Performance Comparison Between Mho Elements and Incremental Quantity-Based Distance Elements

Gabriel Benmouyal, Normann Fischer, and Brian Smyth
Schweitzer Engineering Laboratories, Inc.

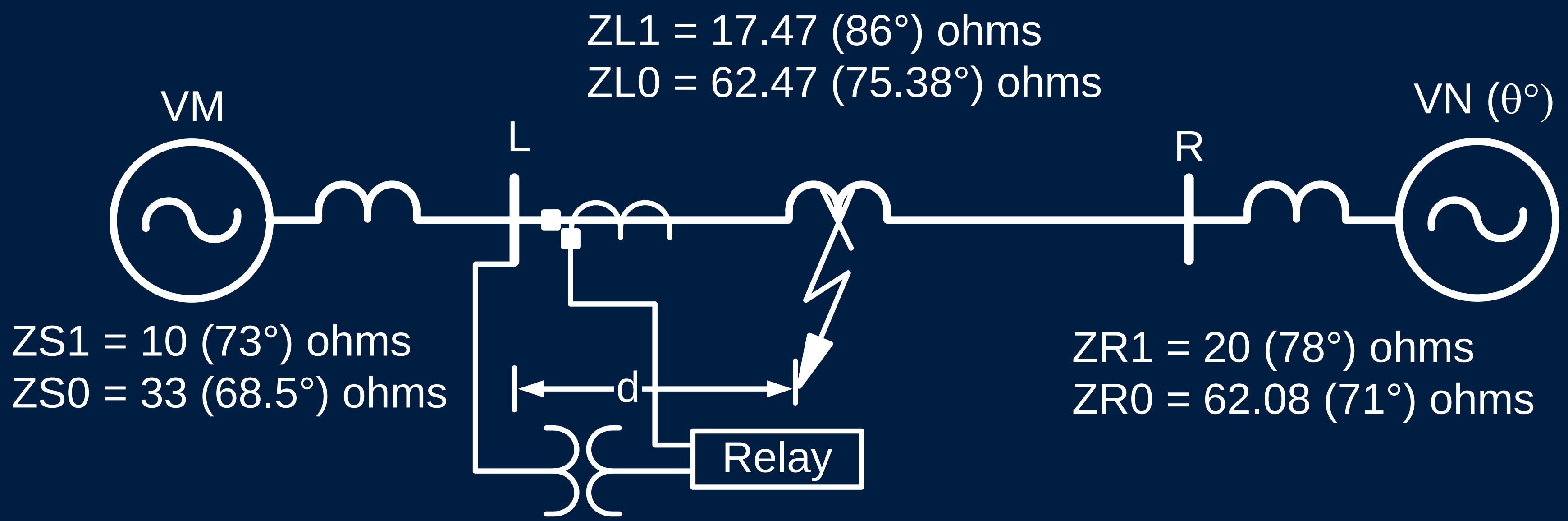
Overview

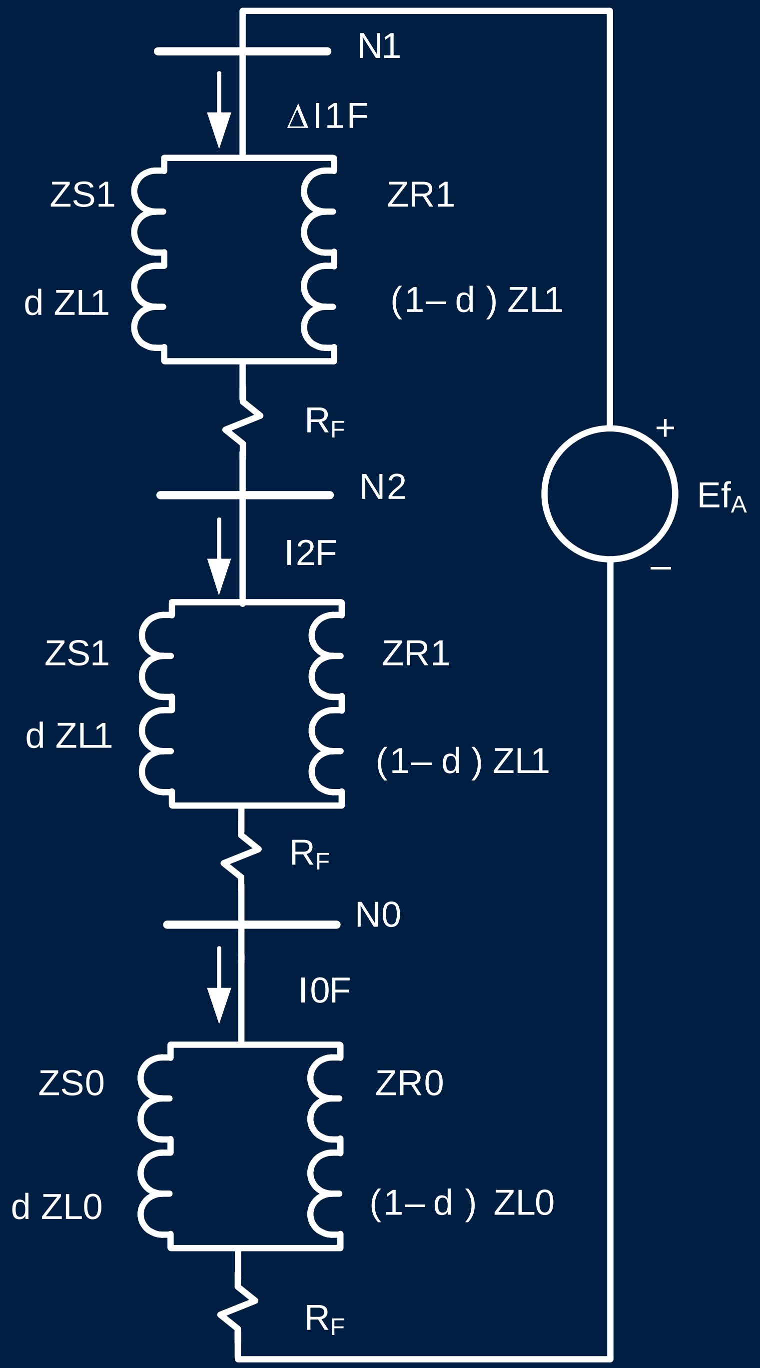
- Present characteristics of incremental distance in impedance plane
- Compare performance of mho elements and incremental distance elements based on their characteristics
- Compare performance with series compensation
- Discover issues with mutually coupled lines and three-terminal lines

