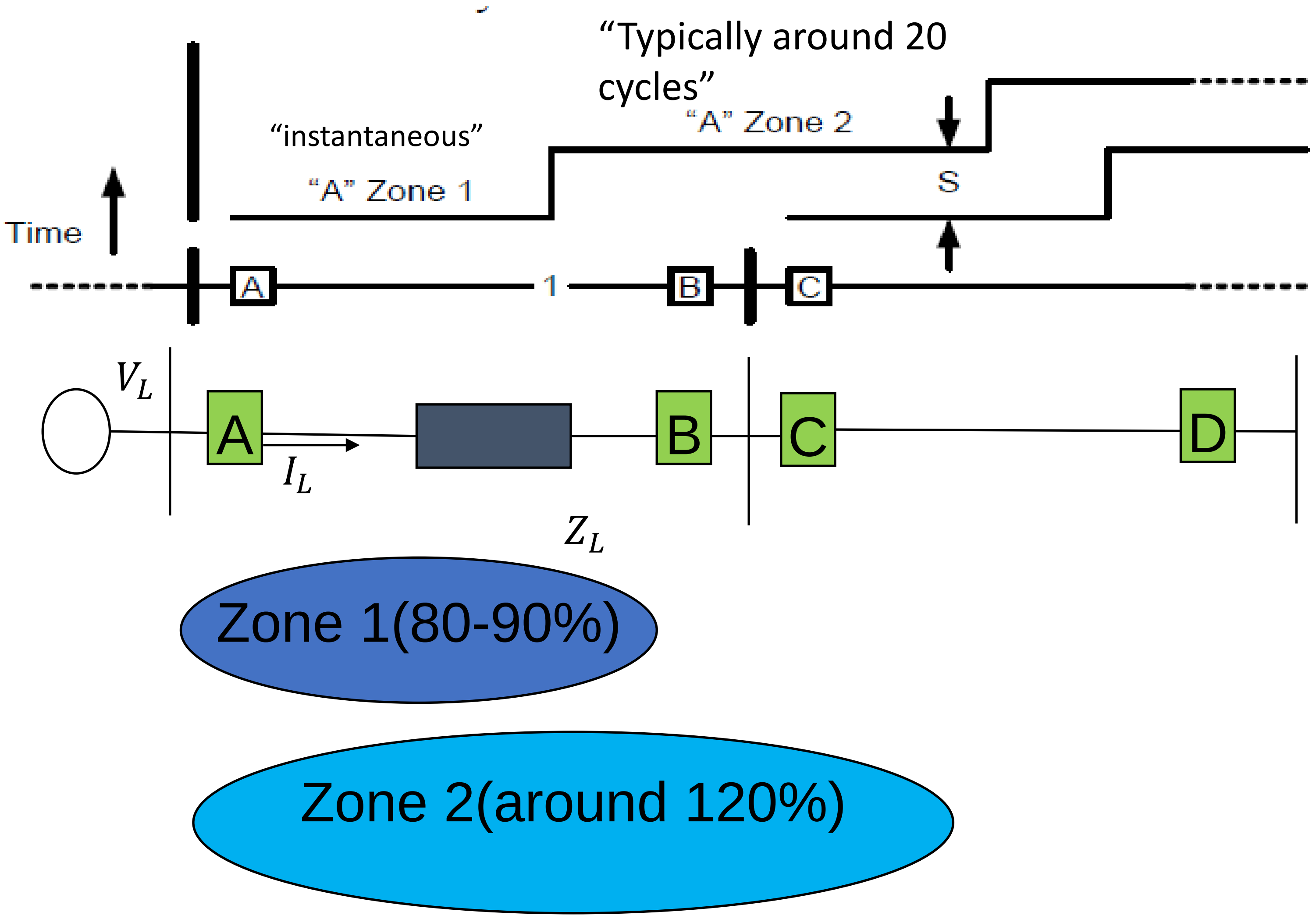
Zones of Protection



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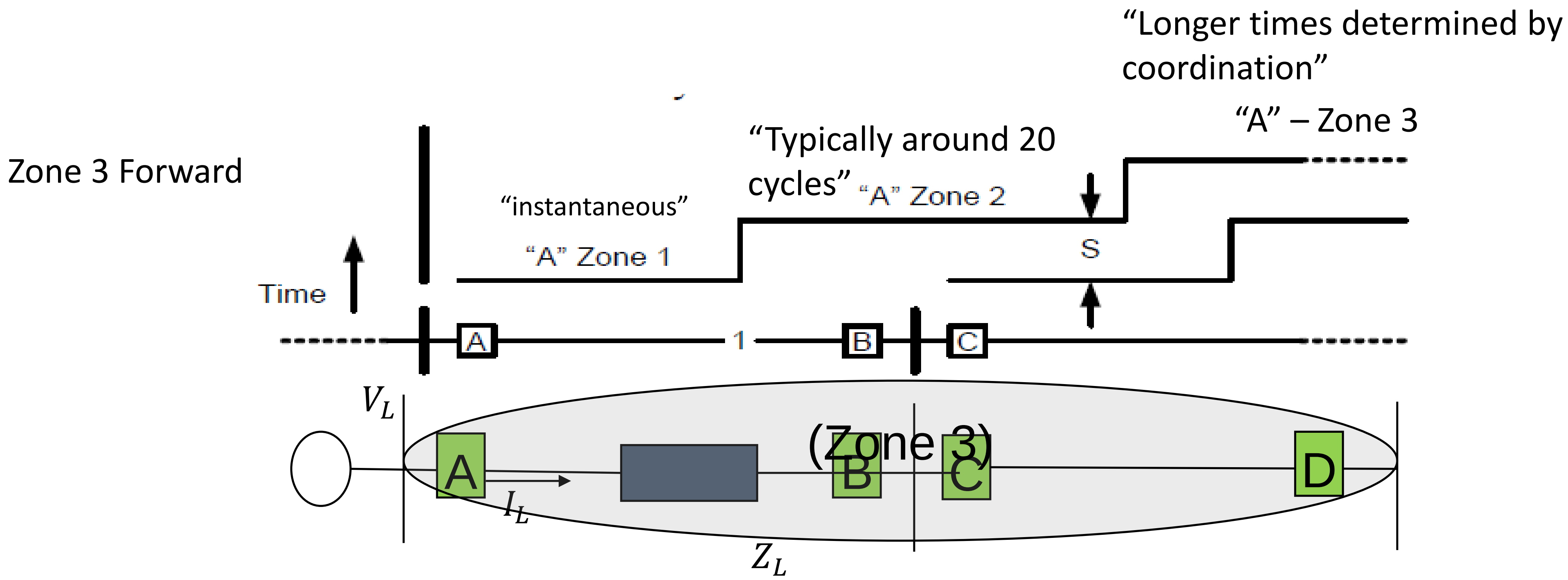
Zones of Protection

