Performance Analysis of Distance Protection Using Different Impedance Calculation Methods

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Overview

- Fundamentals of Distance Protection
- Testing Distance Elements
  a. Constant Voltage Method
  b. Constant Current Method
  c. Constant Source Impedance Method
- Performance Analysis
  a. Mho Characteristic
  b. Quadrilateral Characteristic
- Conclusions

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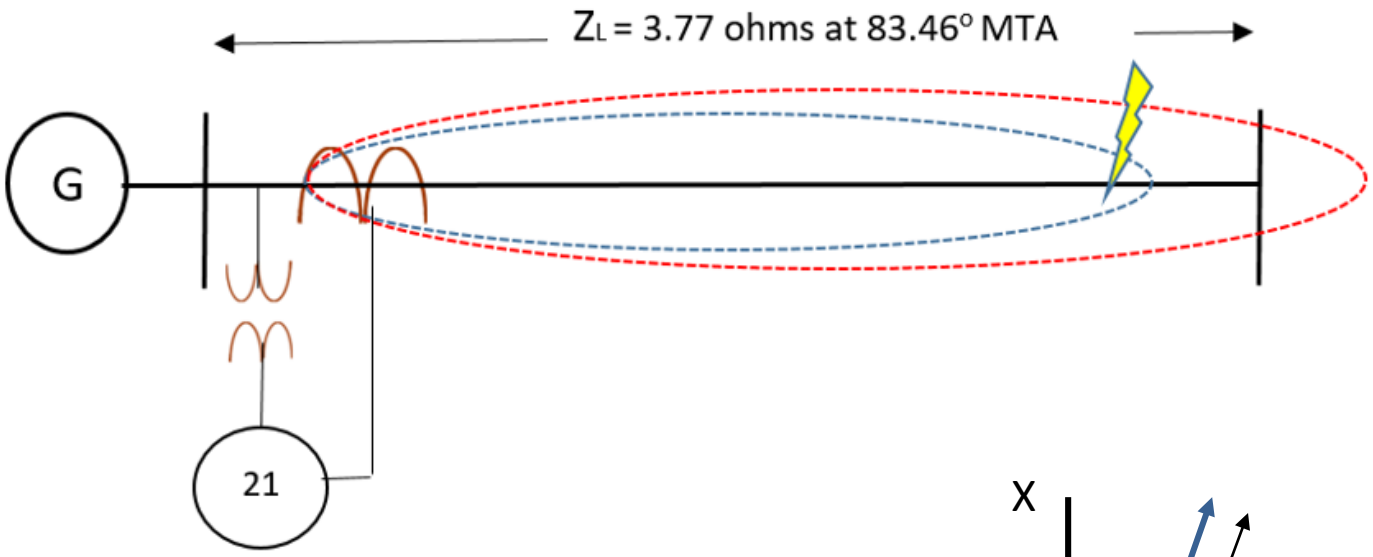
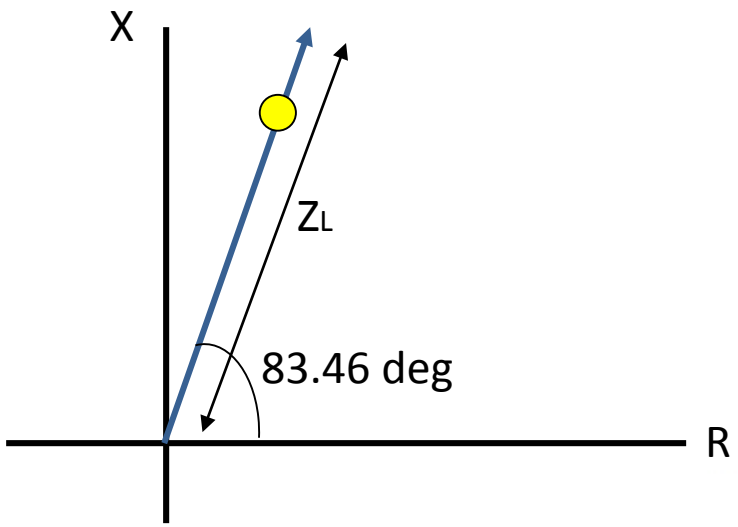
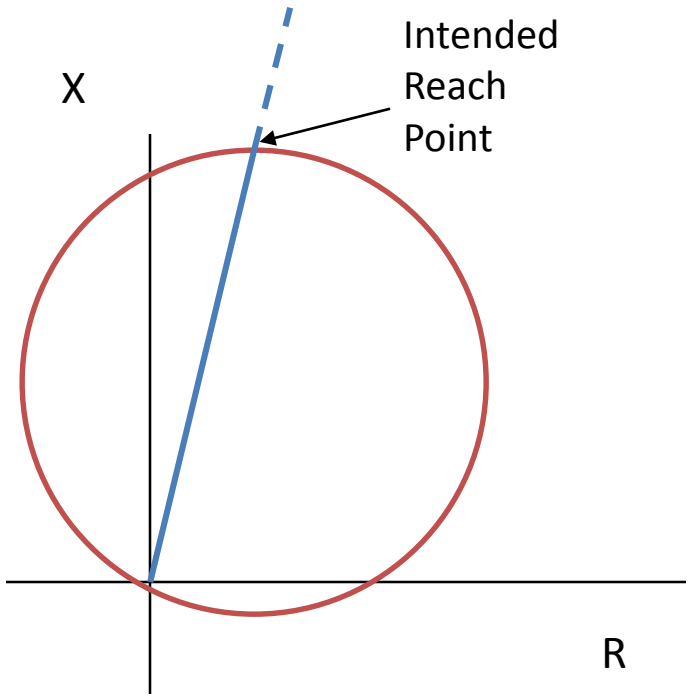
What is 21?

