

# Advances in Series-Compensated Line Protection

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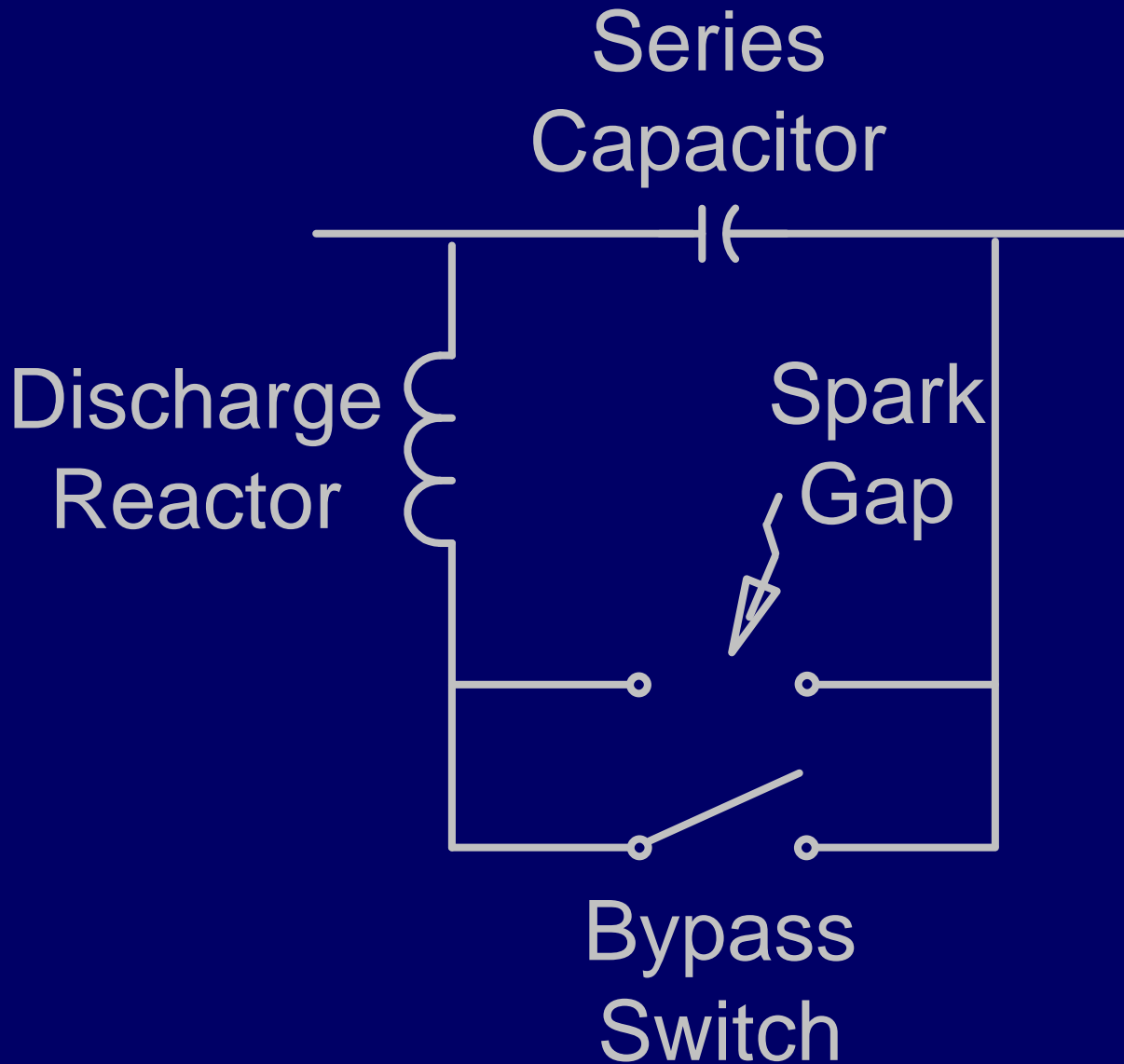
Hector Altuve, George Alexander