Superposition Principle

CT Ratio: 240/1
VT Ratio: 2,000/1
All impedances in primary values

230 kV System





Single-Phase Faults

Pure-Fault Sequence Network

$$V = V_{PF} + \Delta V$$

$$I = I_{PF} + \Delta I$$

$$Ef_A = VM - (ZS1 + d \bullet ZL1) \bullet I_{LD}$$

$$Ef_A = VA_{PF} - d \bullet ZL1 \bullet I_{LD} =$$

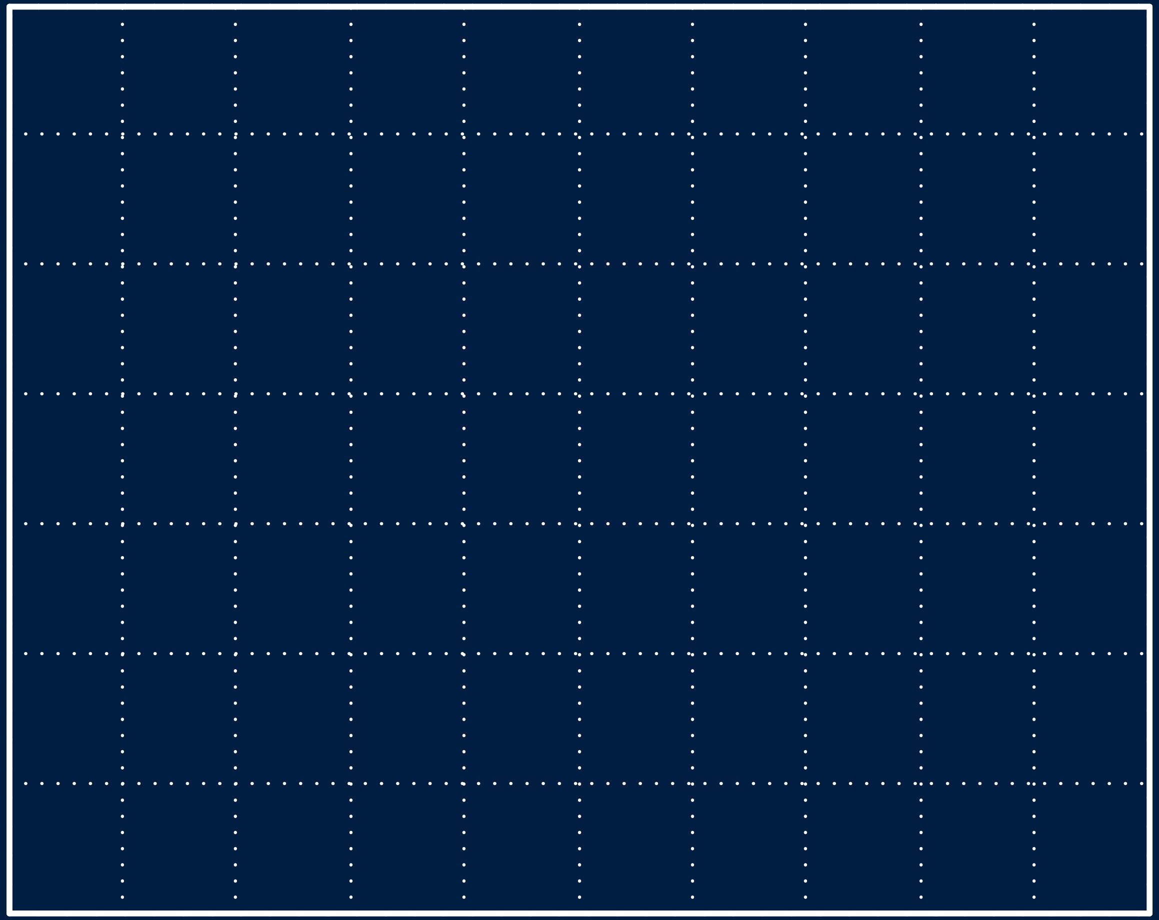
$$-\Delta VA + d \bullet ZL1 \bullet (\Delta IA + K_0 \bullet I0) + 3R_F \bullet \Delta I1F$$

Incremental Distance Principle

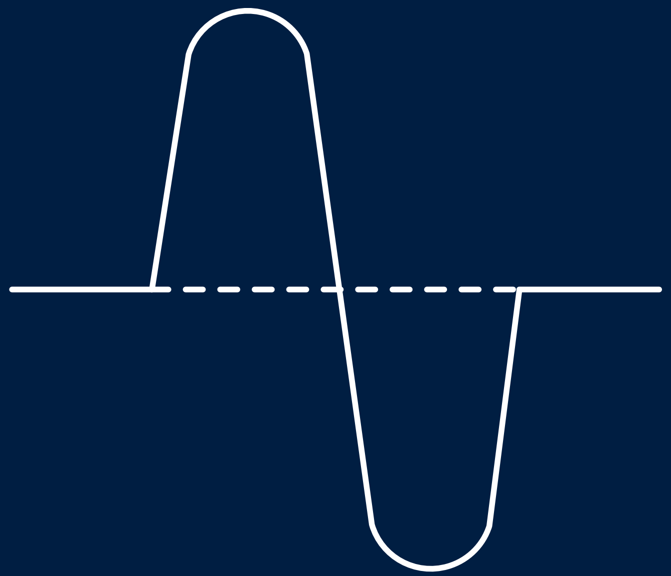
$$Ef_A = VA_{PF} - d \bullet ZL1 \bullet I_{LD} =$$
$$-\Delta VA + d \bullet ZL1 \bullet \left(\Delta IA + K_0 \bullet I0 \right) + 3R_F \bullet \Delta I1F$$

$$Vf_{AG} = VA_{PF} - r \bullet Z1L \bullet IA_{PF}$$
$$Vd_{AG} = -\Delta VA + r \bullet Z1L \bullet \left(\Delta IA + K_0 \bullet I0 \right)$$

Variation of Vf_{AG} and Vd_{AG} (r = 80%)



Simple Delta Filter



Delta Filters

- Delta filters provide ΔV and ΔI during a time interval equal to the delay τ following a fault
- Delta filters can be used either in frequency domain with phasors or in time domain (high- and ultra-high-speed applications)
- Output is zero in steady state
- Limitations are cascading events, evolving faults, and switch-on-to-fault situations

Incremental Distance Three-Phase Fault Characteristics

$$Ef_A = -\Delta VA + d \bullet ZL1 \bullet \Delta IA + R_F \bullet \Delta I1F$$

$$Vd_A = -\Delta VA + r \bullet ZL1 \bullet \Delta IA$$

$$Ef'_A = \frac{Ef_A}{\Delta IA} = ZS1 + d \bullet ZL1 + \frac{R_F}{C1} = ZS1 + Z_{APP\_NLD}$$

$$Vd'_A = \frac{Vd_A}{\Delta IA} = ZS1 + r \bullet Z1L$$

Incremental Distance Three-Phase Fault Characteristics

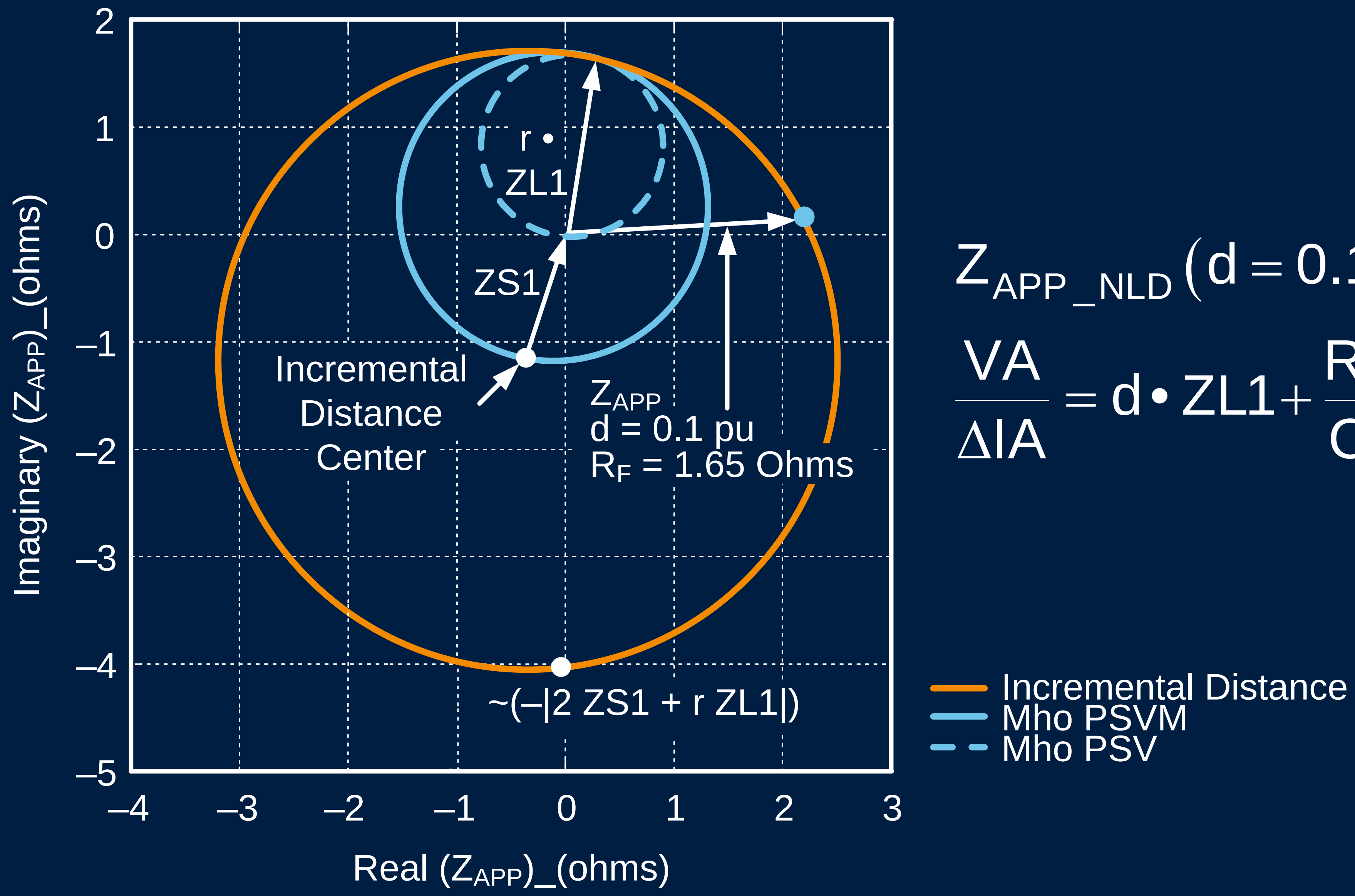
$$\left|\left(ZS1 + r \bullet Z1L\right)\right| \geq \left|\left(ZS1 + Z_{APP\_NLD}\right)\right|$$