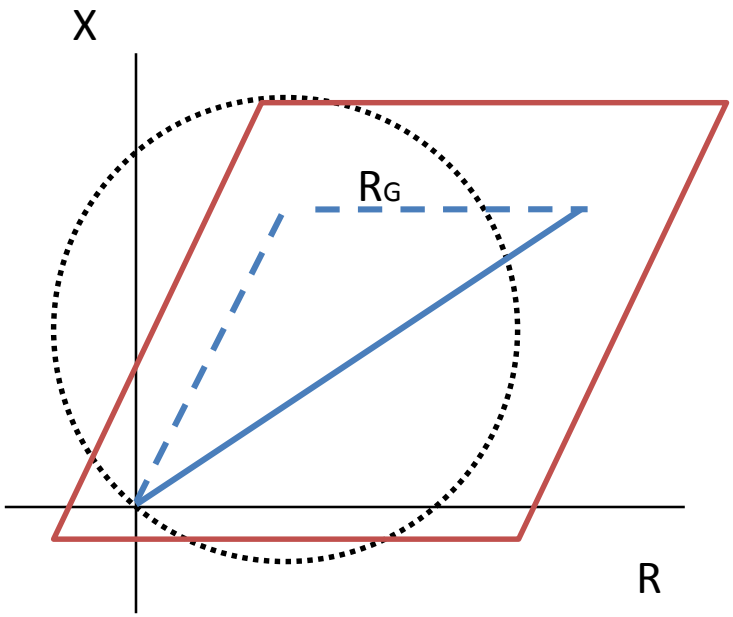




Distance Relay Characteristics

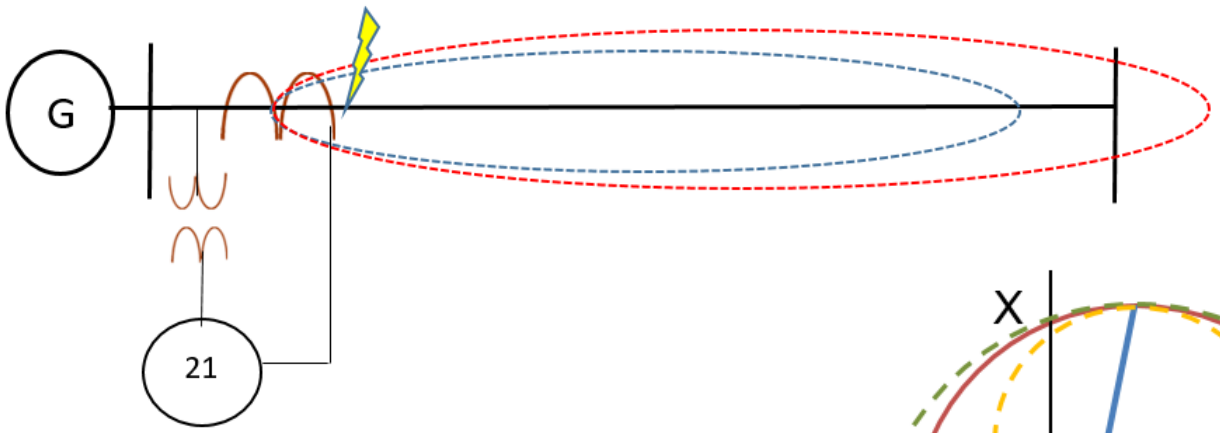


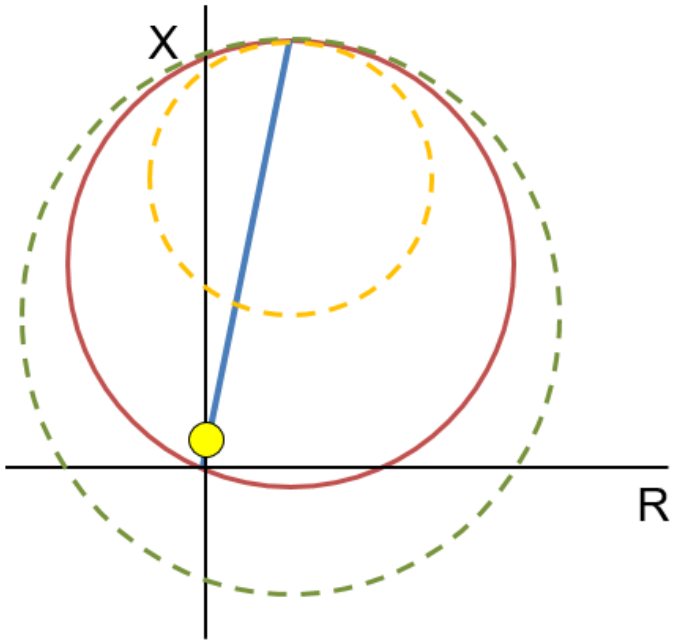
Mho Circle



Quadrilateral

Dynamic Mho





Forward faults – Mho Expands
Reverse faults – Mho Shrinks

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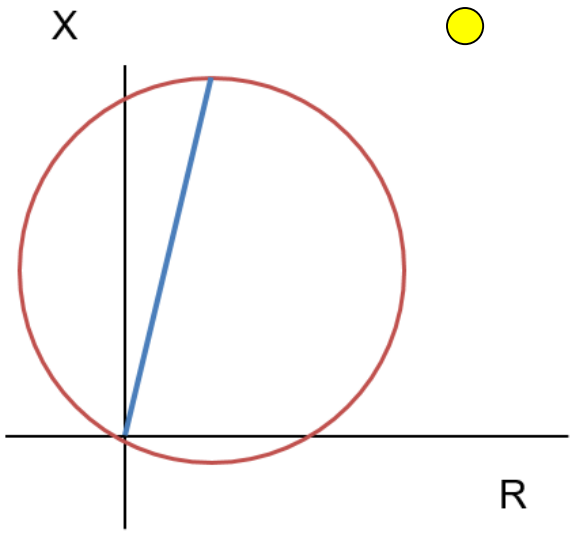
Testing Distance Elements

- Steady State Testing
  a) Constant Voltage Method
  b) Constant Current Method

- Dynamic Testing
  a) Constant Source Impedance Method
  b) Advanced Simulation
  c) DFR playback
  d) COMTRADE playback

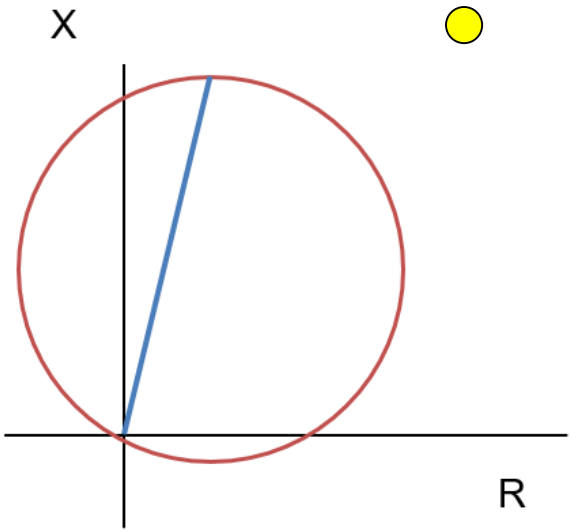
Constant Voltage Method

- Voltage remains constant but current is ramped up till the trip occurs
- Does not truly test the dynamic characteristic of a relay
- Good for medium and long lines
- Not good for short lines due to requirement of extremely high currents
- Assumes single source model



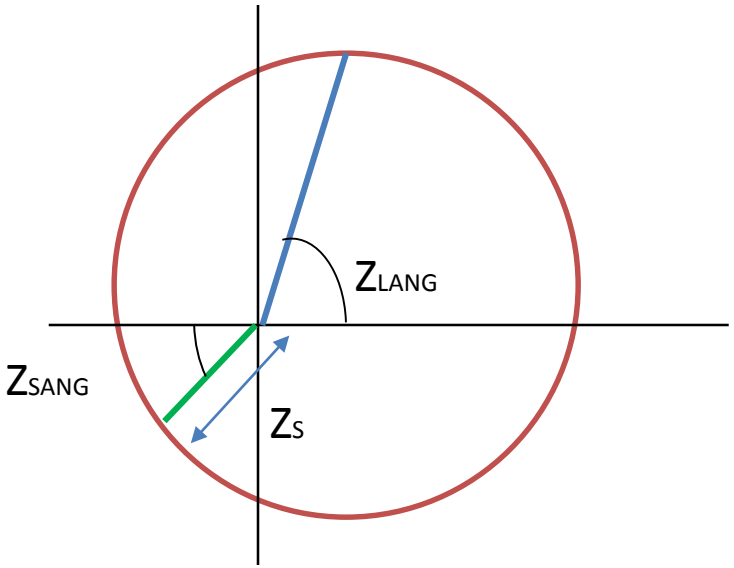
Constant Current Method

- Current remains constant but voltage is ramped down till the trip occurs
- Does not truly test the dynamic characteristic of a relay
- Good for short lines
- Not good for self-polarized mho circles
- Assumes single source model