*Schweitzer Engineering Laboratories, Inc.*

# Series Capacitors

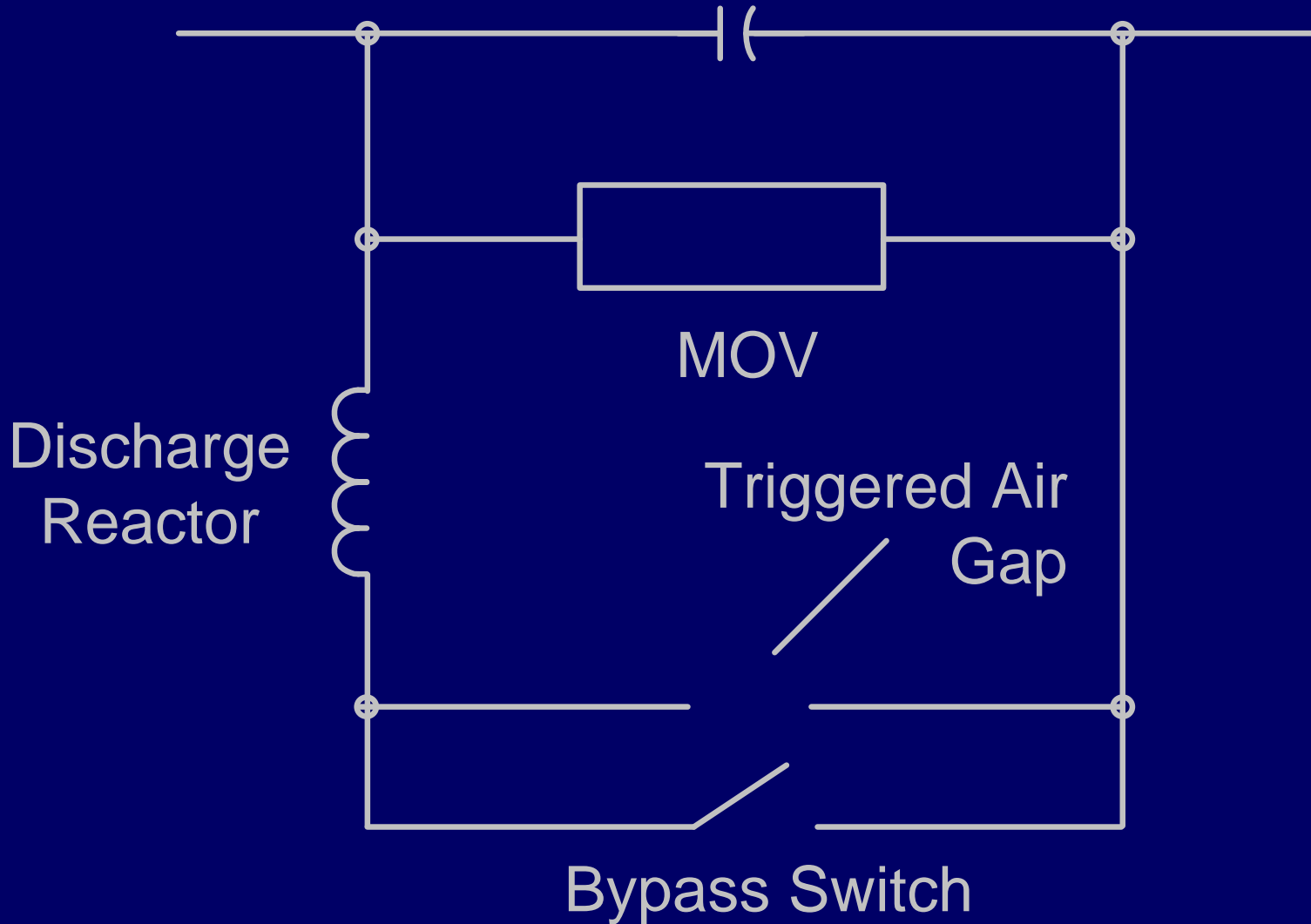
- Improve power transfer
- Improve system stability
- Location of capacitor varies
- Dedicated protection
  - ◆ Spark gap
  - ◆ Metal-oxide varistor (MOV)