$$x_0 = -\text{real}\left(ZS1\right)$$

$$y_0 = -\text{imag}\left(ZS1\right)$$

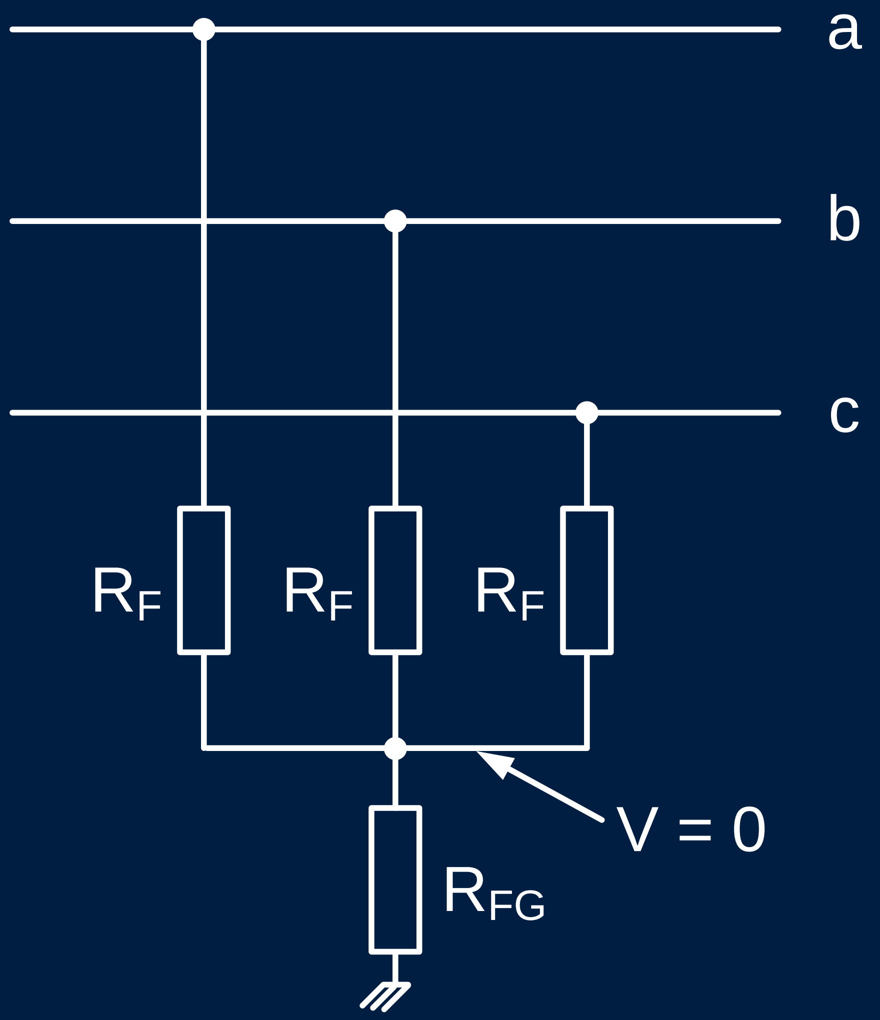
$$R = \left|\left(ZS1 + r \square ZL1\right)\right|$$