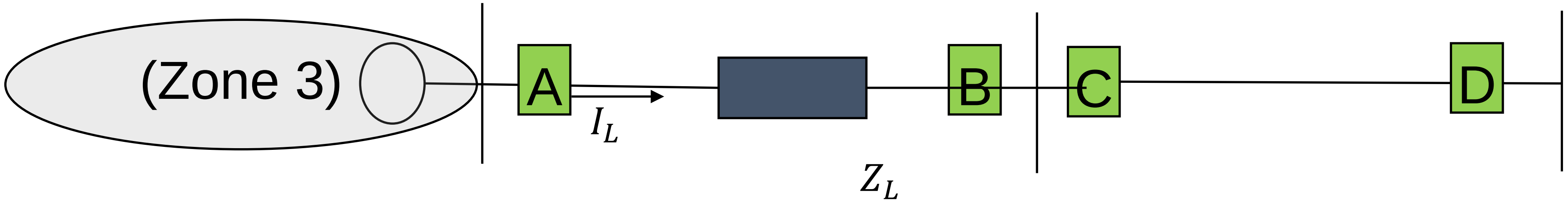


It is not instantaneous.
Time should provide enough time for the operation of zone 1 protection and breaker on B to operate.
Should not reach beyond D

Zones of Protection

"Longer times determined by coordination"

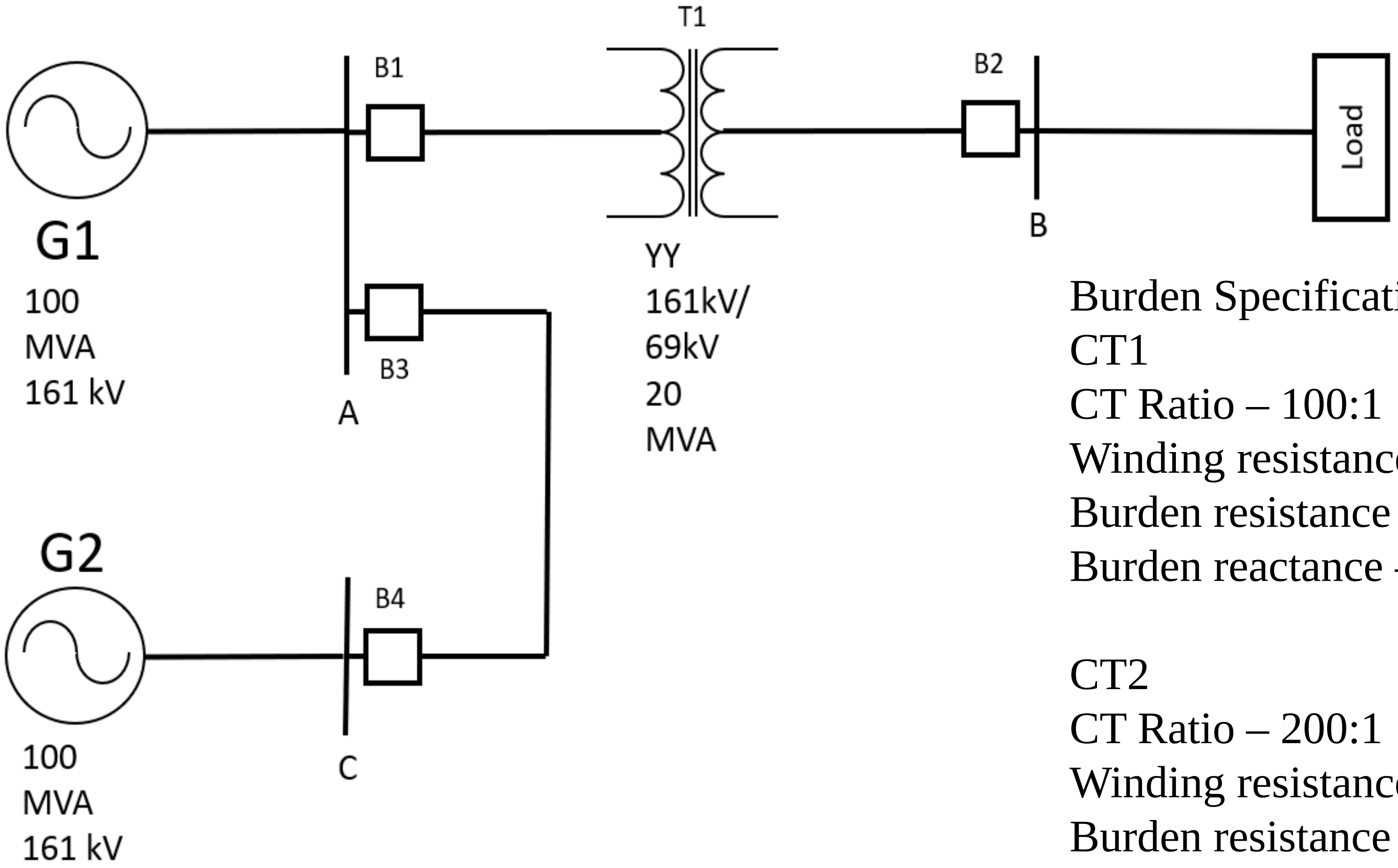
Zone 3 Reverse



It is not instantaneous.
Time should provide enough time for the operation of zone 1 of protection and breaker behind A to operate.
Should not reach very deep into the line behind A