# Gap-Protected Bank



# MOV Protected Bank

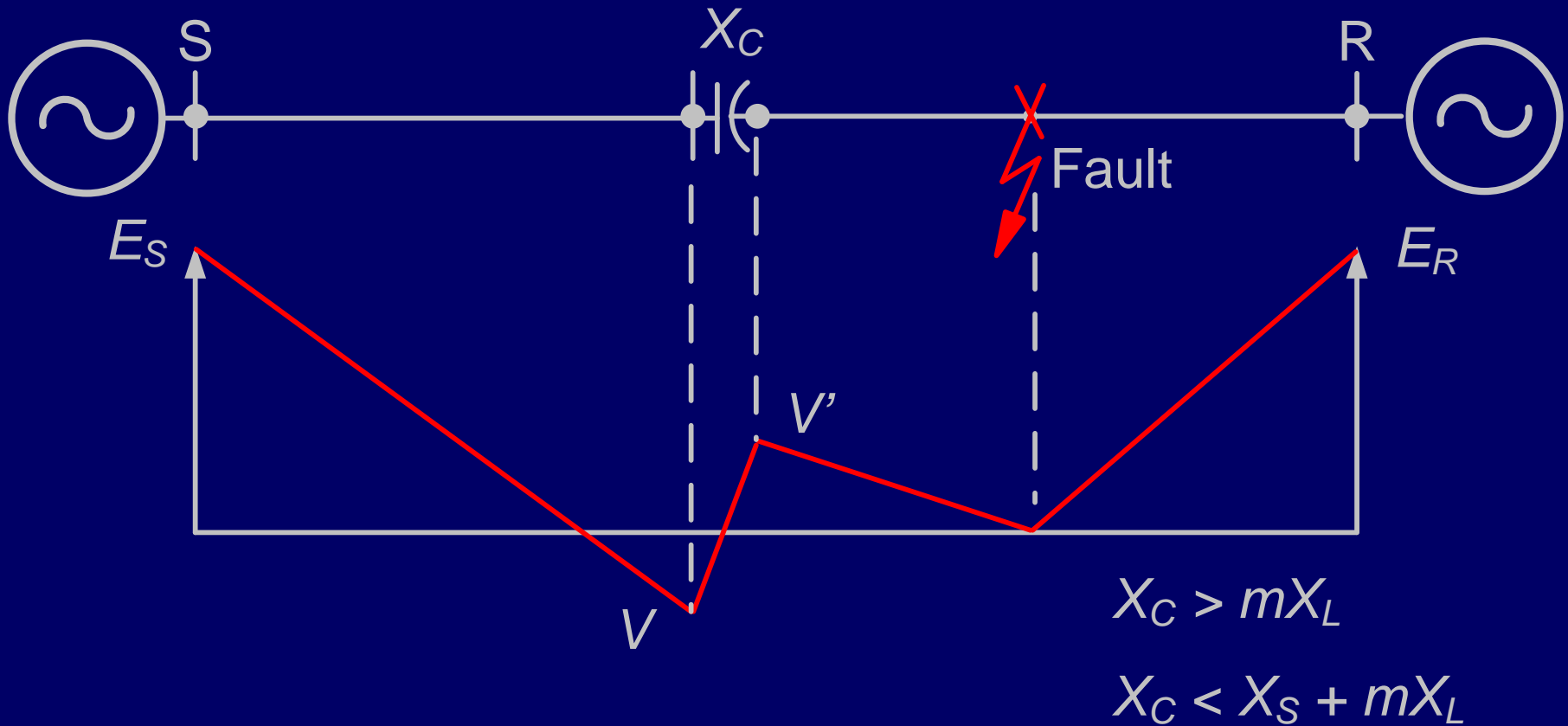
Series Capacitor



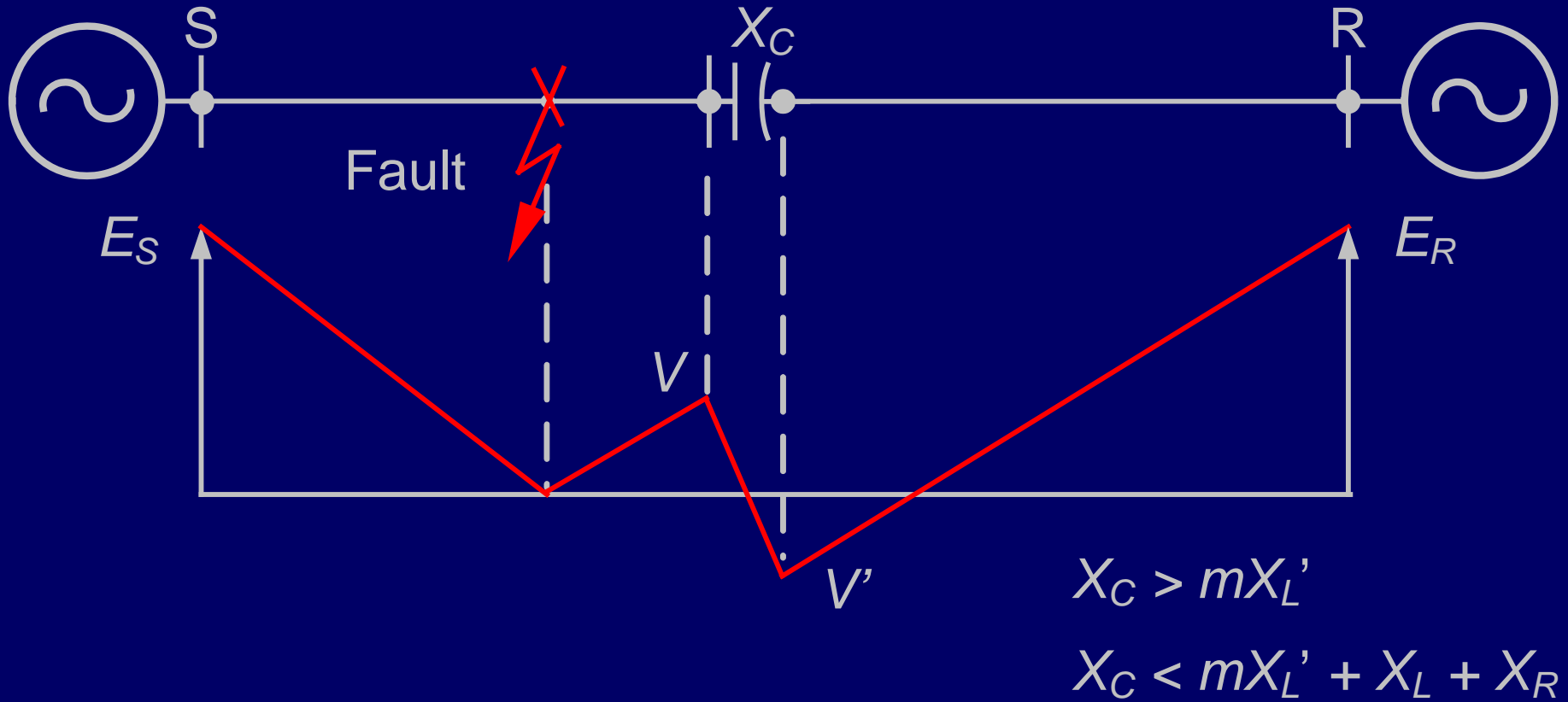
# Line Protection Challenges

- Voltage inversion
- Current inversion
- Directional security
- Reduced line impedance
- Low frequency resonance