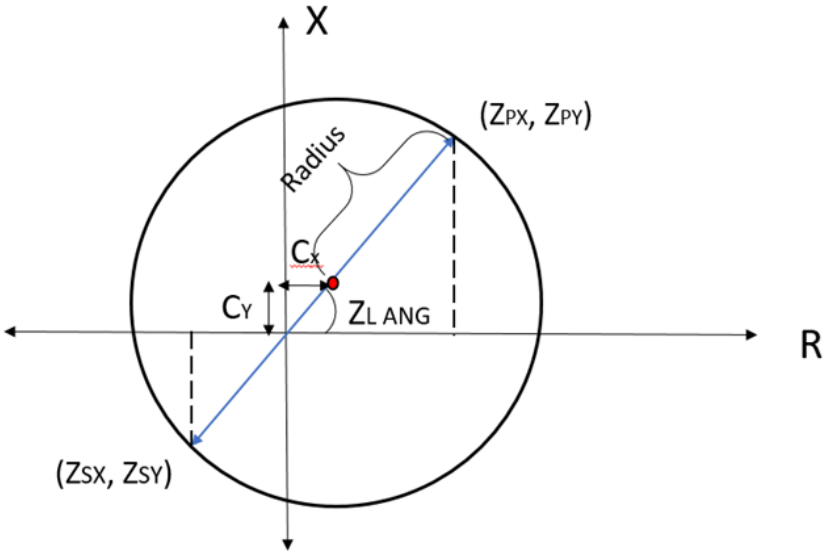


Constant Source Impedance Method

- Steady state method changes source impedance offered to the relay at every point
- Accurate way of testing dynamic behavior of the relay characteristic
- Uses symmetrical component theory to calculate faulted voltages and currents



Constant Source Impedance Method



$Z_{L\,ANG} = Z_{S\,ANG}$

$Z_{P\,REAL} = Z_P \cos(Z_{L\,ANG})$

$Z_{P\,IM} = Z_P \sin(Z_{L\,ANG})$

$Z_{S\,REAL} = Z_S \cos(Z_{L\,ANG})$

$Z_{S\,IM} = Z_S \sin(Z_{L\,ANG})$

$$C_X = \frac{Z_{P\,REAL} + Z_{S\,REAL}}{2}$$

$$C_Y = \frac{Z_{P\,IM} + Z_{S\,IM}}{2}$$

- After radius is computed, the total apparent reach and line angle can be derived which will take Z_S into account
- With sequence networks, faulted voltages and currents can be computed
- Calculated values are the values right on the edge

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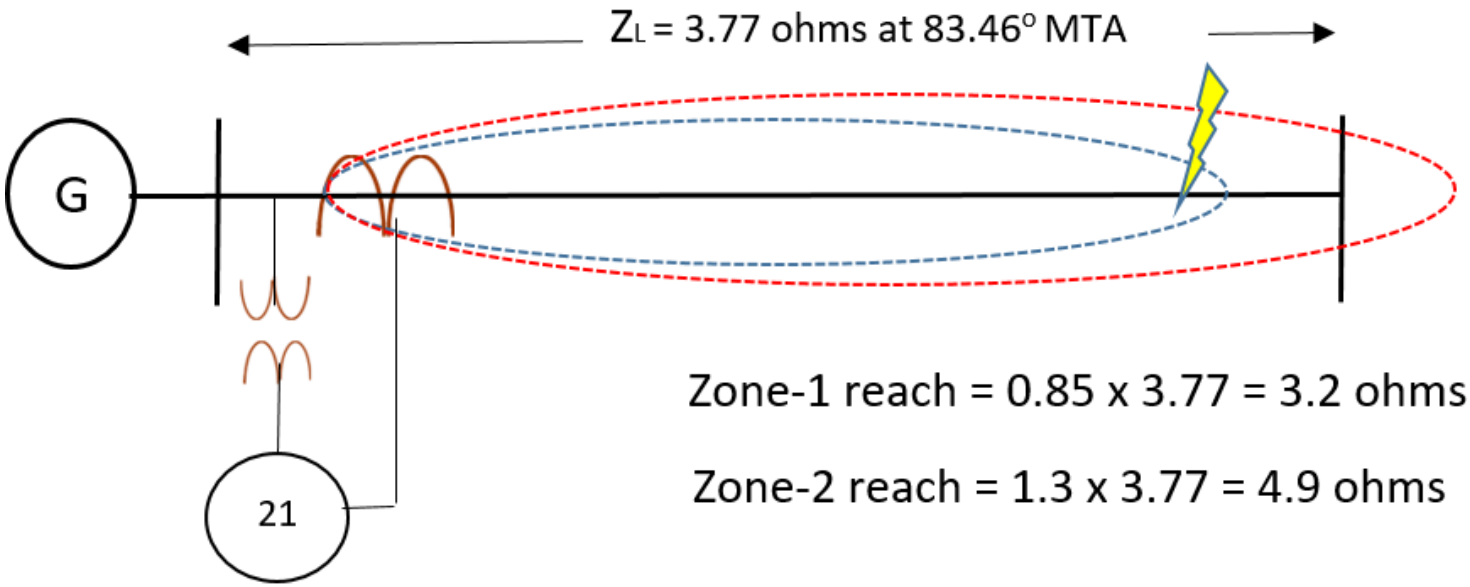
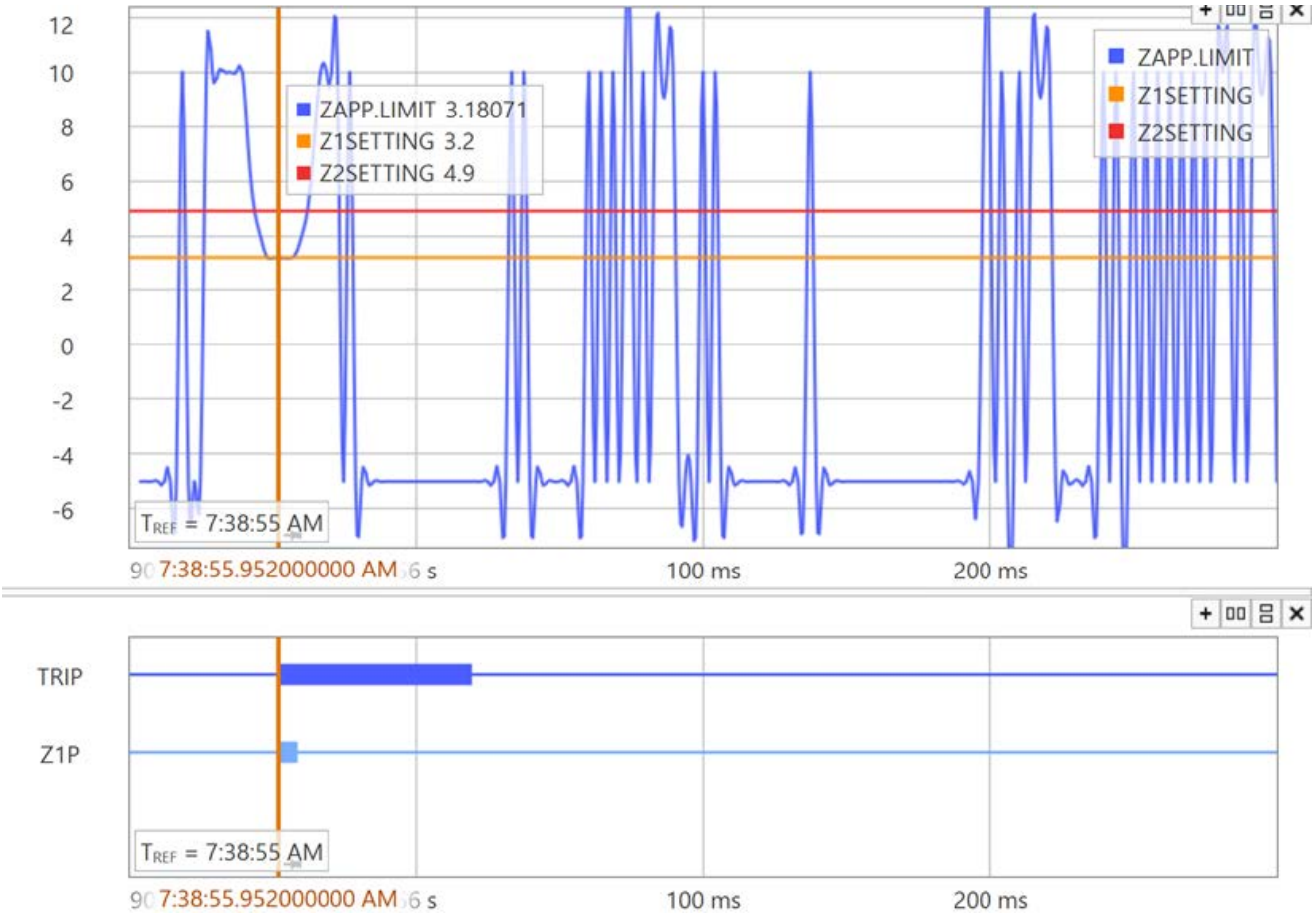
System Description- Mho Enabled