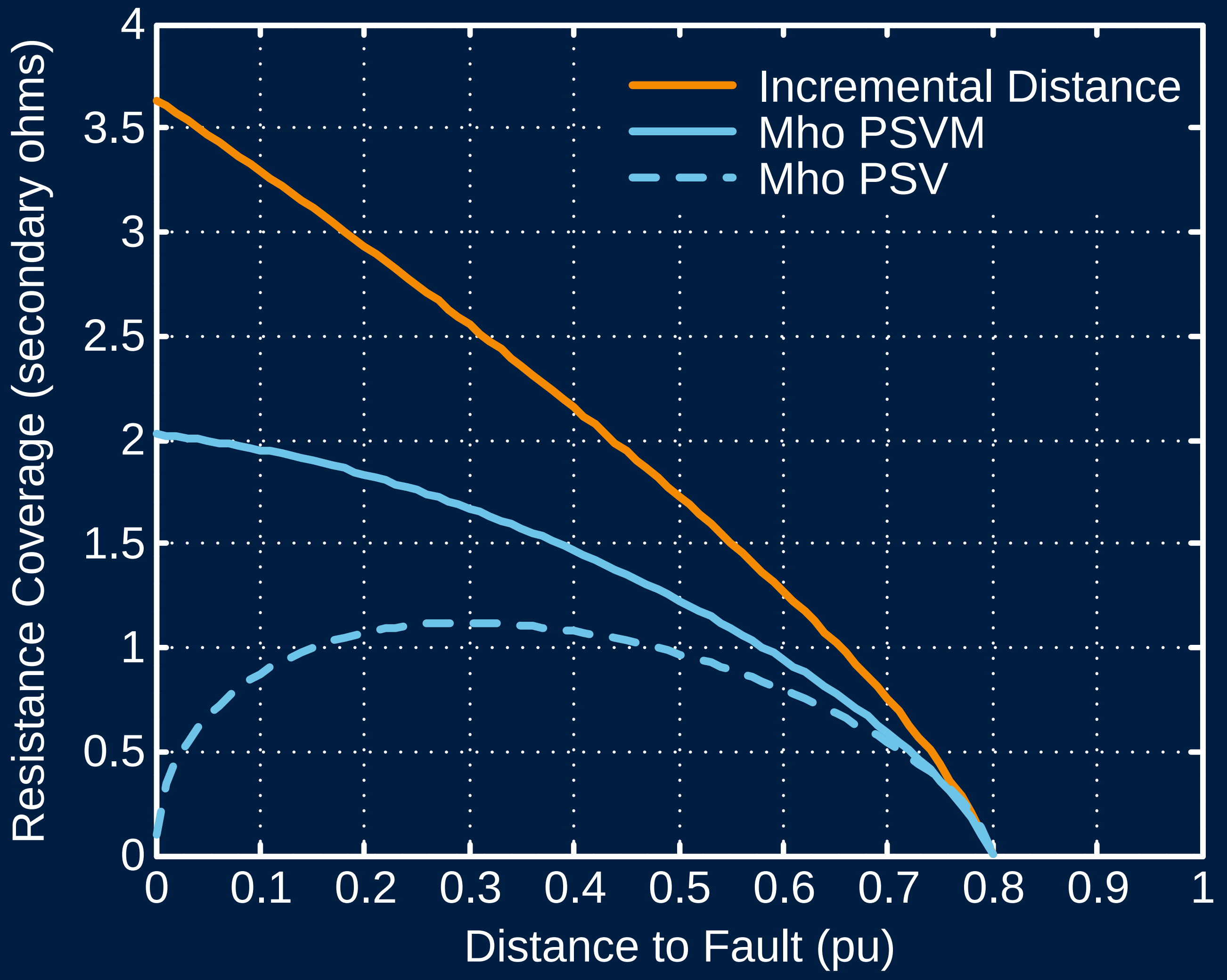
Three-Phase Fault Characteristics



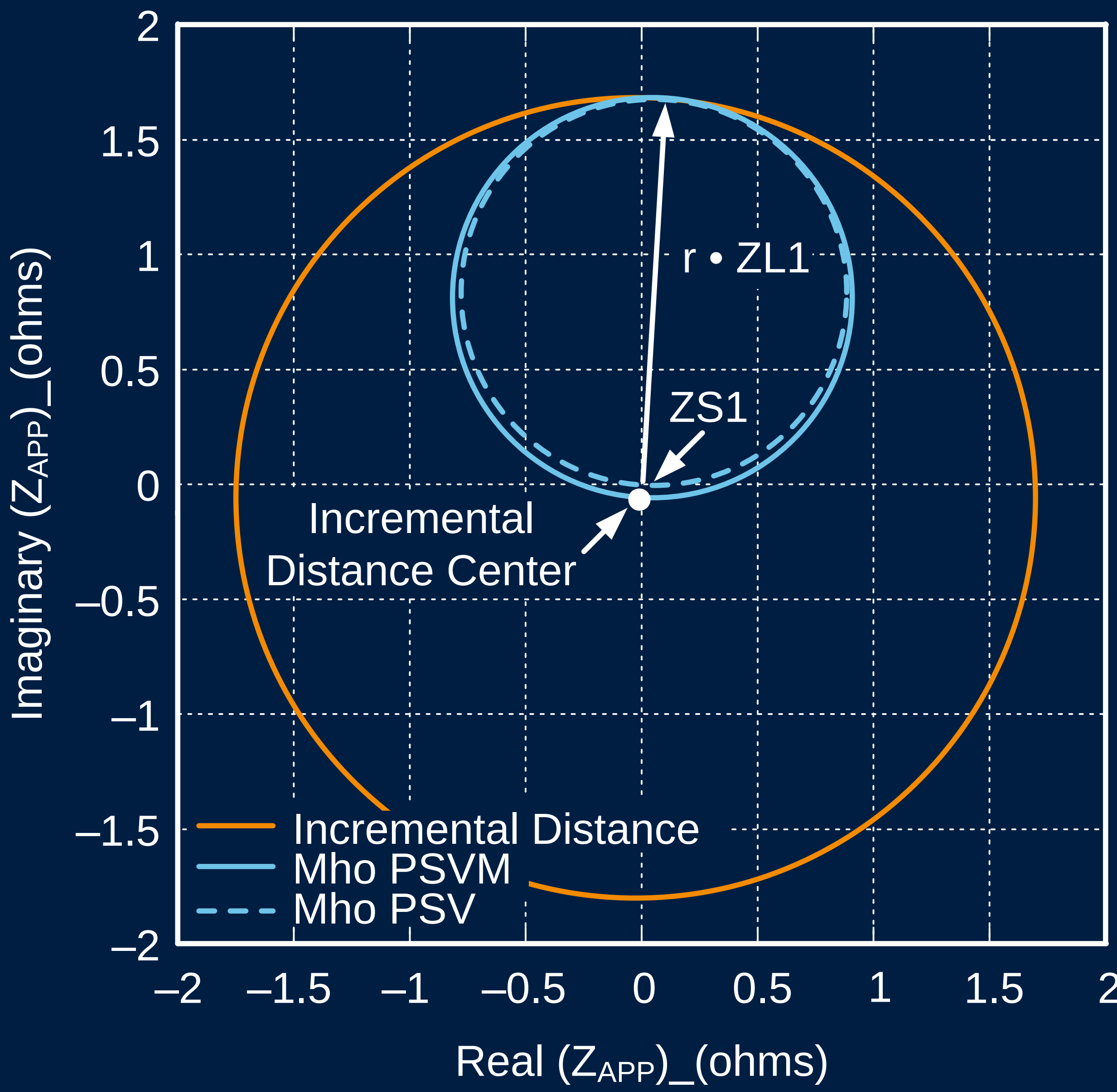
$$Z_{APP\_NLD}\left(d = 0.1, R_F = 1.6465\right) = \frac{VA}{\Delta IA} = d \bullet ZL1 + \frac{R_F}{C1} = \left(2.199 + j0.147\right)\Omega$$

Three-Phase Faults
Resistance Coverage

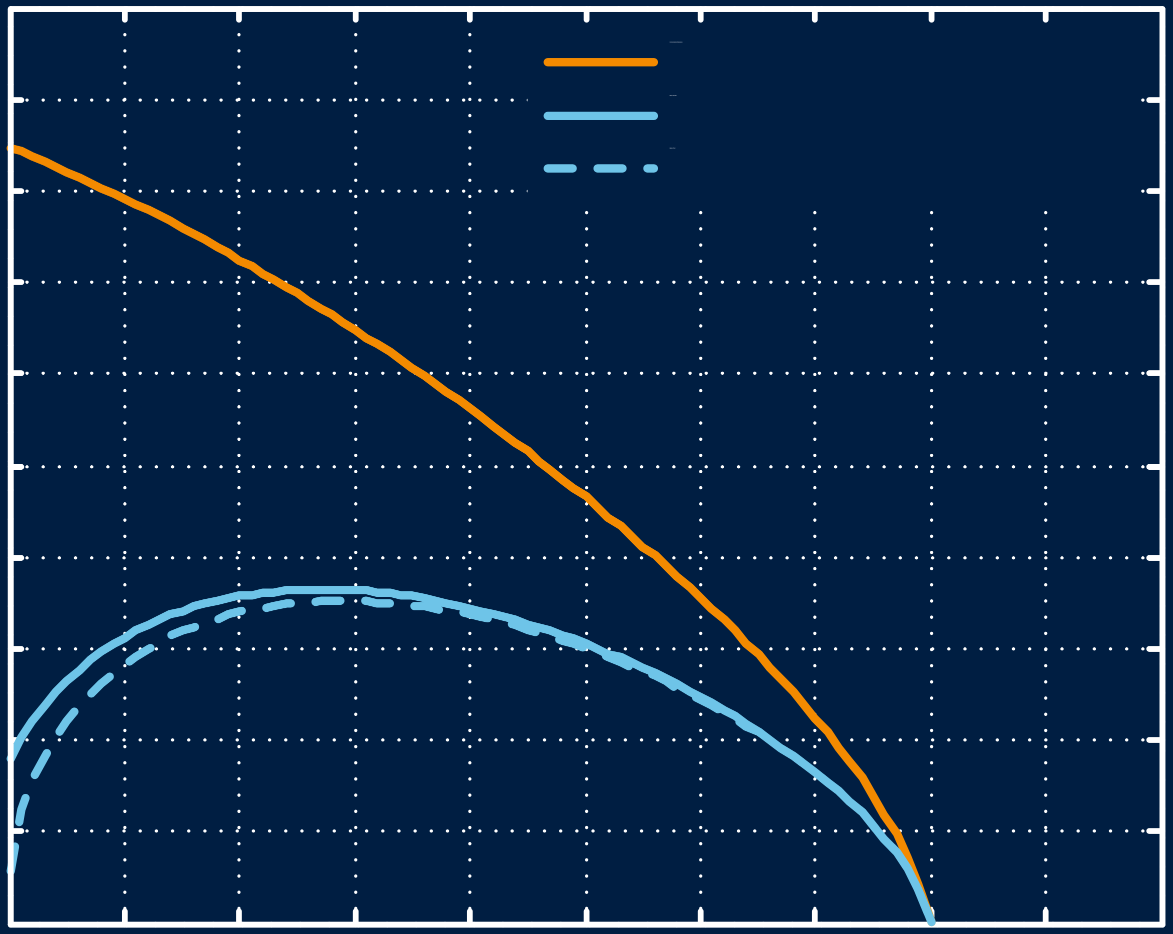




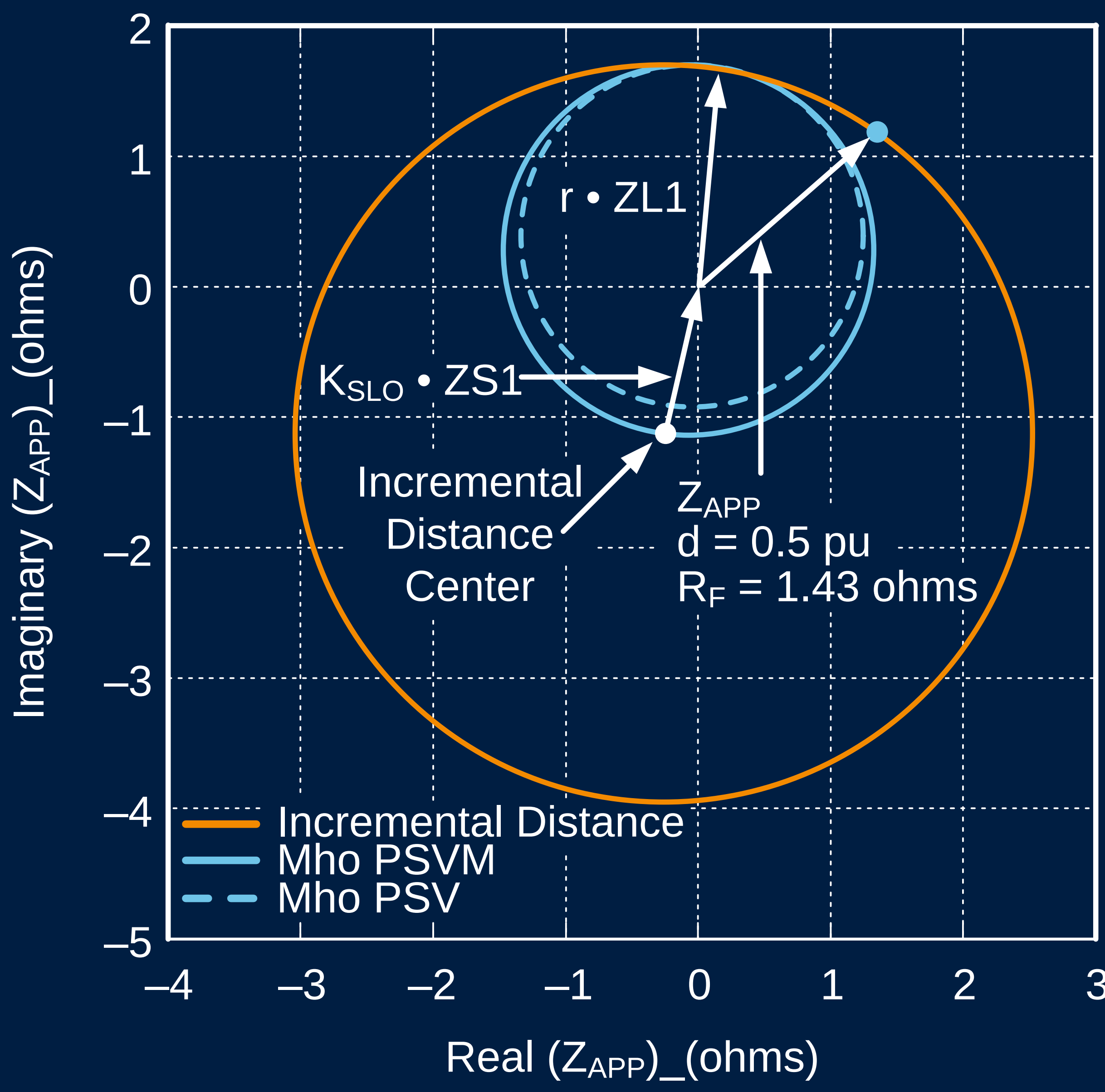
Three-Phase Fault With ZS1 Divided by 20