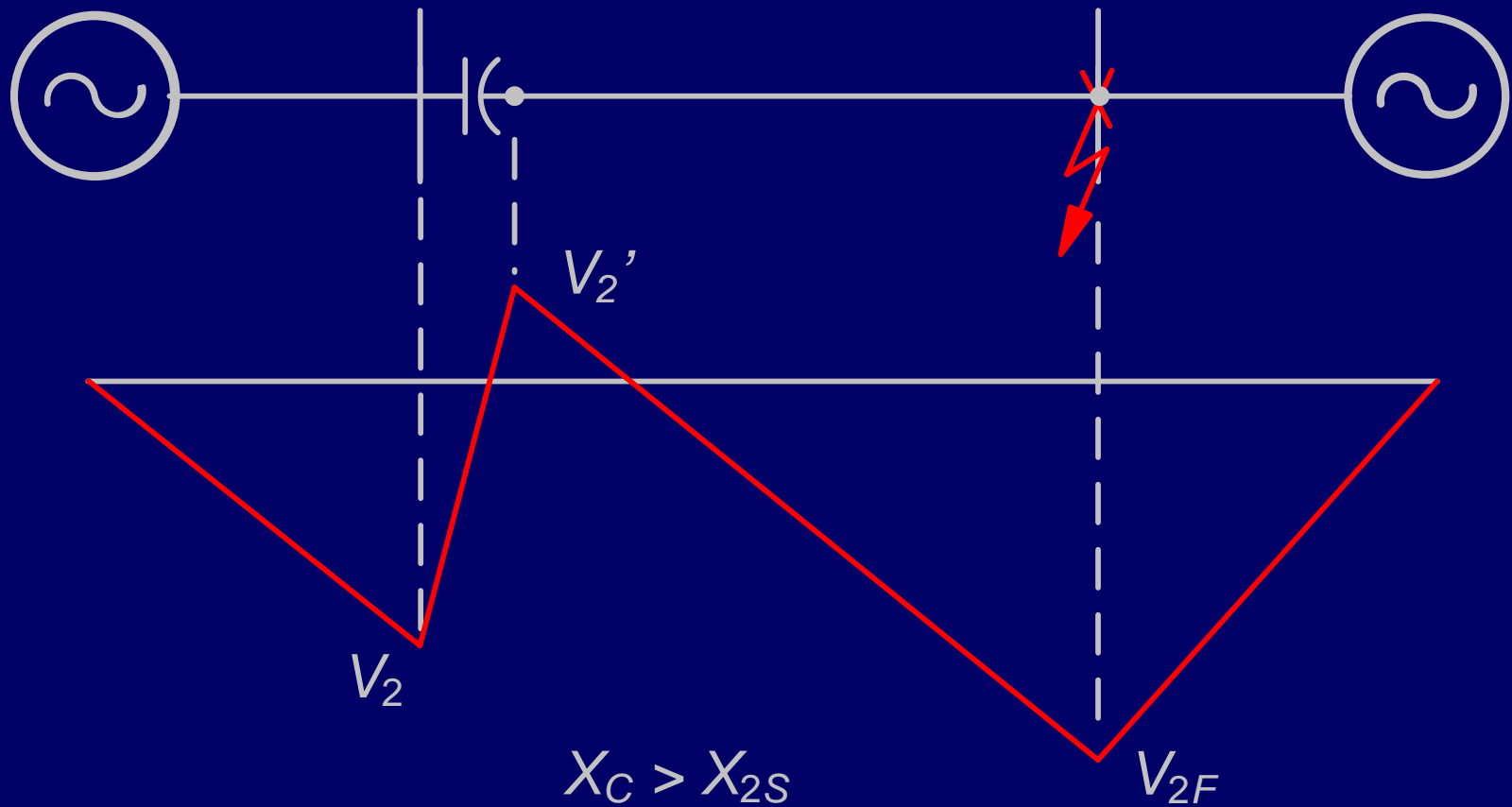
# Voltage Inversion – Forward Fault



# Voltage Inversion – Reverse Fault



# Voltage Inversion – Negative-Sequence



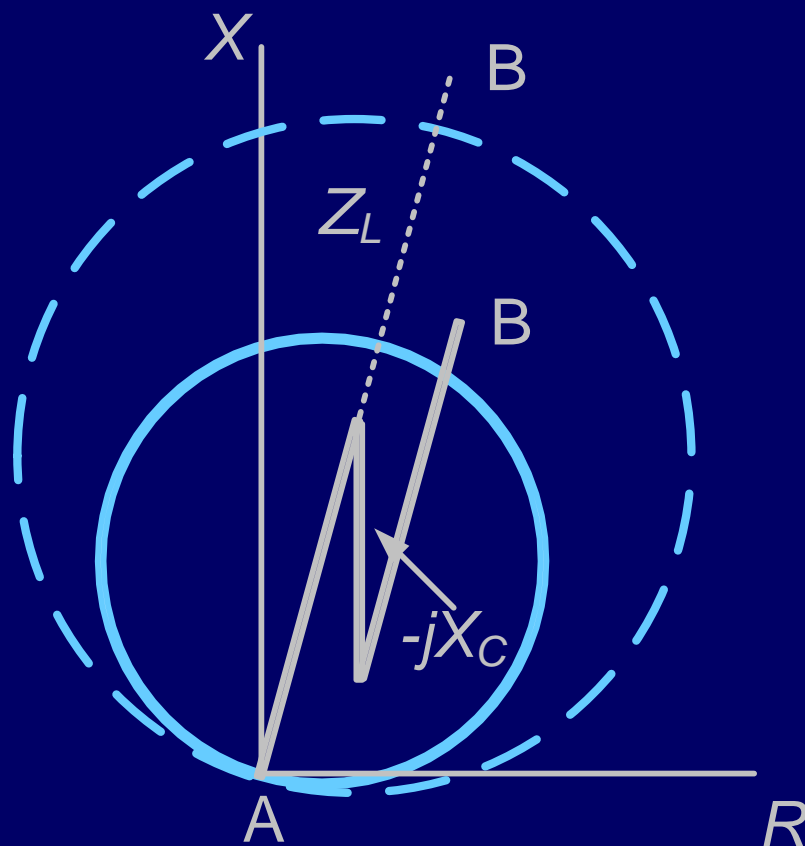