Assumptions

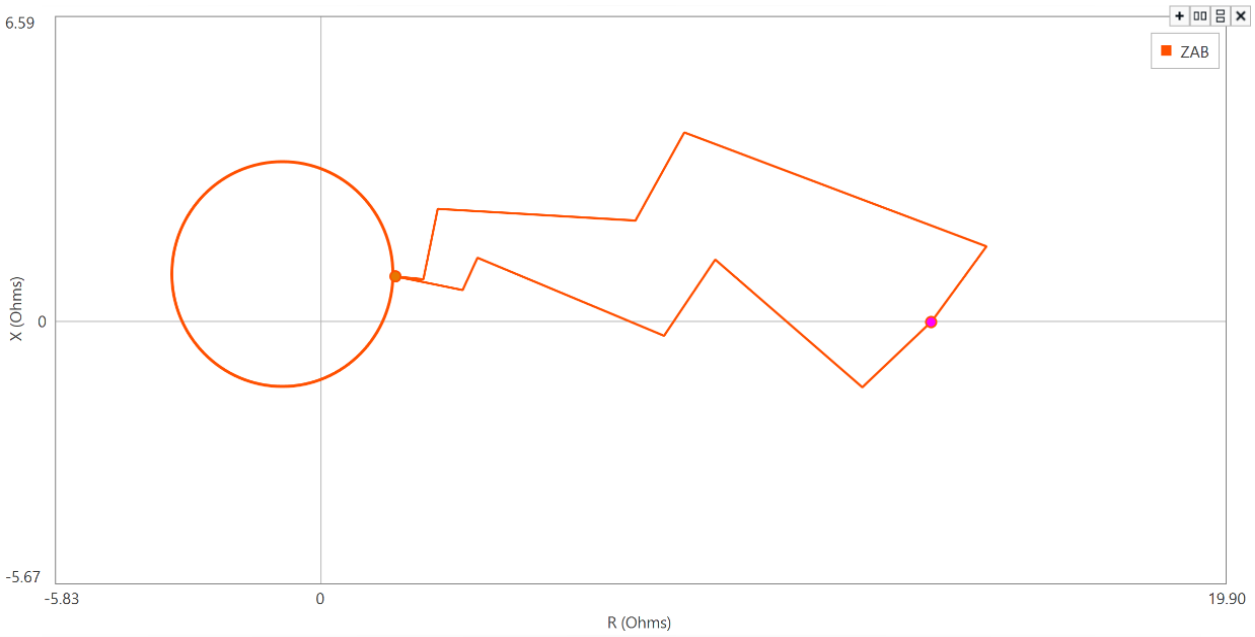
- Constant Voltage Method is tested at 33.5 V
- Constant Current Method is tested at 9.959 A
- Constant Source Impedance Method is tested at 0.2 x 3.77 = 0.754 Ω at 83.46 degrees
- Test points are at MTA, 30 degrees

Constant Voltage Method- Mho



- Zone-1 Pick Up is tested at MTA

Constant Voltage Method- Mho



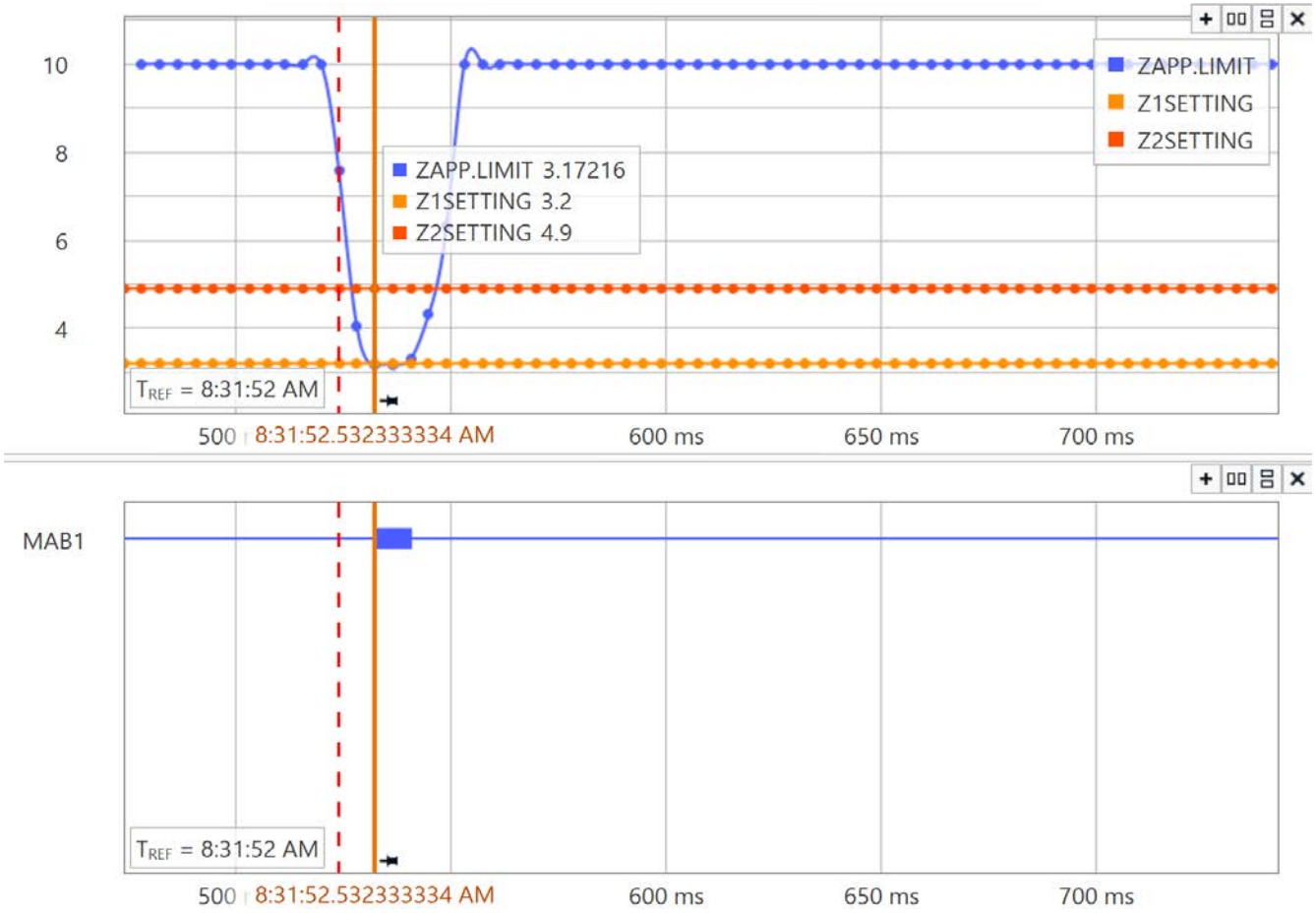
Cursor	Color	Name	R	X
		ZAB	1.64131 Ω	0.973934 Ω
		ZAB	13.4264 Ω	-0.01709 Ω