Three-Phase Fault Resistance Coverage With ZS1 Divided by 20



Single-Phase Fault Characteristics

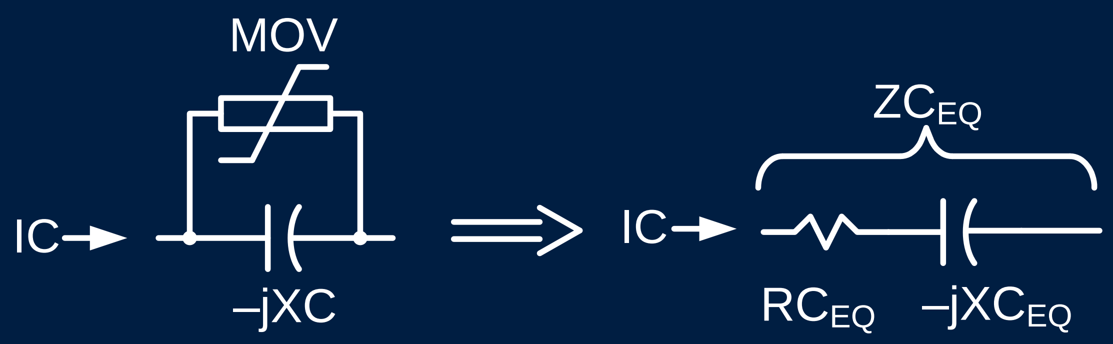


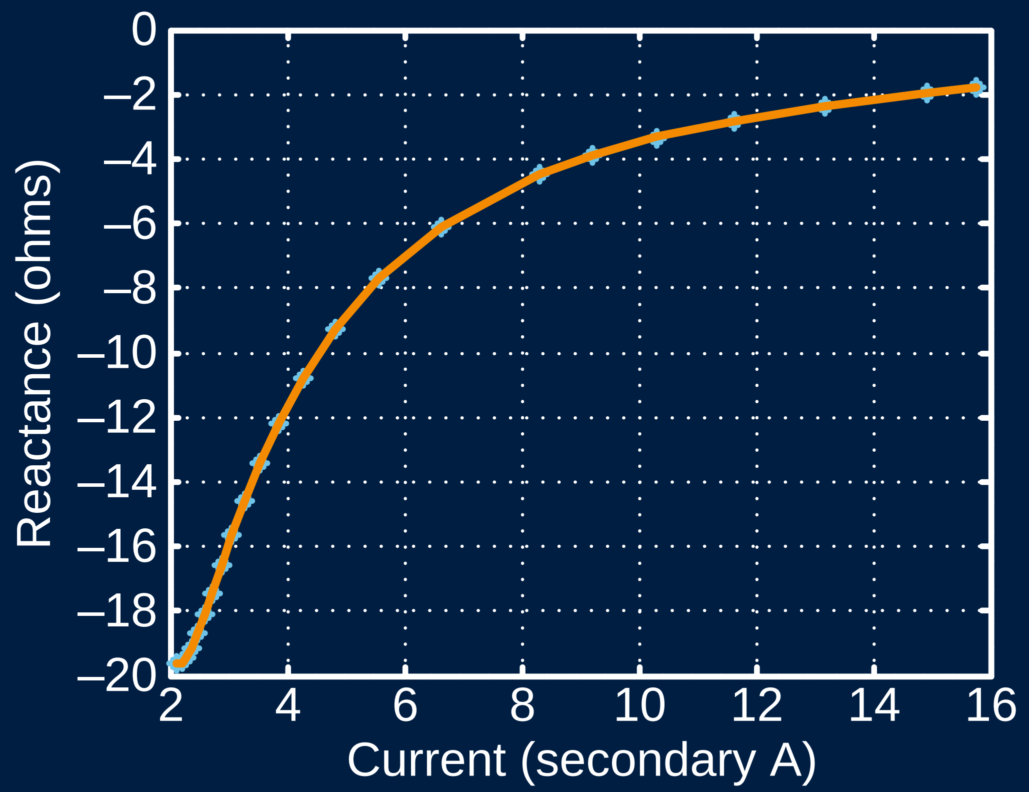
Distance Element Characteristics

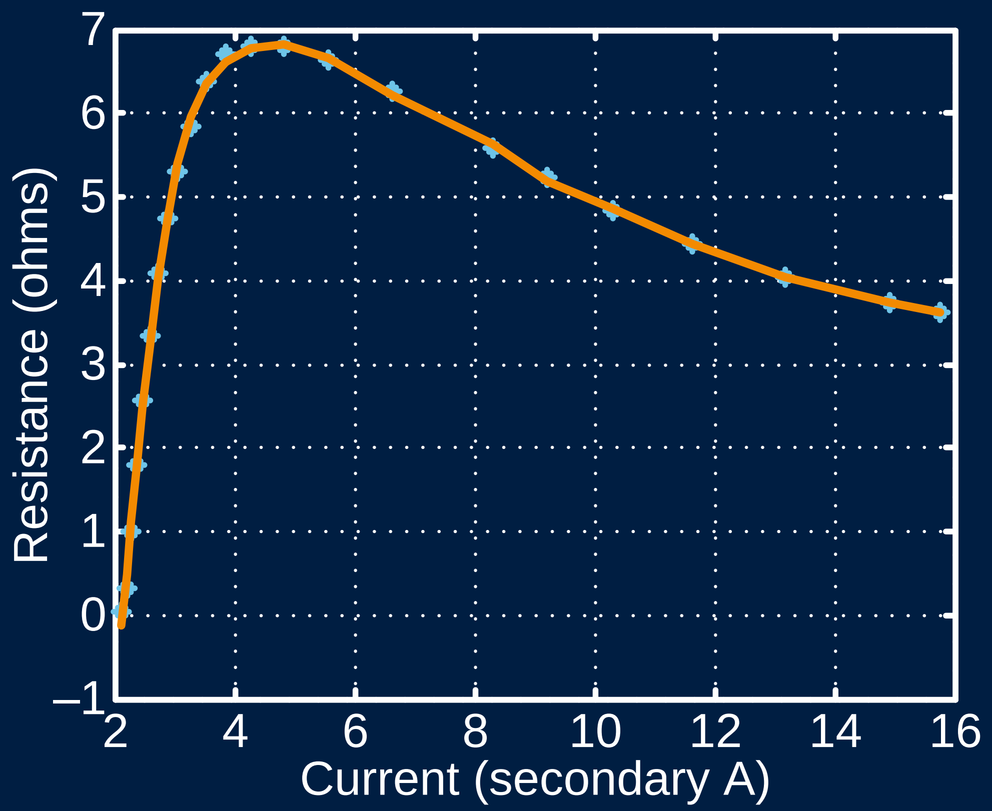
- Mho element characteristics in impedance plane always exist
- Incremental distance element characteristics in impedance plane are defined only if ΔV and ΔI are non-zero (they do not exist in steady state)
- In steady state, mho element asserts for overload condition (incremental distance element does not)