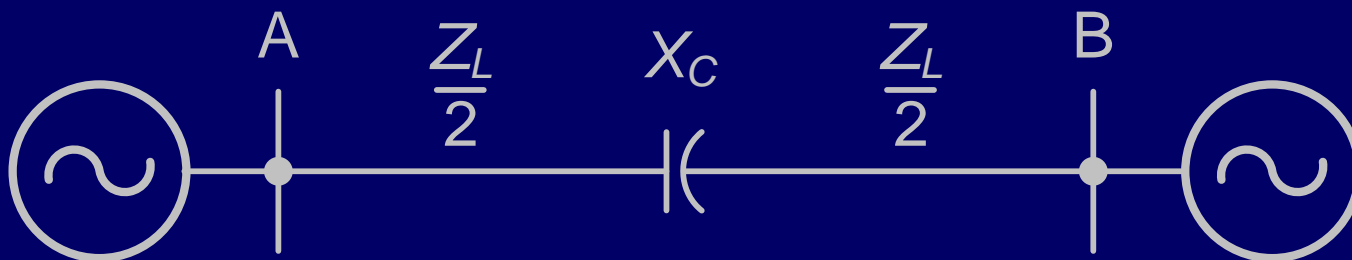
# Current Inversion



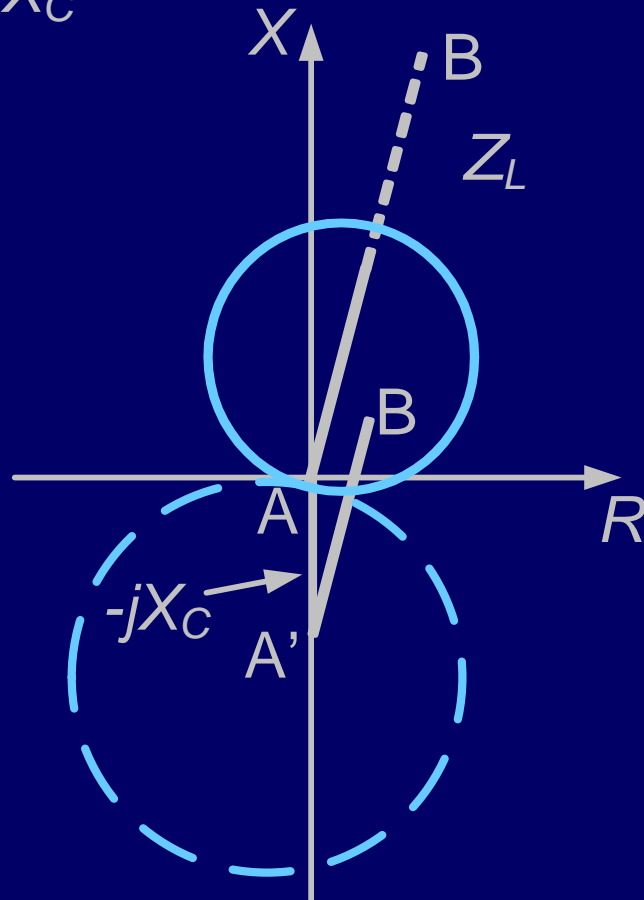
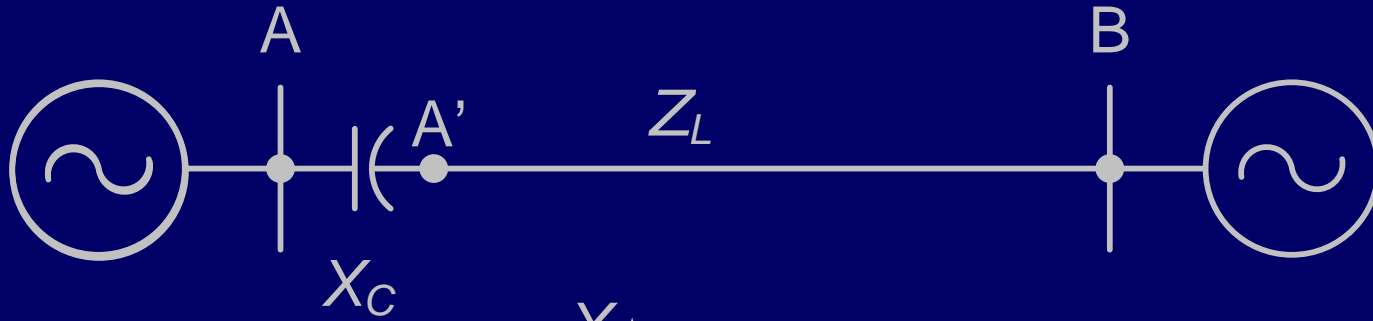
$$X_C > X_S$$