- Zone-1 Pick Up is tested at 30 degrees

Constant Voltage Method - Results

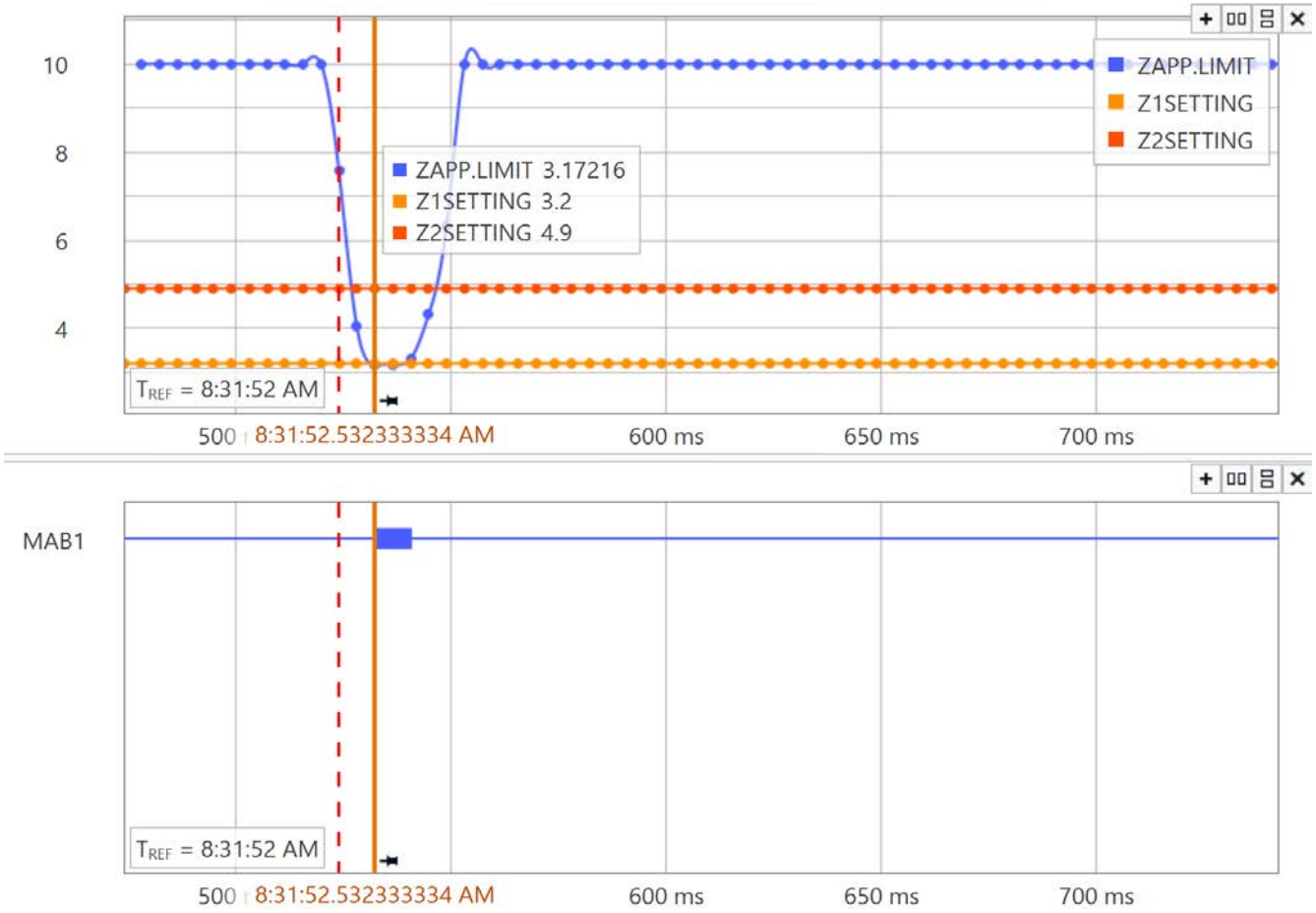
Test Angle	Measured Faulted Voltage at Pick-Up (VAN)	Measured Faulted Current at Pick-Up (IAN)	Theoretical Impedance (Ω)	Calculated Impedance (Ω)	% Error
83.46°	33.5 V	5.269 A	3.2	3.18	0.625
30°	33.5 V	8.778 A	1.93	1.908	1.14

Constant Current Method- Mho



- Zone-1 Pick Up is tested at MTA

Constant Current Method- Mho



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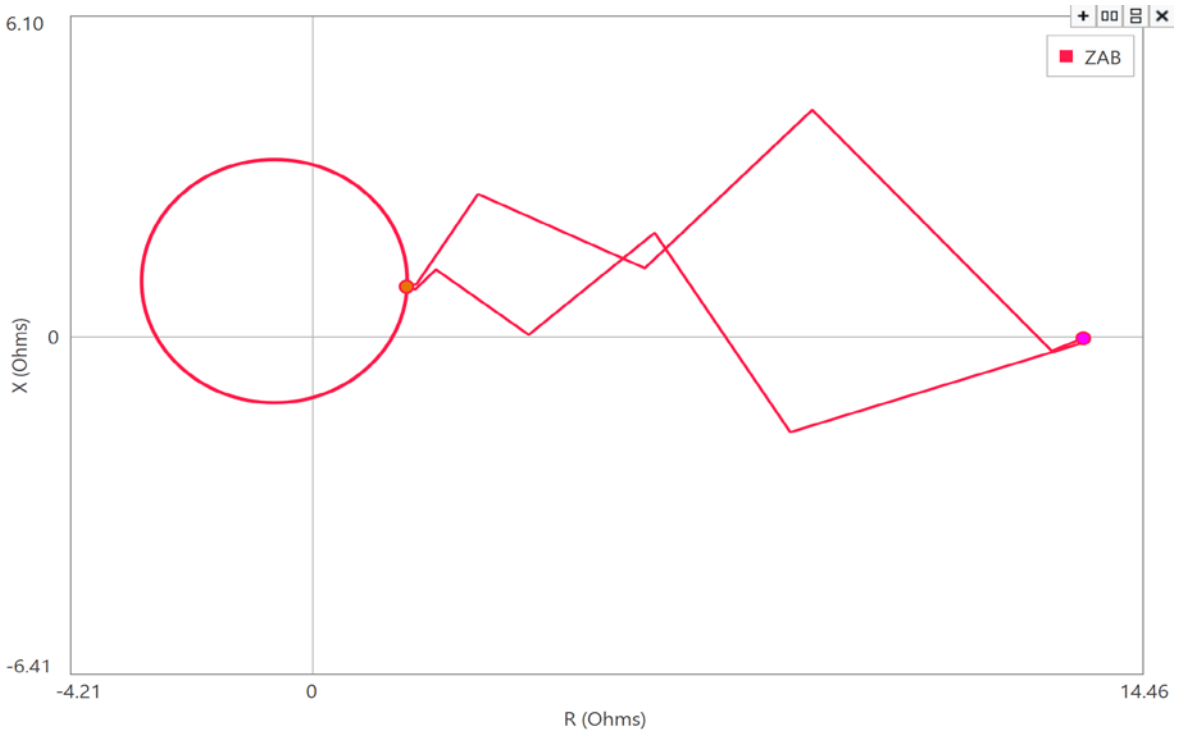
Constant Current Method- Mho