Series Compensation

MOV / Capacitor Equivalent







Voltage Inversion

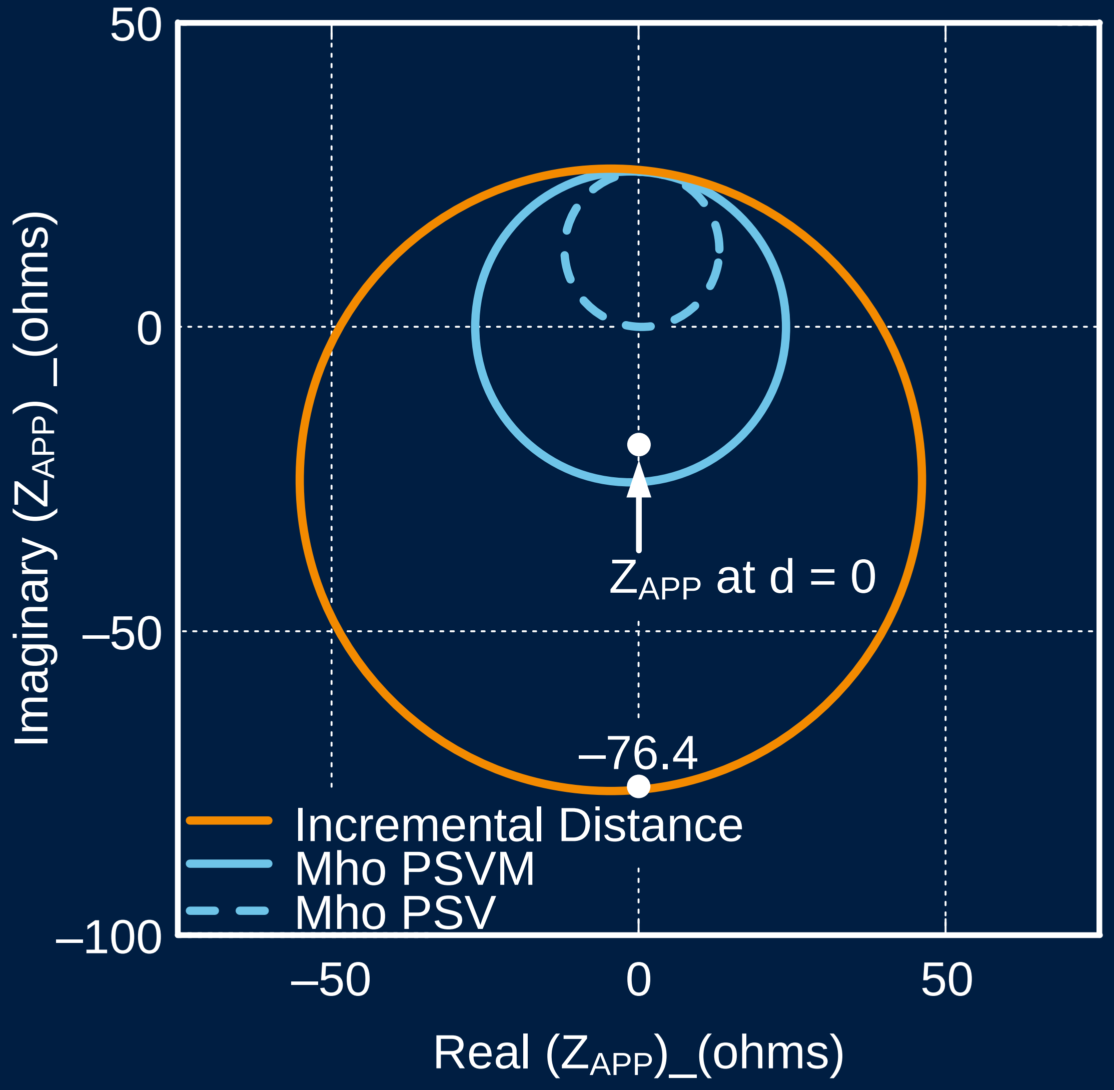
No MOV, d = 0, R_F = 0

$$|ZC_{EQ}| > |d \bullet ZL1|$$

$$|ZS1 + d \bullet ZL1| > |ZC_{EQ}|$$

$$|-j19.6|\,\text{ohms} > 0$$

$$25.4\,\text{ohms} > |-j19.6|\,\text{ohms}$$

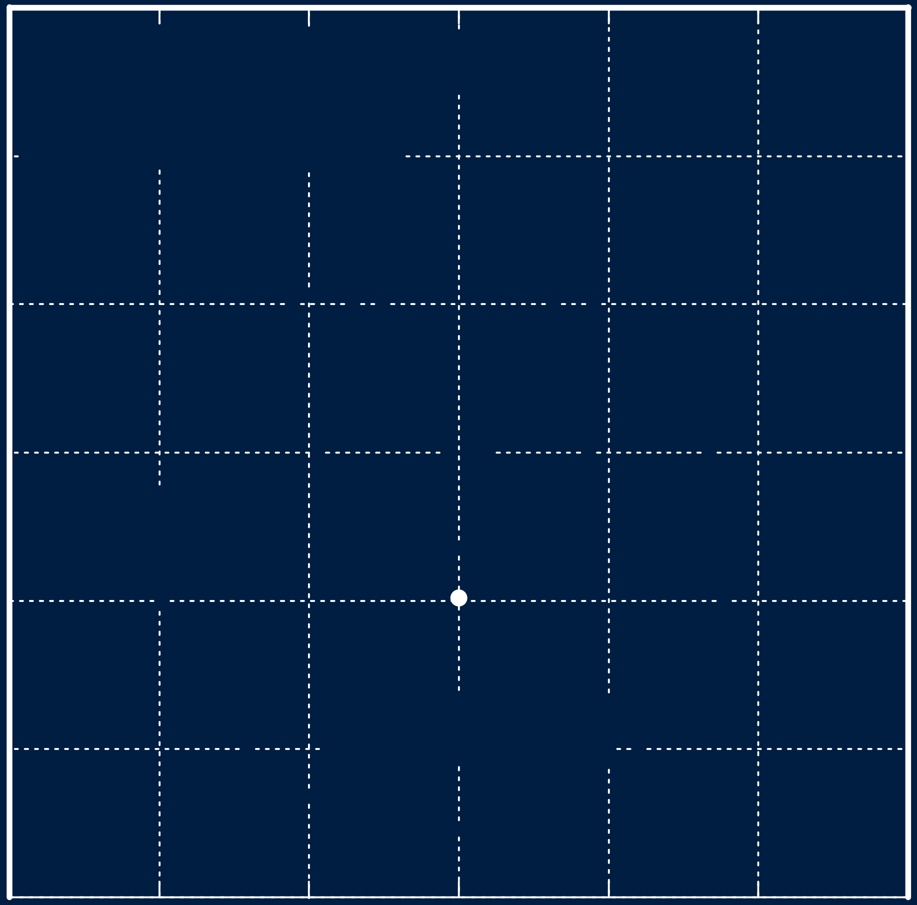


Current Inversion

No MOV, d = 0, R_F = 0, ZS1 Divided by 2

$$\left|ZC_{EQ}\right| > \left|ZS1 + d \bullet ZL1\right|$$

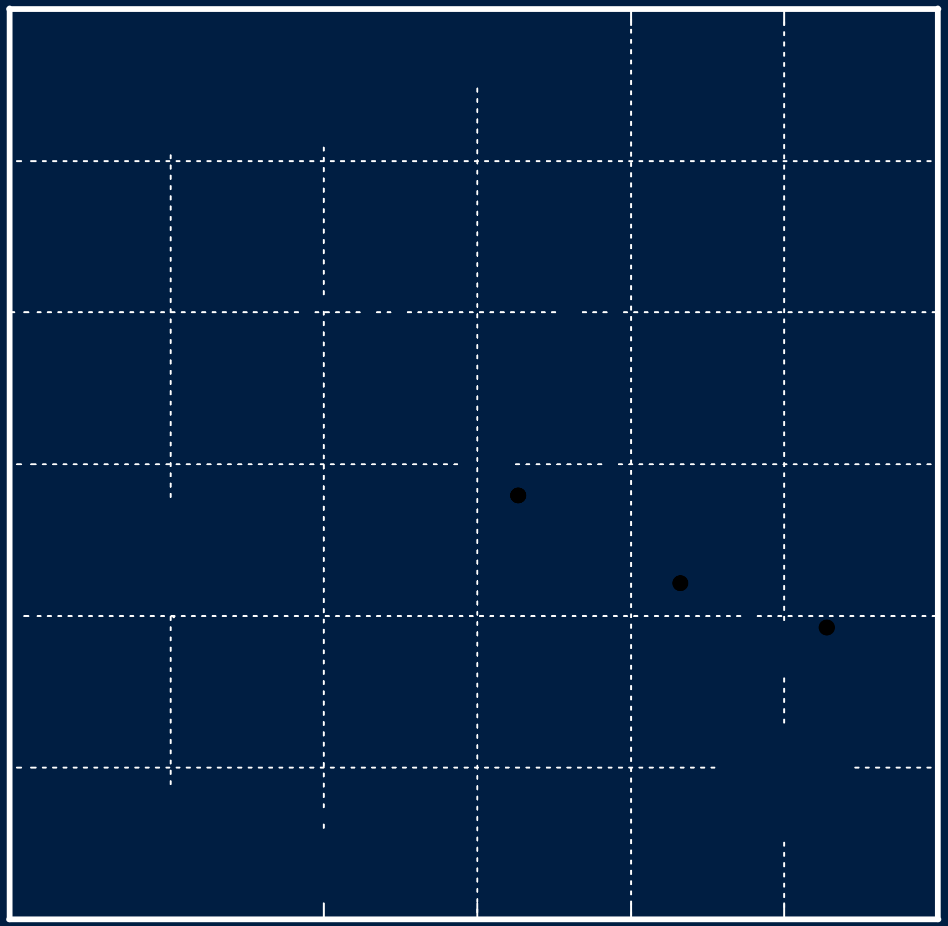
$$\left|-j19.6\right| \text{ohms} > 12.7 \text{ ohms}$$