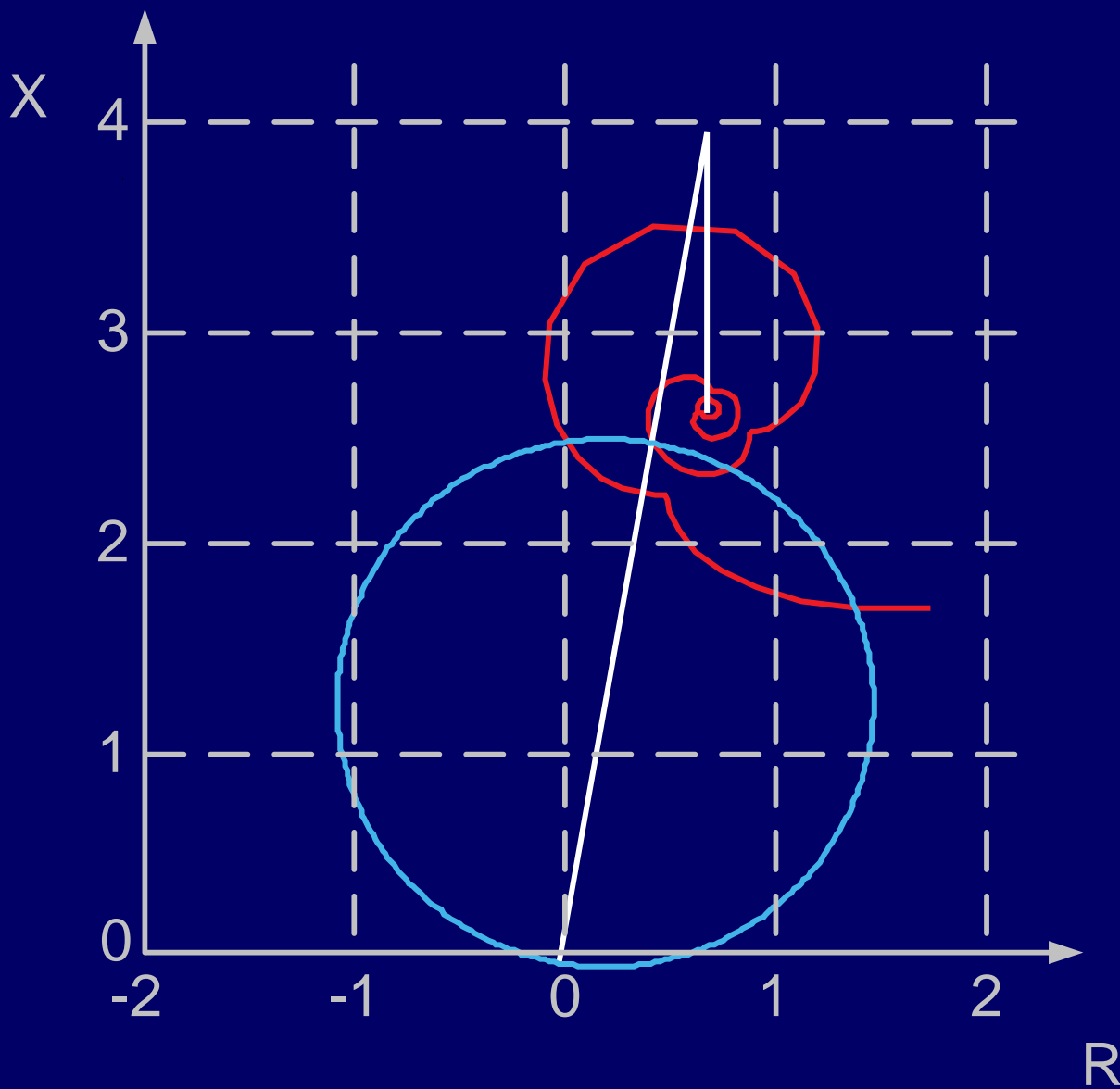
# Impedance Measurement – Mid-Line



# Impedance Measurement – End-of-Line



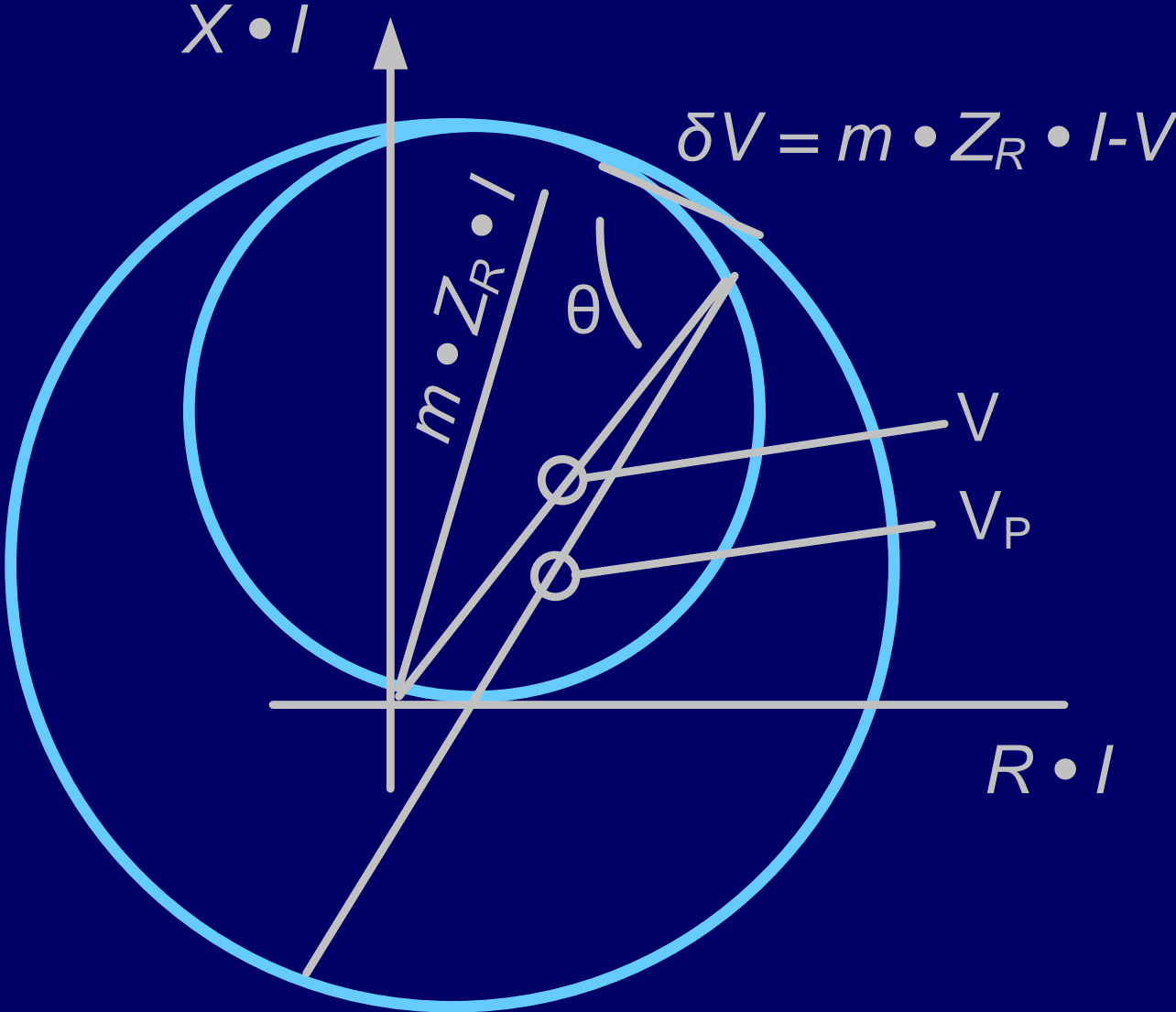