System under consideration

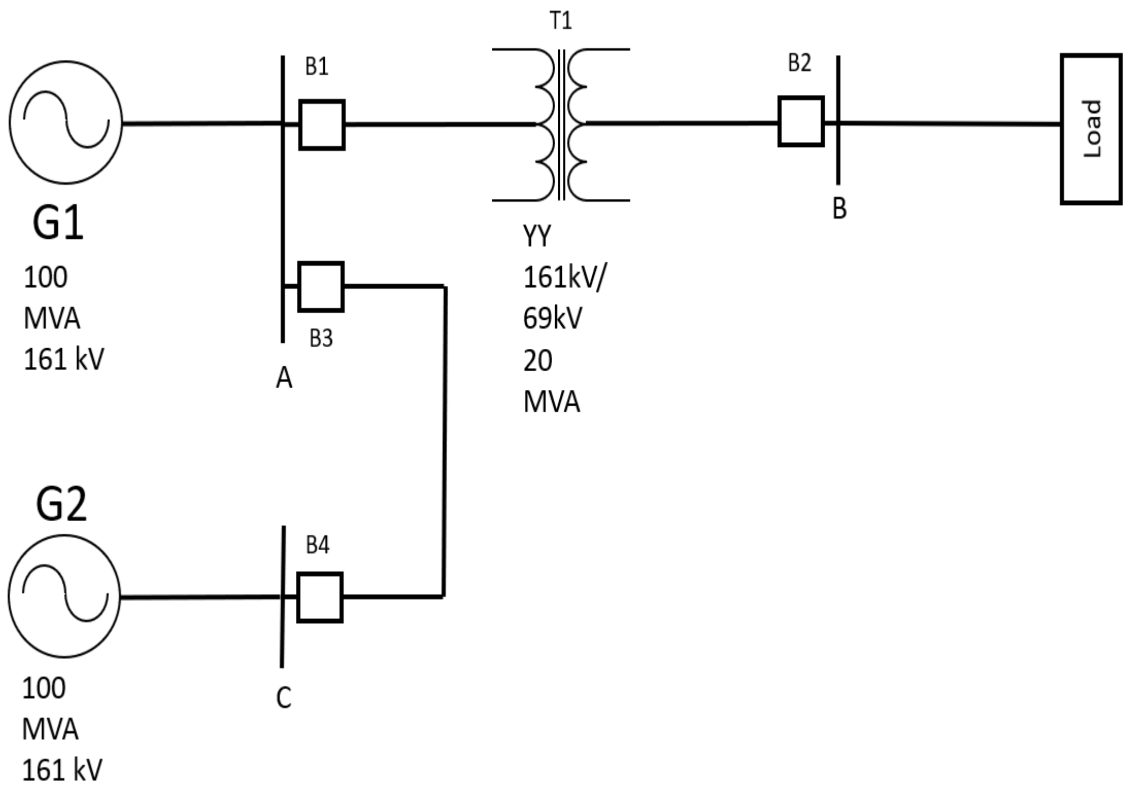
Simulated Line



Burden Specifications –
CT1
CT Ratio – 100:1
Winding resistance – 0.001 ohms
Burden resistance – 0.865 ohms
Burden reactance – 0.5 ohms

CT2
CT Ratio – 200:1
Winding resistance – 0.001 ohms
Burden resistance – 1.94 ohms
Burden reactance – 0.5 ohms

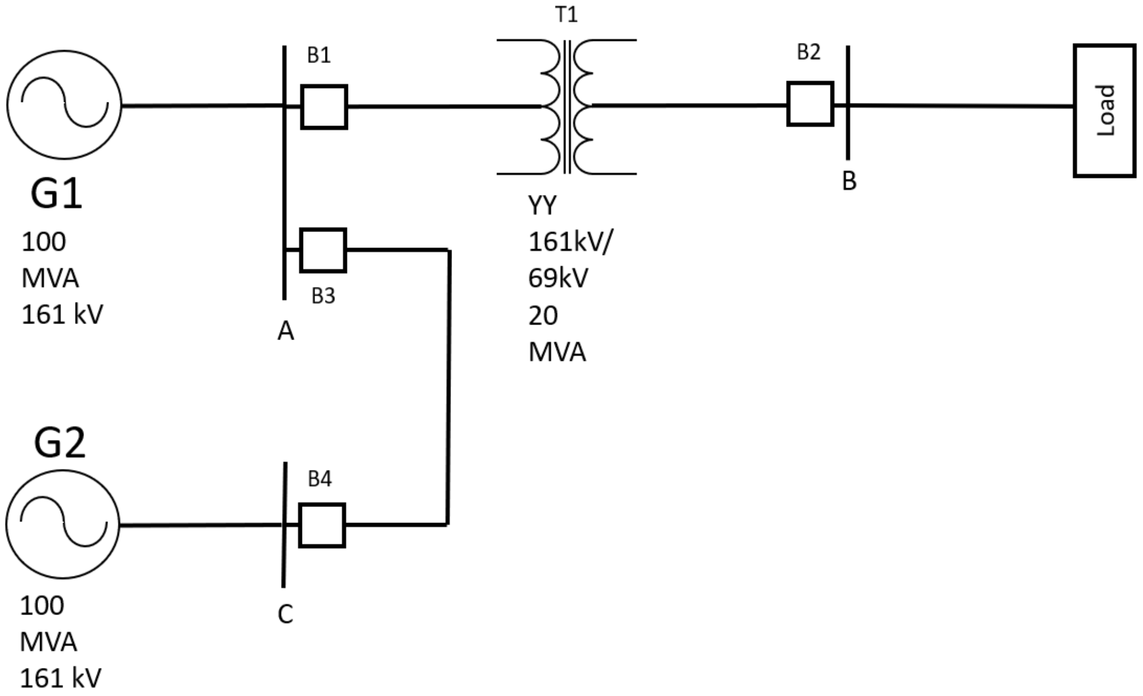
Differential Relay Settings



MVA	20	Max Power Trans Capacity
Wdg1 V	161kV	Wdg1 Line to Line Voltage
Wdg2 V	69kV	Wdg2 Line to Line Voltage
TRCON	YY	Transformer connection
CTCON	YY	CT connection
CTR1	100	Wdg1 CT ratio
CTR2	200	Wdg2 CT ratio
TAP1	0.717	Wdg1 current TAP
TAP2	0.837	Wdg2 current TAP
Pick up	0.3	Restrained operating pickup
Slope 1	30	Restrained slope 1 %
Slope 2	70	Restrained slope 2 %
IRS1	3	Restrained slope 1 limit

Distance Relay Settings

Distance relay(21) at station A protects the transmission line that connects station A and station C.



Z1Mag	7.8	Pos Seq Line Impedance Mag
Z1Ang	83.97	Pos Seq Line Impedance Angle
Z0Mag	24.79	Zero Seq Line Impedance Mag
Z0Ang	81.46	Zero Seq Line Impedance Angle
LL	100	Line Length
CTR	100	CT Ratio
PTR	1610	PT Ratio
DIR1	F	Direction Zone 1
DIR2	F	Direction Zone 2
Z1P	6.24	Impedance Reach Z1
Z2P	9.36	Impedance Reach Z2
Z1PD	0	Zone 1 Phase Time Delay
Z2PD	25	Zone 2 Phase Time Delay
Z1G	6.24	Impedance reach Z1
Z2G	9.36	Impedance reach Z2
Z1GD	0	Zone 1 ground time delay
Z2GD	25	Zone 2 ground time delay