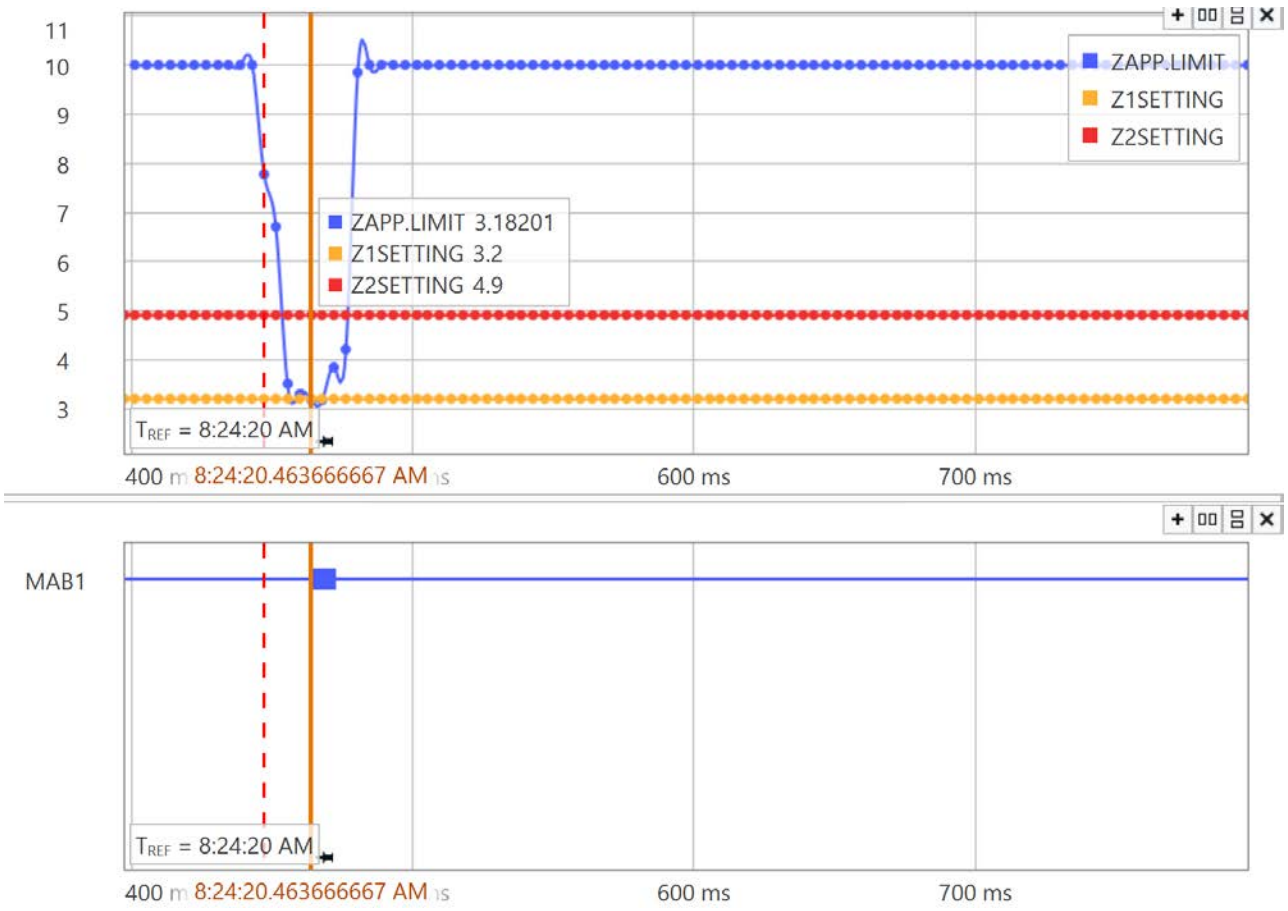
Cursor Color	Name	R	X
	ZAB	1.63645 Ω	0.966698 Ω
	ZAB	13.4279 Ω	-0.0172624 Ω

- Zone-1 Pick Up is tested at 30 degrees

Constant Current Method - Results

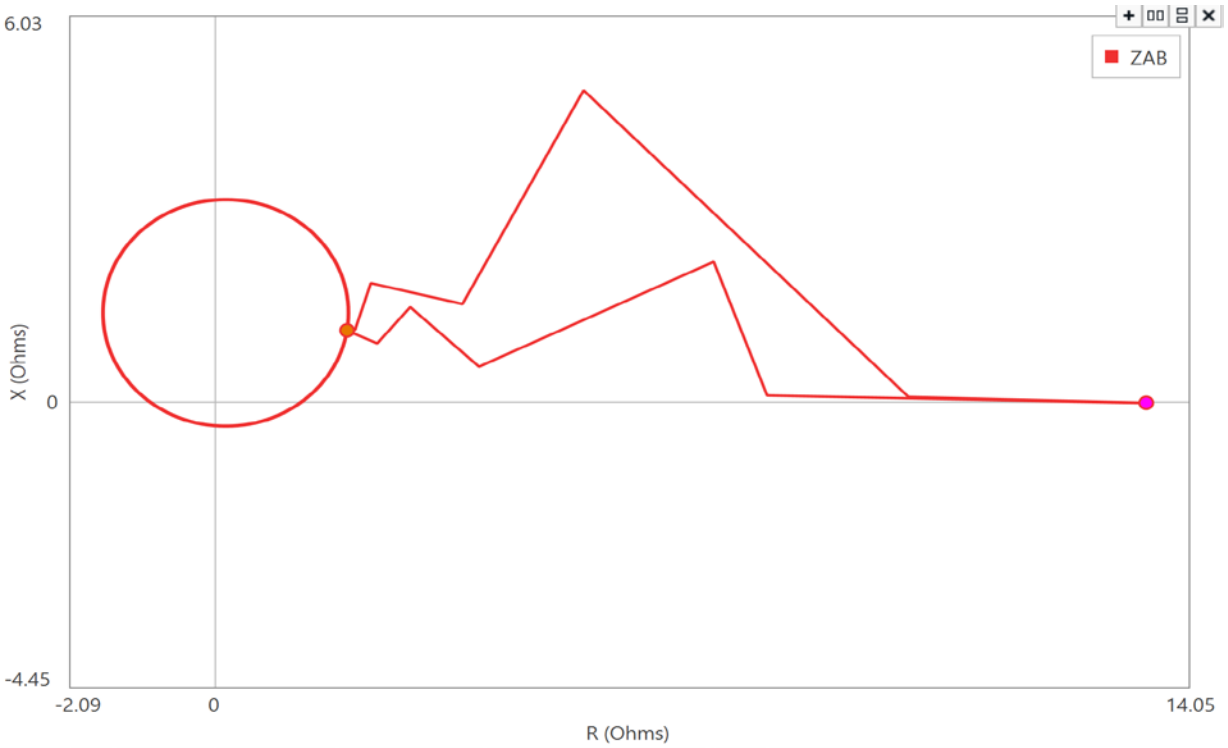
Test Angle	Measured Faulted Voltage at Pick-Up (VAN)	Measured Faulted Current at Pick-Up (IAN)	Theoretical Impedance (Ω)	Calculated Impedance (Ω)	% Error
83.46^{O}	63.18 V	9.959 A	3.2	3.172	0.87
30^{O}	37.84 V	9.959 A	1.93	1.9	1.14