# Transient Response



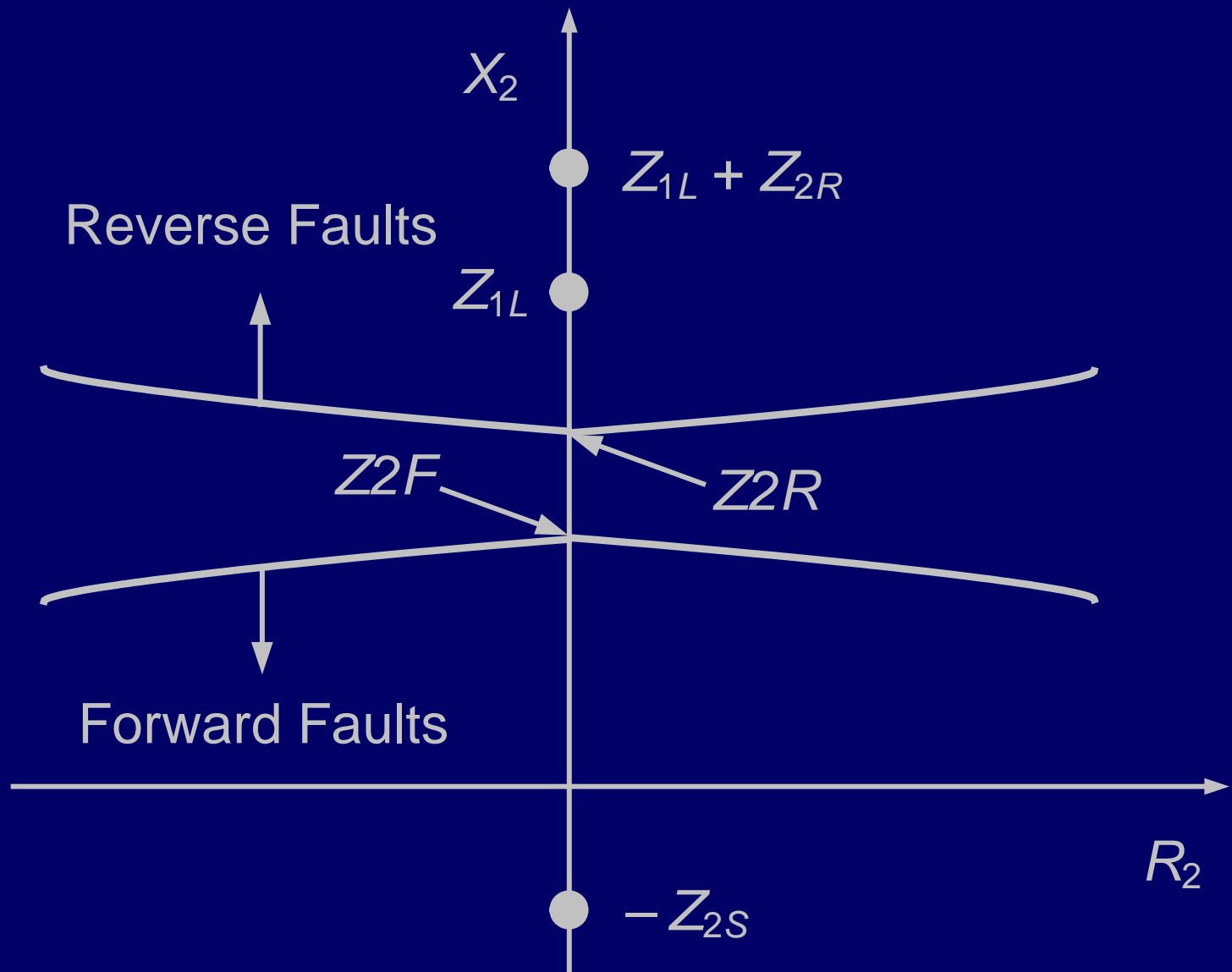
# Advancements and Solutions

- Memory polarization
- Directional element offset