Test Setup

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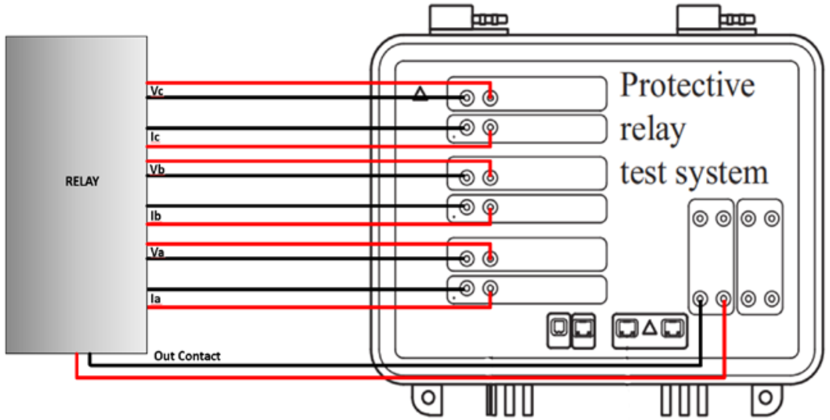
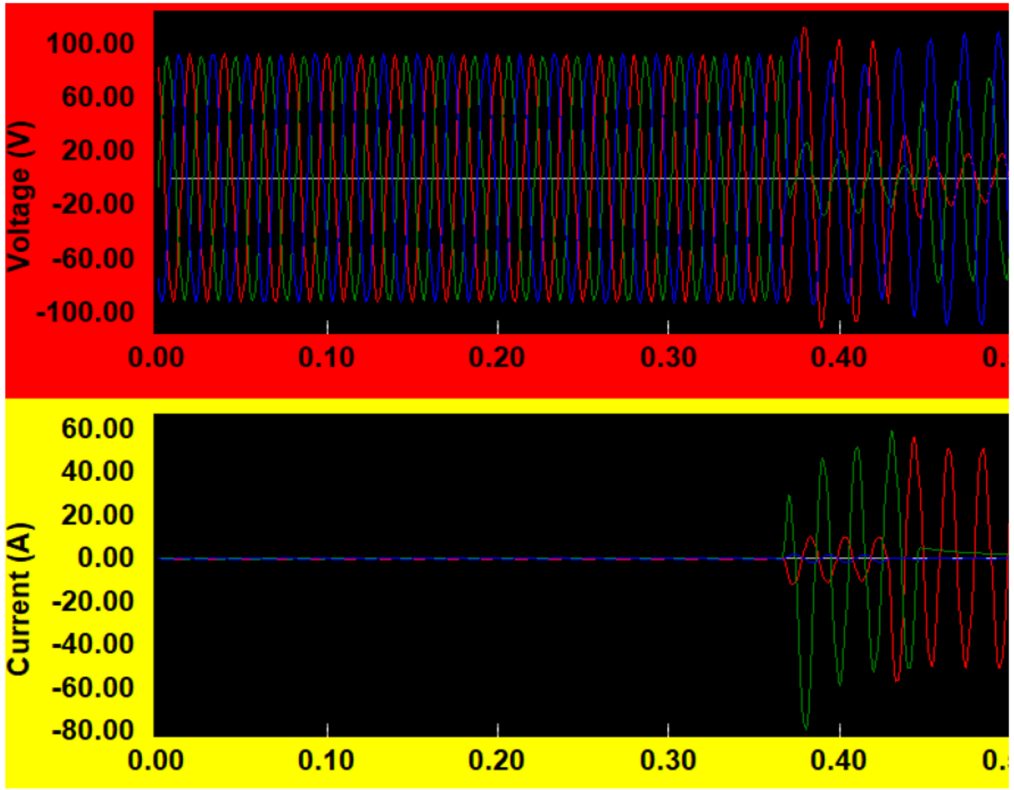
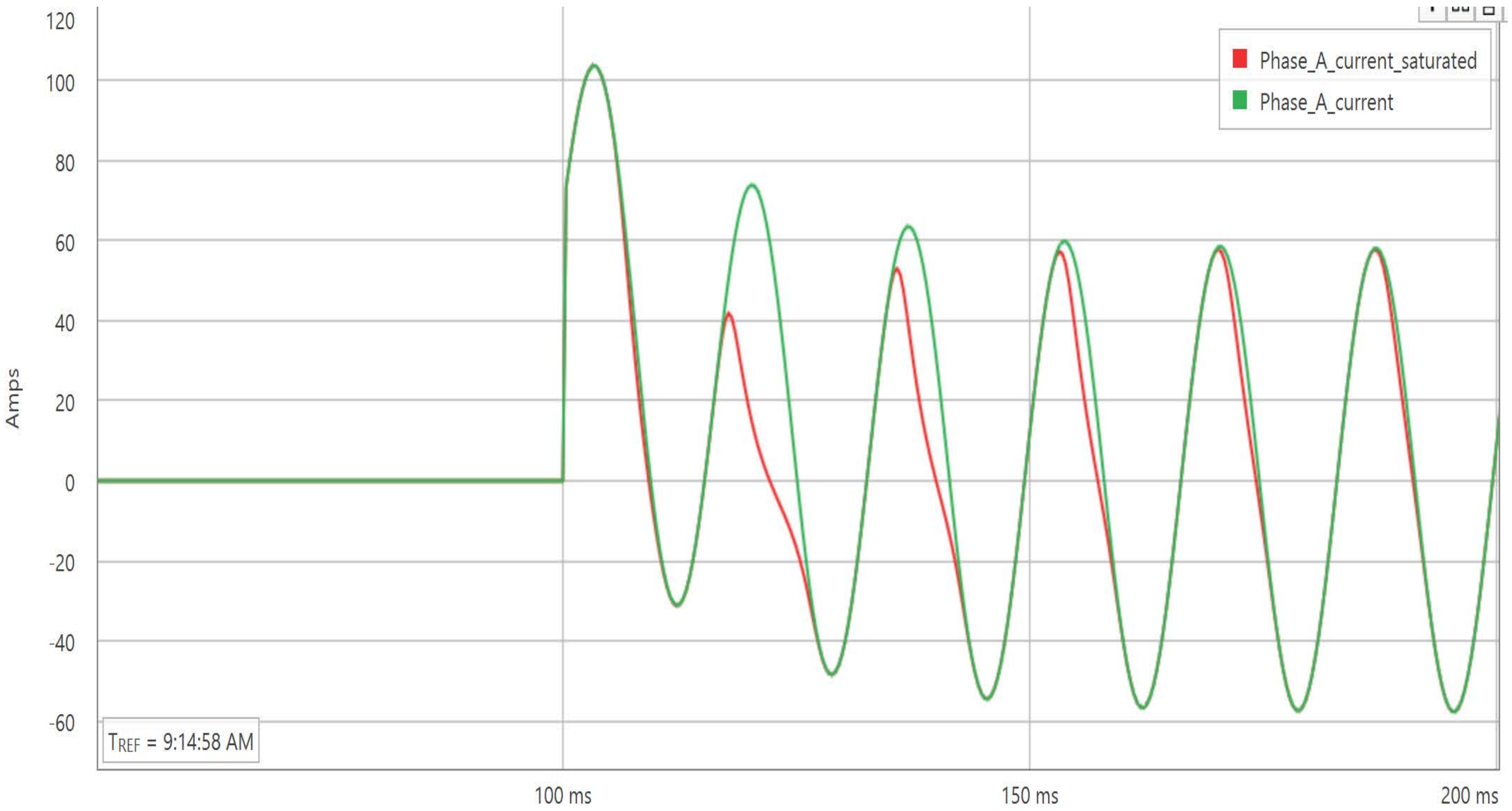