Constant Source Impedance Method-Mho



- Zone-1 Pick Up is tested at MTA

Constant Source Impedance Method- Mho



Cursor Color	Name	R	X
	ZAB	1.90512 Ω	1.11757 Ω
	ZAB	13.4355 Ω	-0.0107183 Ω

- Zone-1 Pick Up is tested at 30 degrees

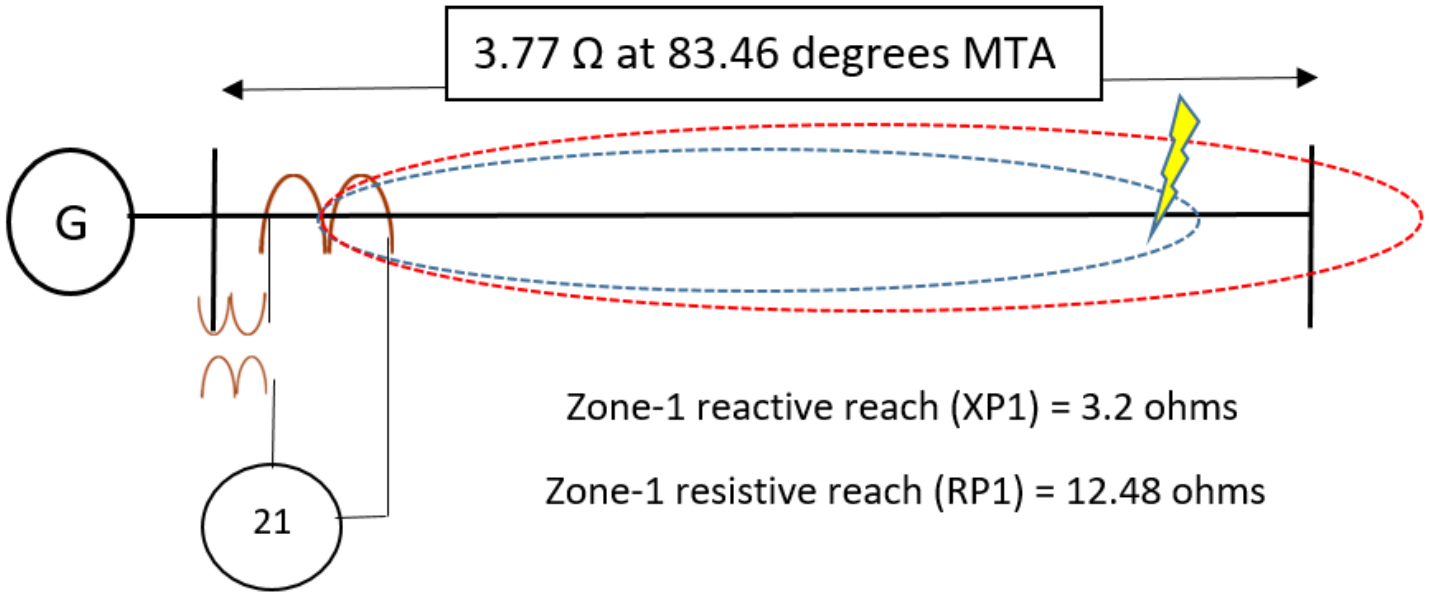
Constant Source Impedance Method - Results

Test Angle	Measured Faulted Voltage at Pick-Up (VAN)	Measured Faulted Current at Pick-Up (IAN)	Theoretical Impedance (Ω)	Calculated Impedance (Ω)	% Error
83.46^{O}	60.76 V	20.723 A	3.2	3.182	0.56
30^{O}	59.83 V	19.825 A	1.93	2.208	**12.62**

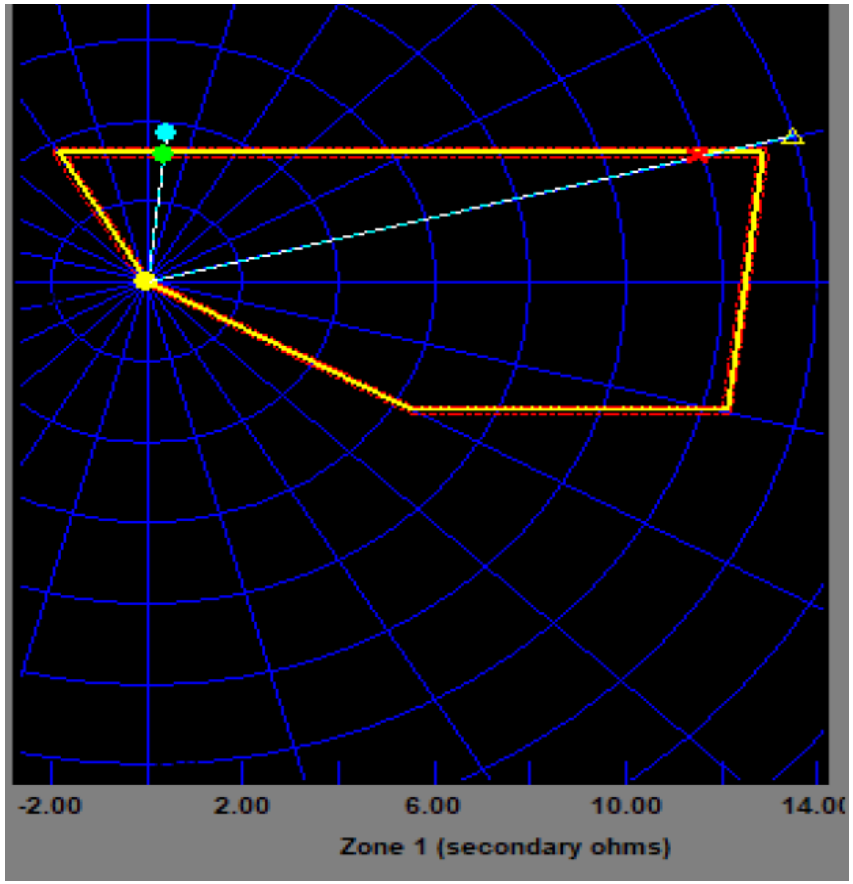
Performance of Mho

Testing Method	Expected Pickup		Actual Pickup	
	MTA	30°	MTA	30°
Constant Voltage	3.2	1.93	3.18	1.908
Constant Current	3.2	1.93	3.172	1.9
Constant Source	3.2	1.93	3.182	**2.208**