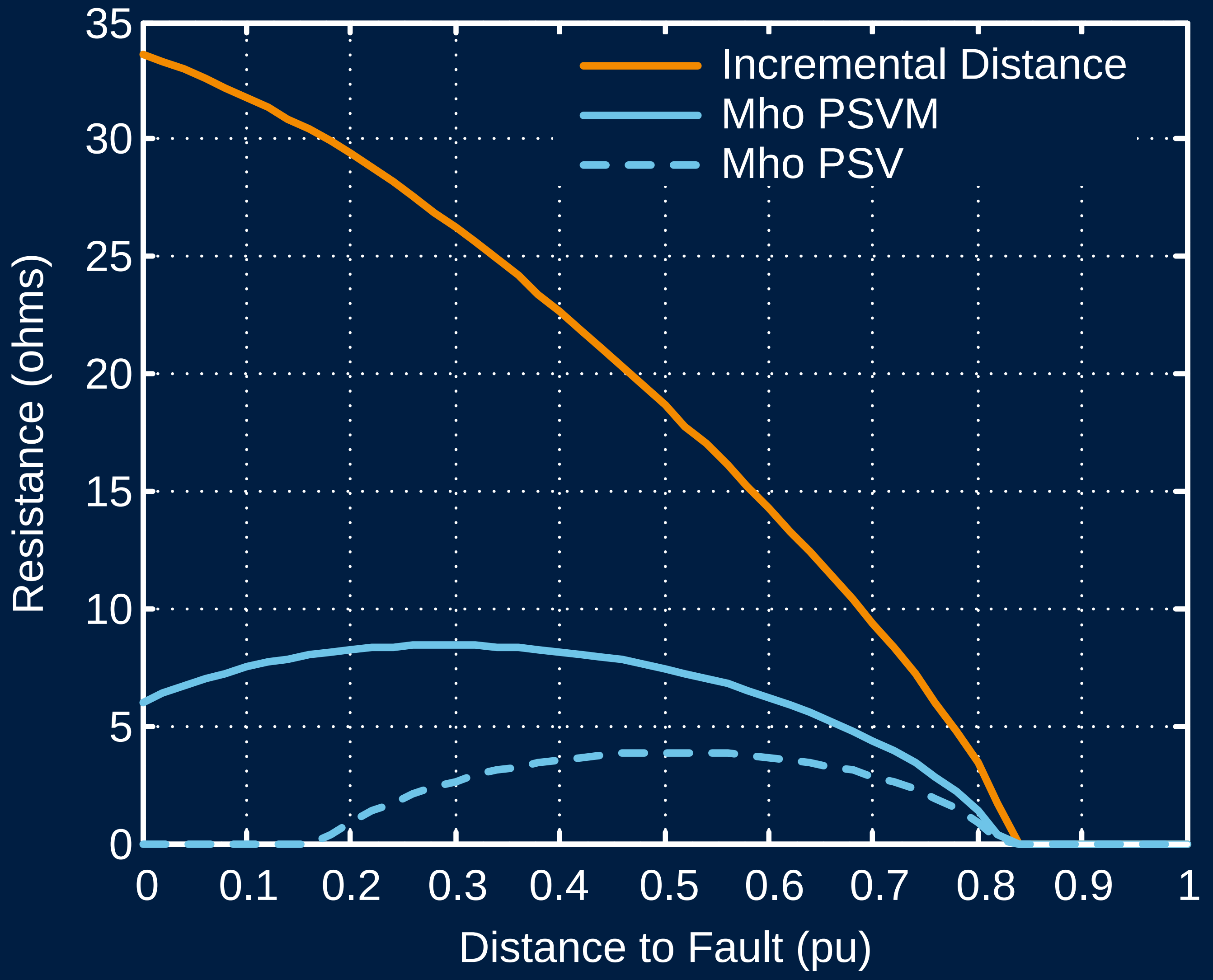
Linearized Sequence Network for Three-Phase Fault