RELAY
Vc
Ic
Vb
Ib
Va
Ia
Out Contact
Protective
relay
test system

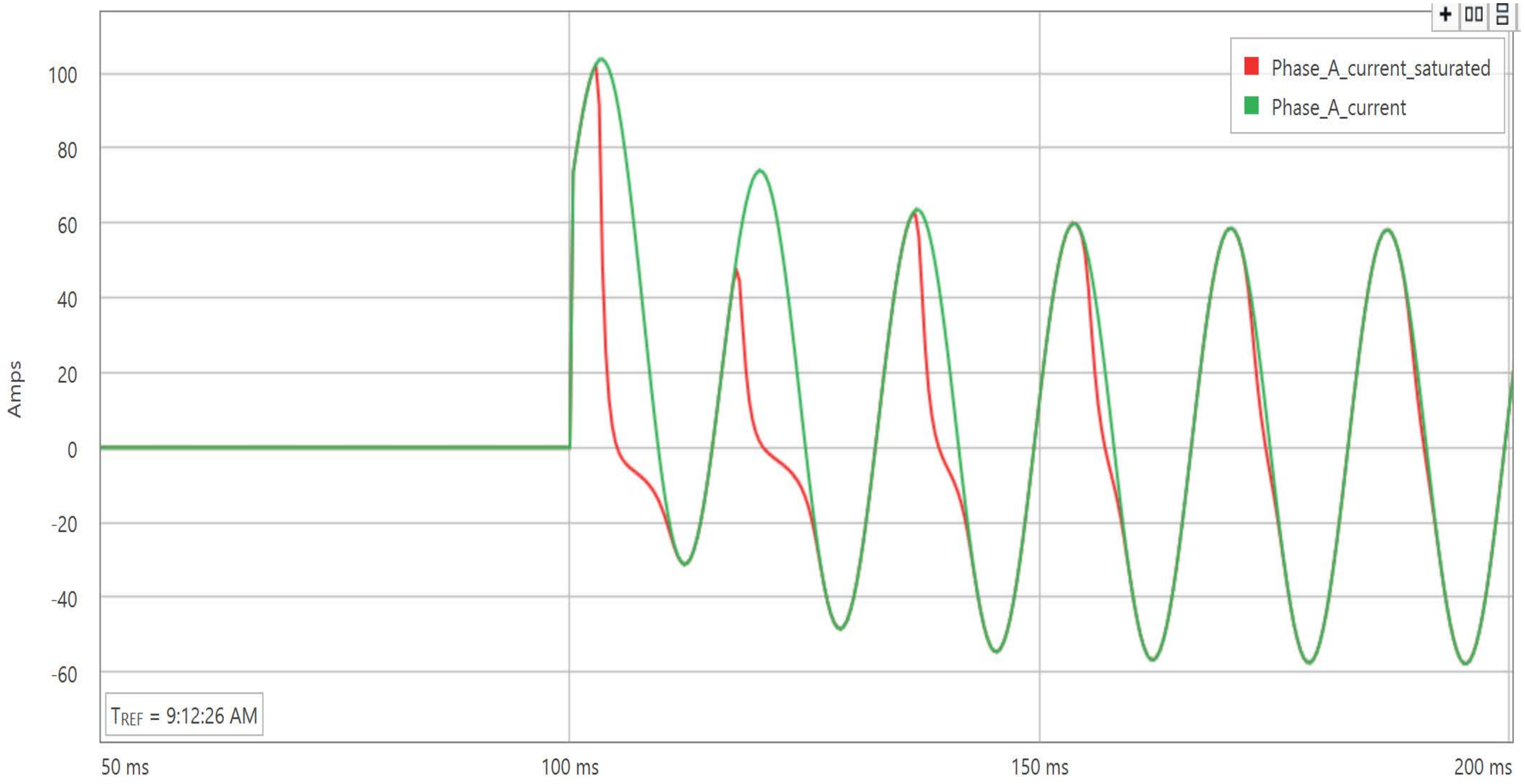

Voltage (V)
100.00
60.00
20.00
-20.00
-60.00
-100.00
0.00
0.10
0.20
0.30
0.40
Current (A)
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00