System Description- Quad Enabled



Constant Voltage Method- Quad

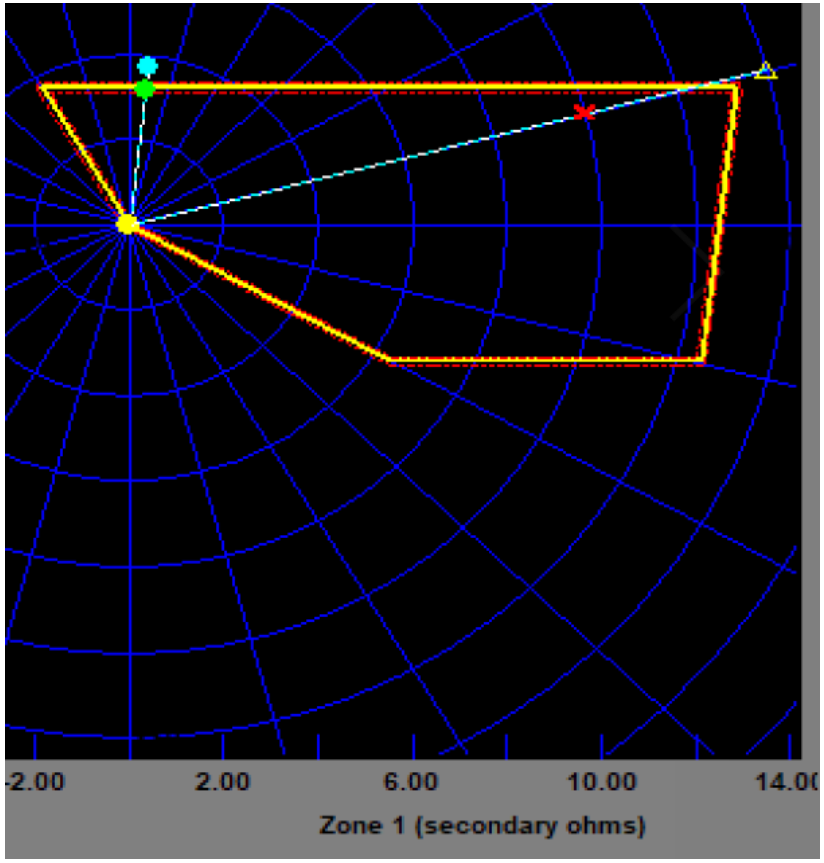


- Zone-1 Pick Up is tested at MTA and 15 degrees

Constant Voltage Method - Results

Test Angle	Measured Faulted Voltage at Pick-Up (VAN)	Measured Faulted Current at Pick-Up (IAN)	Theoretical Impedance (Ω)	Calculated Impedance (Ω)	% Error
83.46°	33.5 V	5.25 A	3.2	3.19	0.31
15°	33.5 V	1.404 A	12.36	11.93	**3.48**

Constant Current Method- Quad

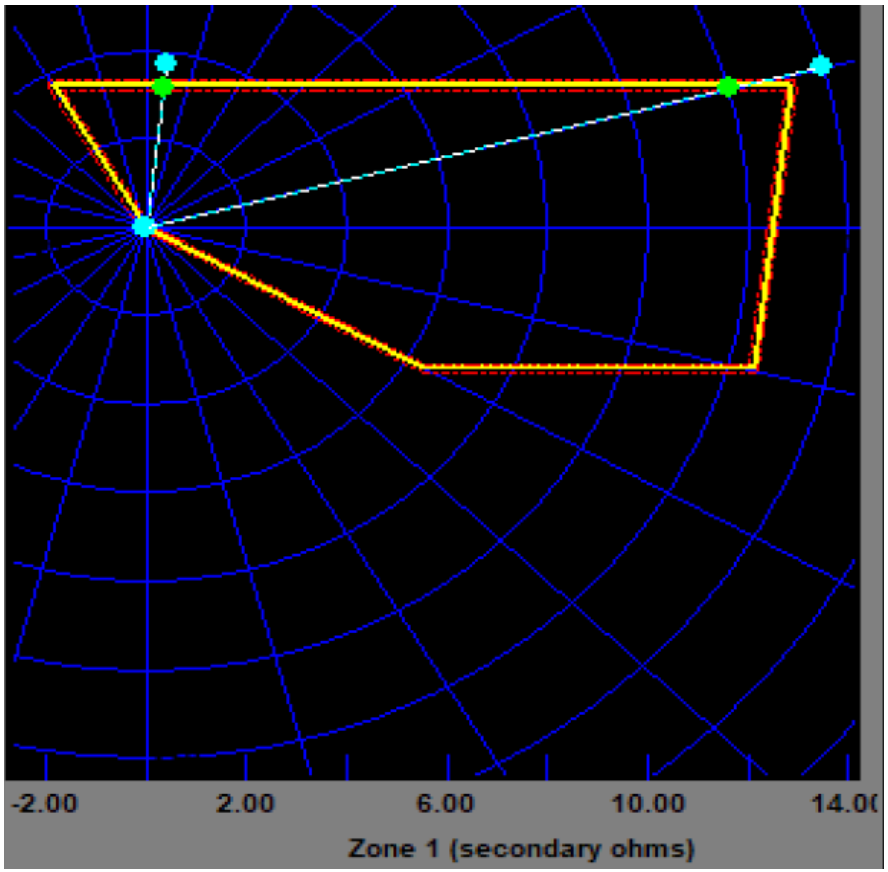


- Zone-1 Pick Up is tested at MTA and 15 degrees

Constant Current Method - Results

Test Angle	Measured Faulted Voltage at Pick-Up (VAN)	Measured Faulted Current at Pick-Up (IAN)	Theoretical Impedance (Ω)	Calculated Impedance (Ω)	% Error
83.46°	63.54 V	9.959 A	3.2	3.19	0.31
15°	98.09 V	4.9 A	12.36	10.01	**19.01**

Constant Source Impedance Method- Quad



- Zone-1 Pick Up is tested at MTA and 15 degrees

Constant Source Impedance Method - Results

Test Angle	Measured Faulted Voltage at Pick-Up (VAN)	Measured Faulted Current at Pick-Up (IAN)	Theoretical Impedance (Ω)	Calculated Impedance (Ω)	% Error
83.46°	11.94 V	17.39 A	3.2	3.19	0.31
15°	46.3 V	4.58 A	12.36	12.03	2.67

Performance of Quad

Testing Method	Expected Pickup		Actual Pickup	
	MTA	15°	MTA	15°
Constant Voltage	3.2	12.36	3.19	**11.93**
Constant Current	3.2	12.36	3.19	**10.01**
Constant Source	3.2	12.36	3.19	12.03

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Conclusions

- The effect of dynamic behavior of mho circle can accurately be validated by constant source impedance model
- Impact of memory polarization on the characteristic can be better realized at fault angles far off from MTA
- If symmetrical components are used to calculate faulted voltages and currents, the directional units supervising the distance elements will be transparent to the testing procedure

Q&A

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