Apparent Impedances for Three-Phase Fault

d = 0, r = 50%

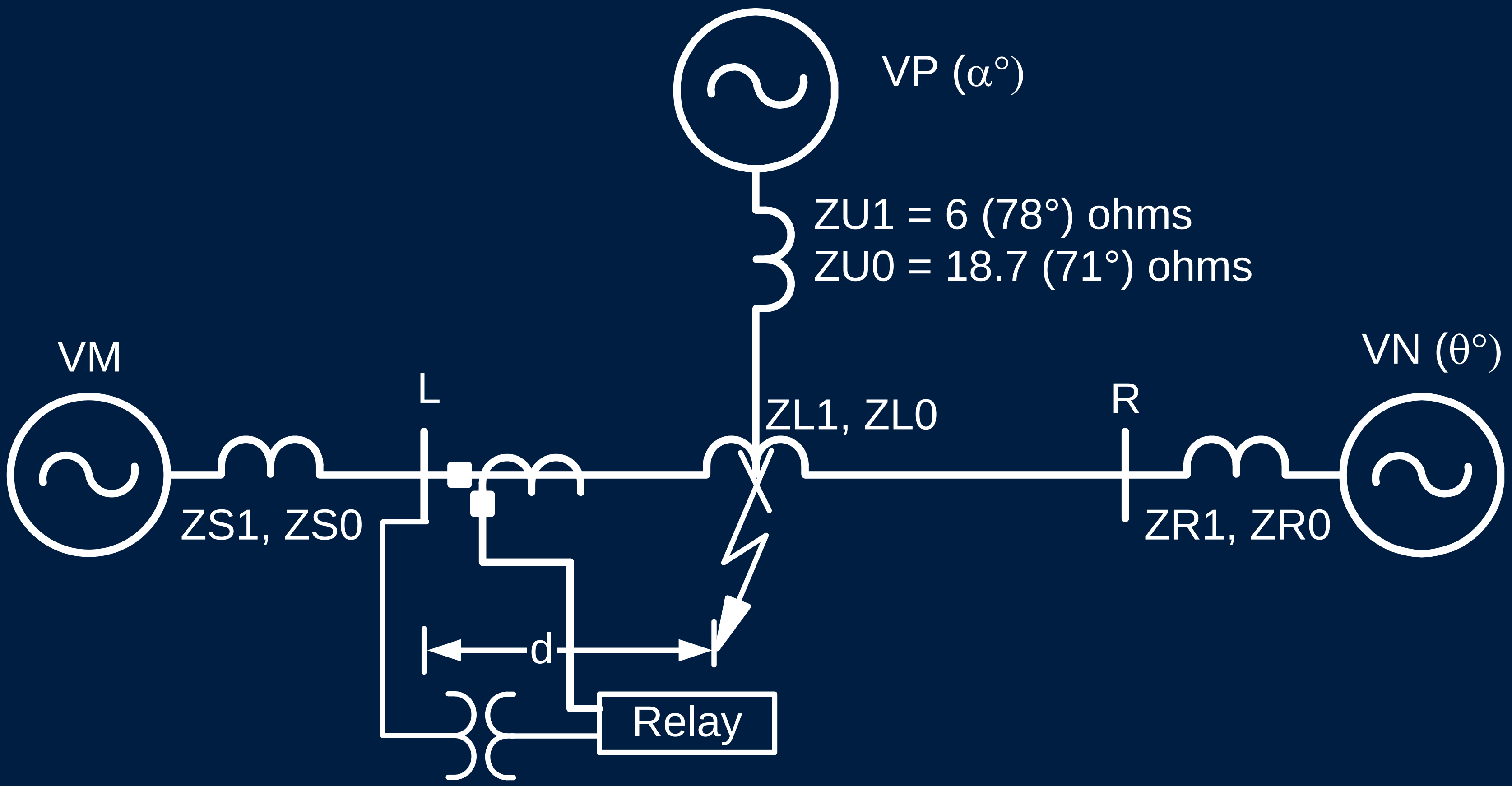


Three-Phase Fault Resistance Coverage

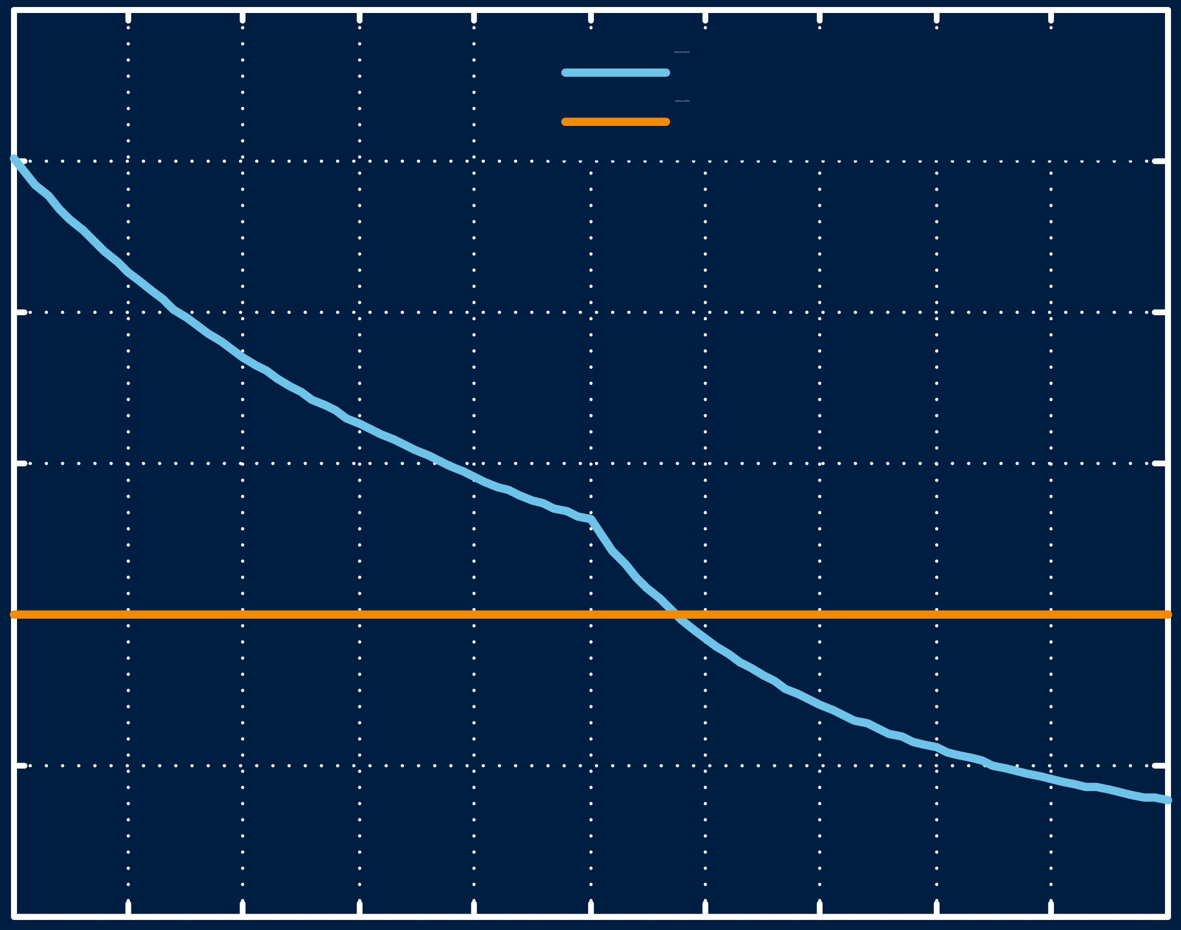


Impact of Element Reach

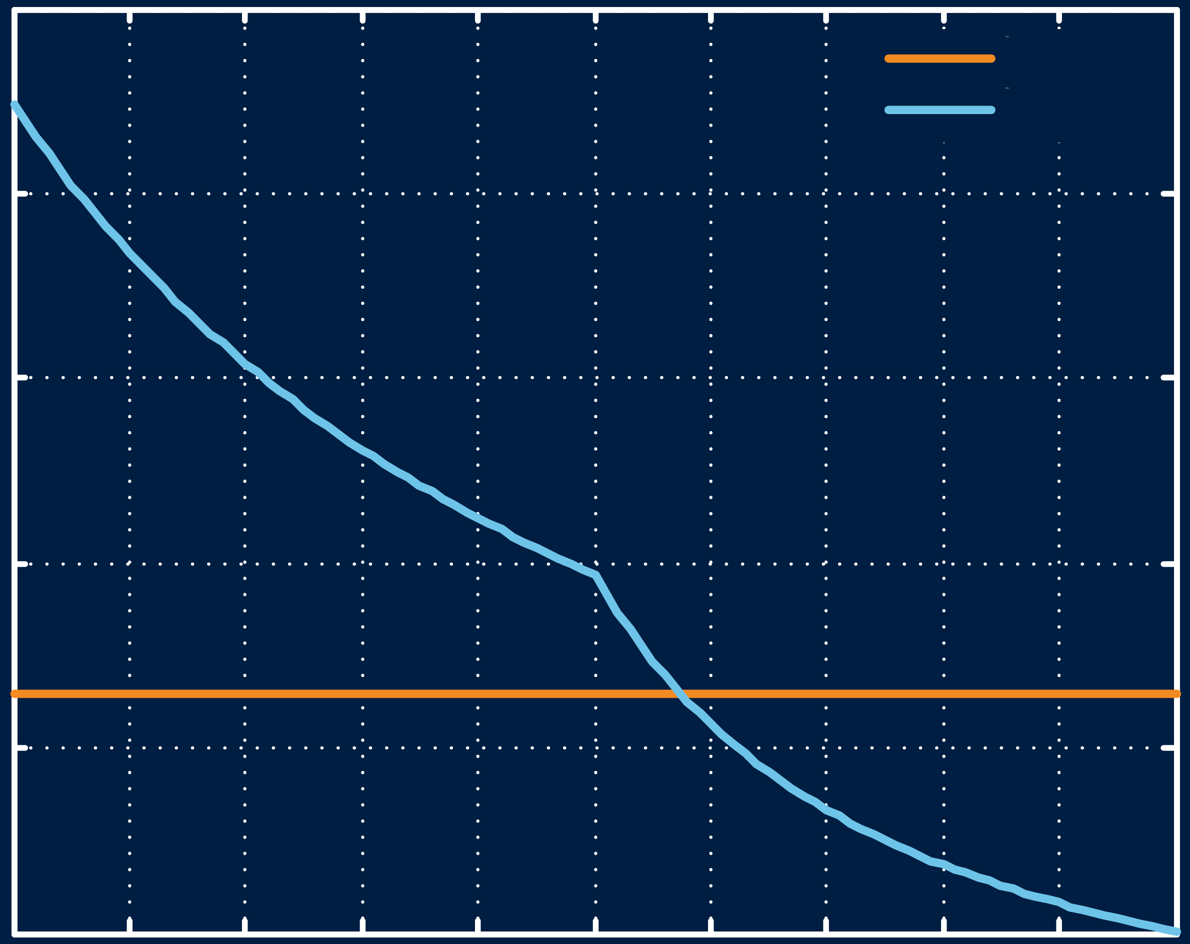
Example of Remote Infeed



Mho AB Loop Scalar Product for Three-Phase Fault Applied From d = 0 to 1 pu



Vf_{AB} and Vd_{AB} for Three-Phase Fault Applied From d = 0 to 1 pu



Conclusion

- Incremental distance characteristics do not exist in steady state
- Incremental distance elements have increased sensitivity, increased resistance coverage, and immunity to voltage or current inversion
- Incremental distance element reach is affected in same way as mho elements (series compensation, remote infeed or outfeed, and parallel lines)

Conclusion

- Limits of incremental distance elements are limits imposed by delta filters (window typically of 1 cycle)
- Optimal configuration consists of mho element that is parallel with incremental distance element (high- or ultra-high-speed element with slower conventional mho element backup)
- Single comparator was considered in the study

Questions?