Results

CT Saturation with Nominal burden – 3P Fault



CT Saturation with High burden – 3P Fault



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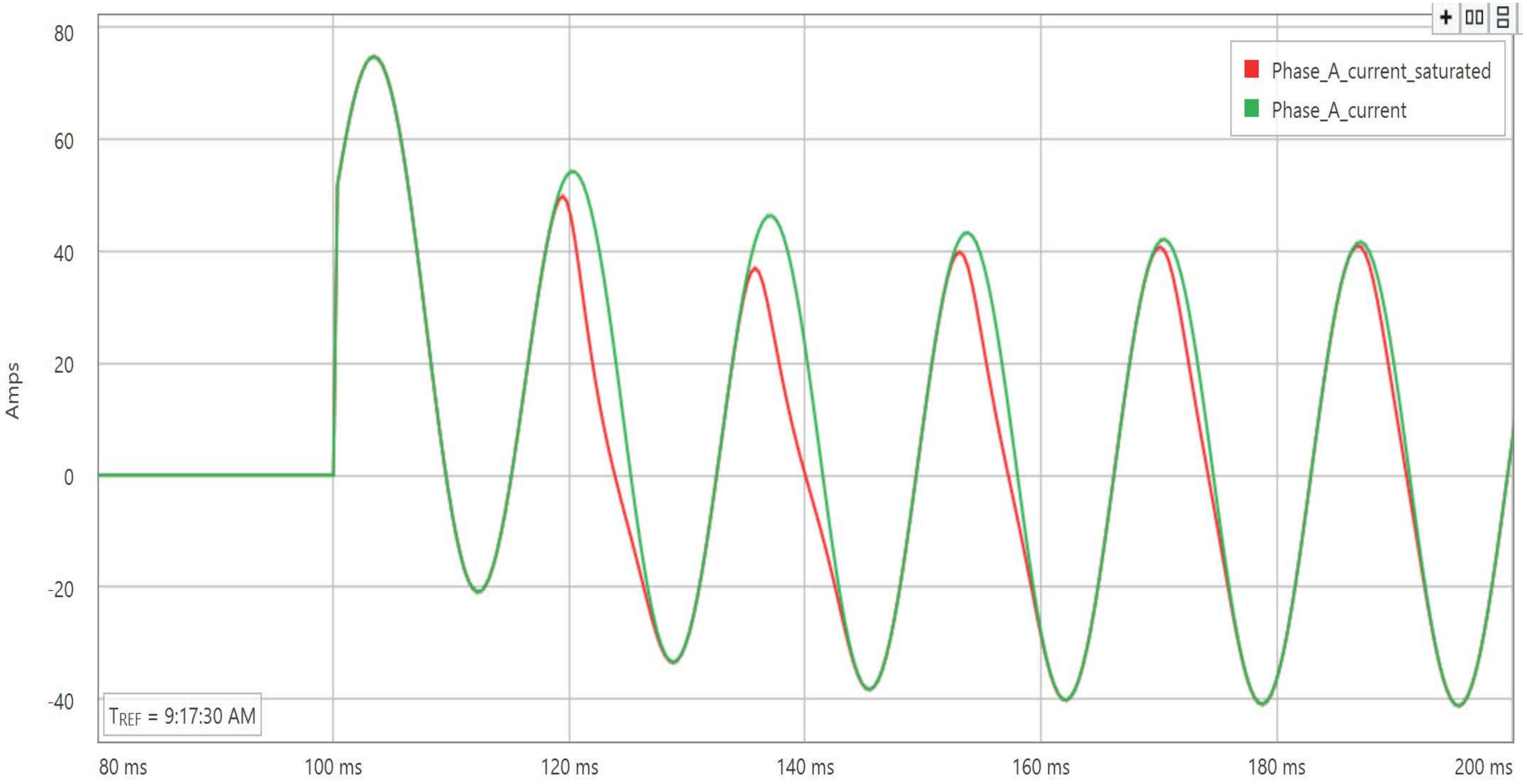
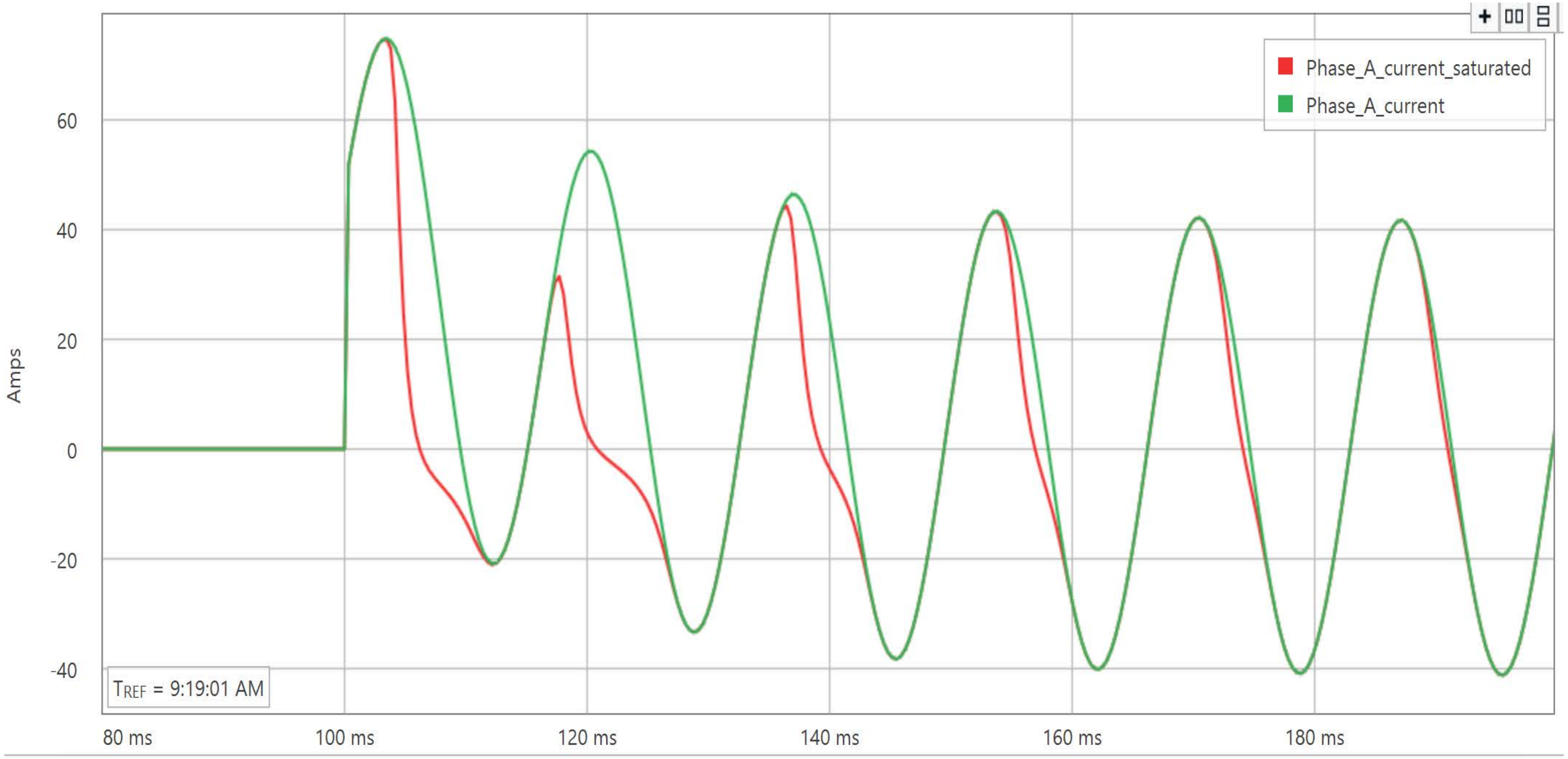
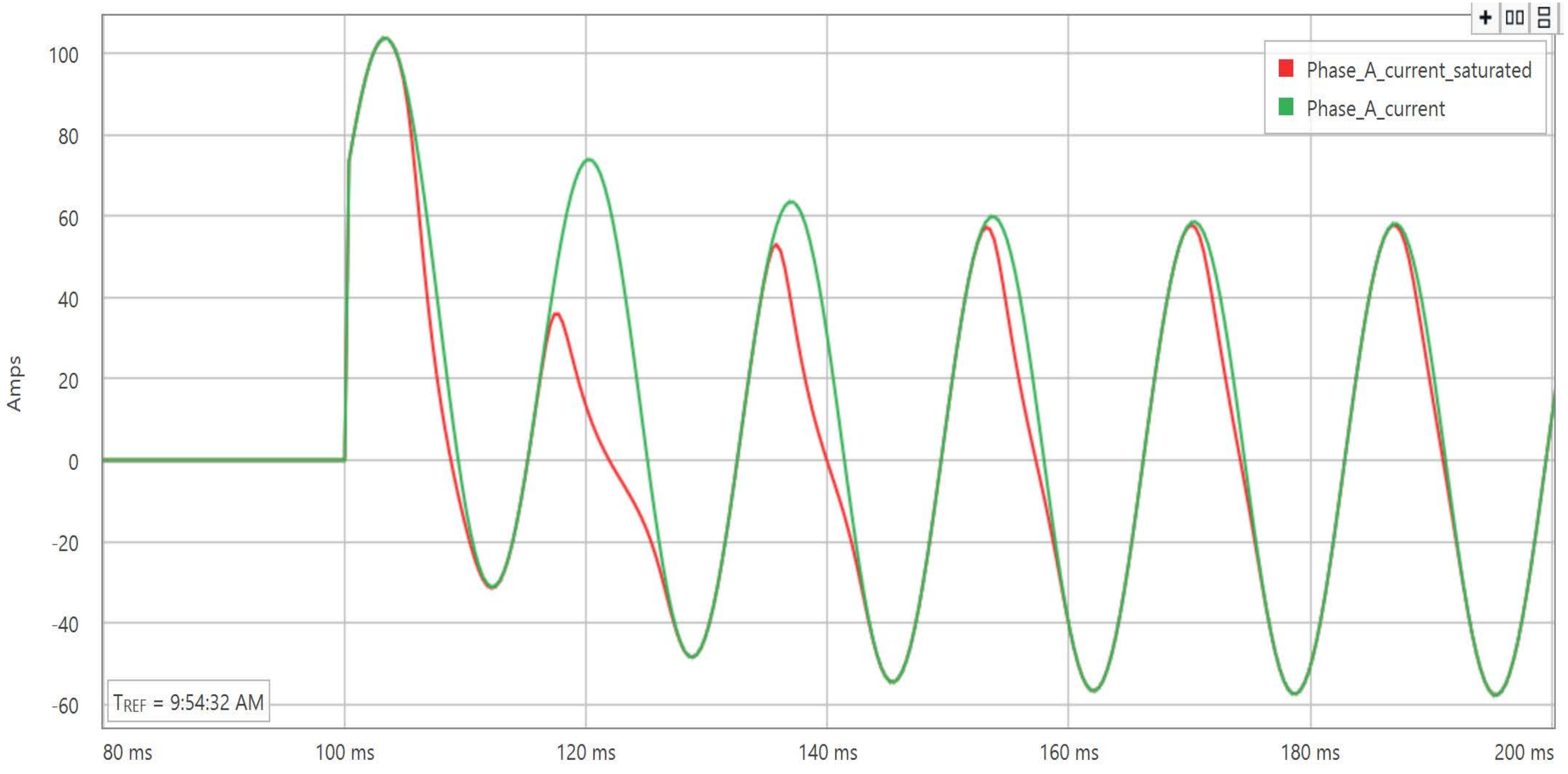
CT Saturation with Nominal Burden – SLG Fault



CT Saturation with High Burden – SLG Fault



CT Saturation with Low Remanence – 3P Fault



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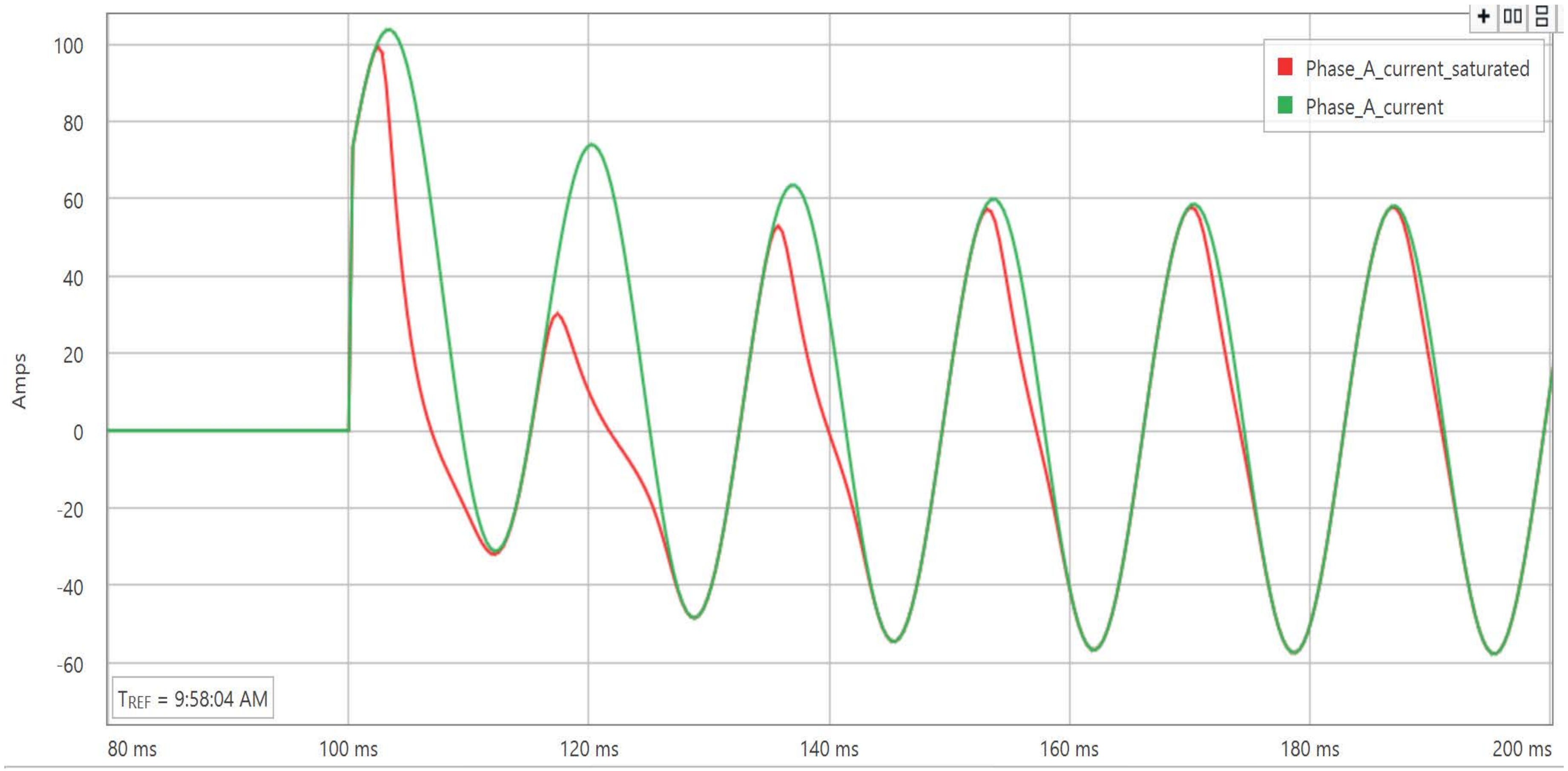
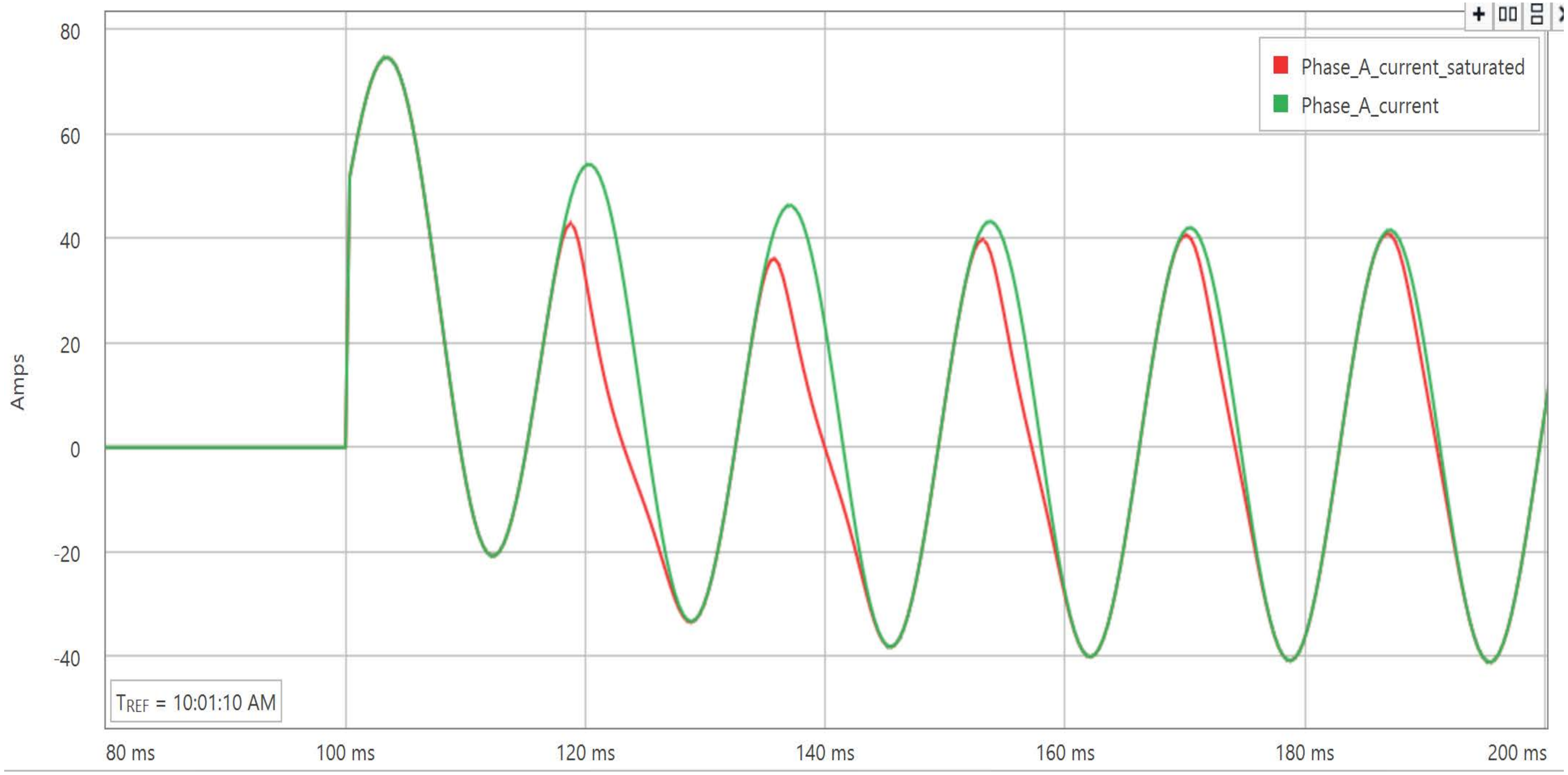
CT Saturation with High Remanence – 3P Fault



Megger

CT Saturation with Nominal Remanence – SLG Fault



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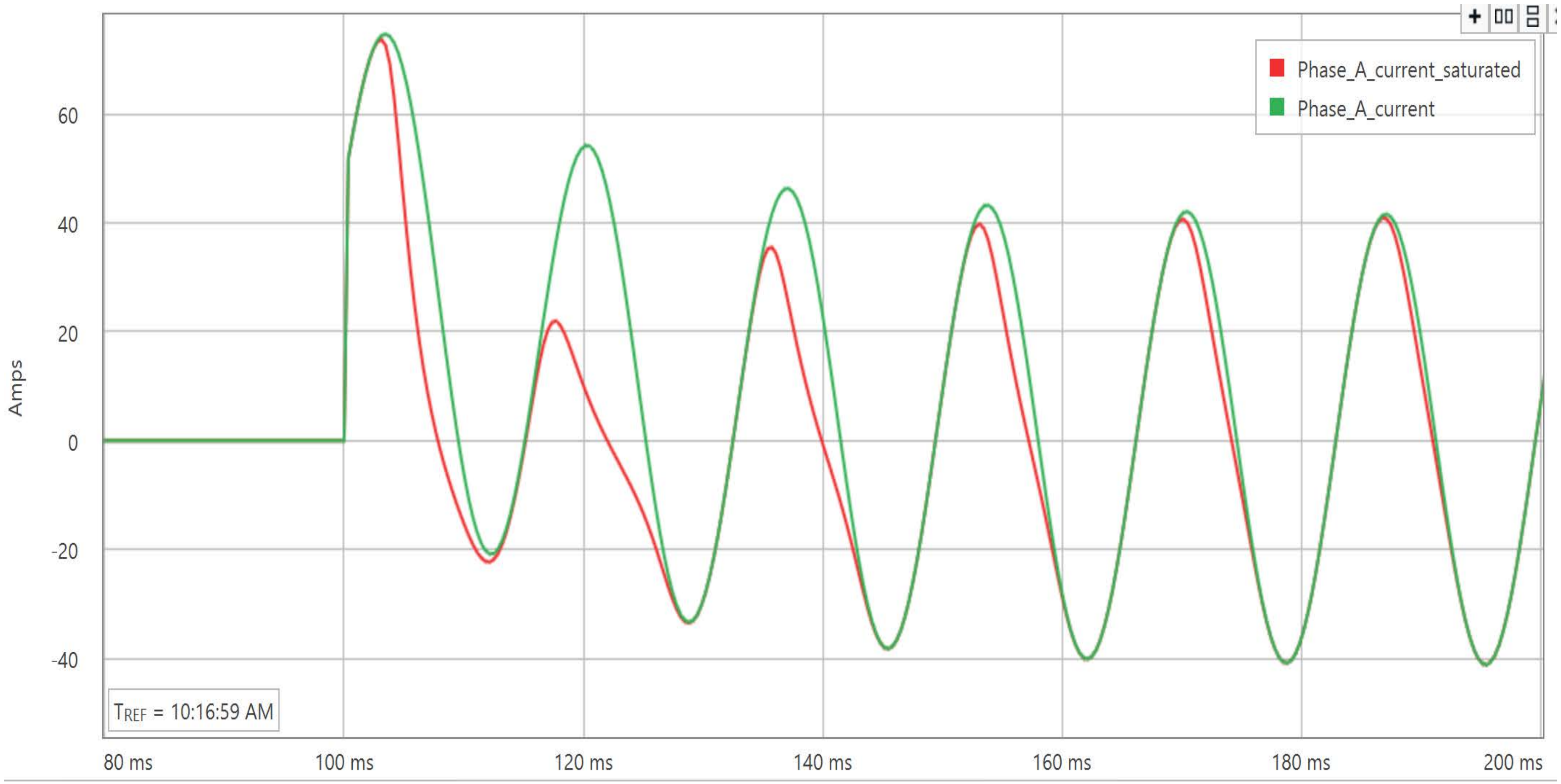
CT Saturation with High Remanence – SLG Fault



Megger

Conclusions

Conclusions

- Factors that influence the possibility of CT saturation are remnant flux, burden, x/r ratio of the line, CT history, CT design and manufacturing as well as previous tests
- CT Saturation can Impact the operation of differential and Distance protection relays
- The effects of CT saturation are greater when CT have a relatively high level of remnant flux in the core
- When a CT is saturated as a result of a fault there is a greater chance of relay misoperation for subsequent faults as a result of the remnant flux
- CT saturation can be mitigated with proper CT selection and adequate design of the connected burden