- Overreach supervision
- Differential elements

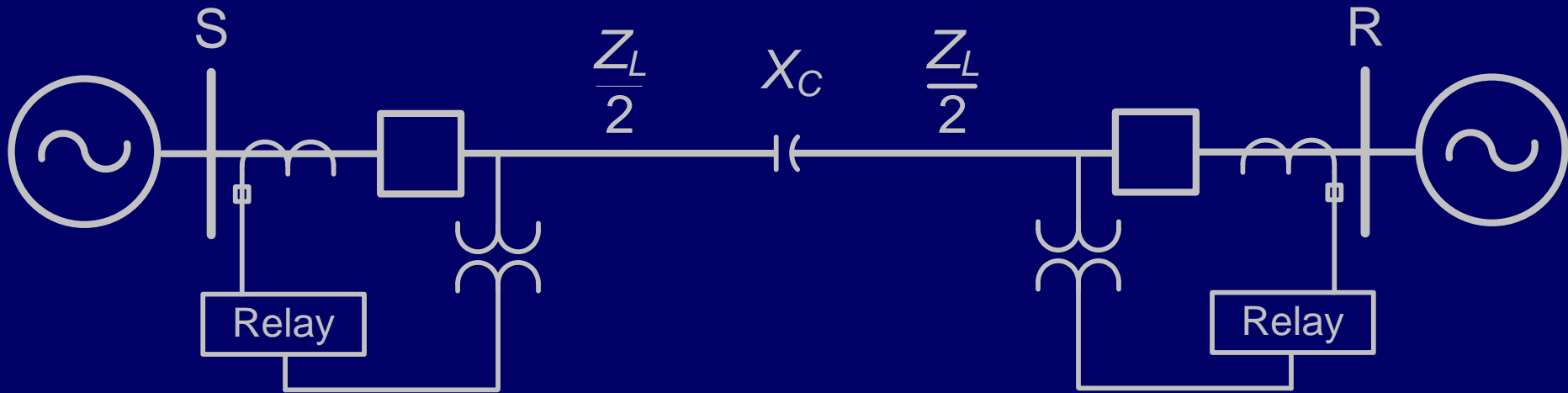
# Mho Characteristic



# Directional Element Characteristic

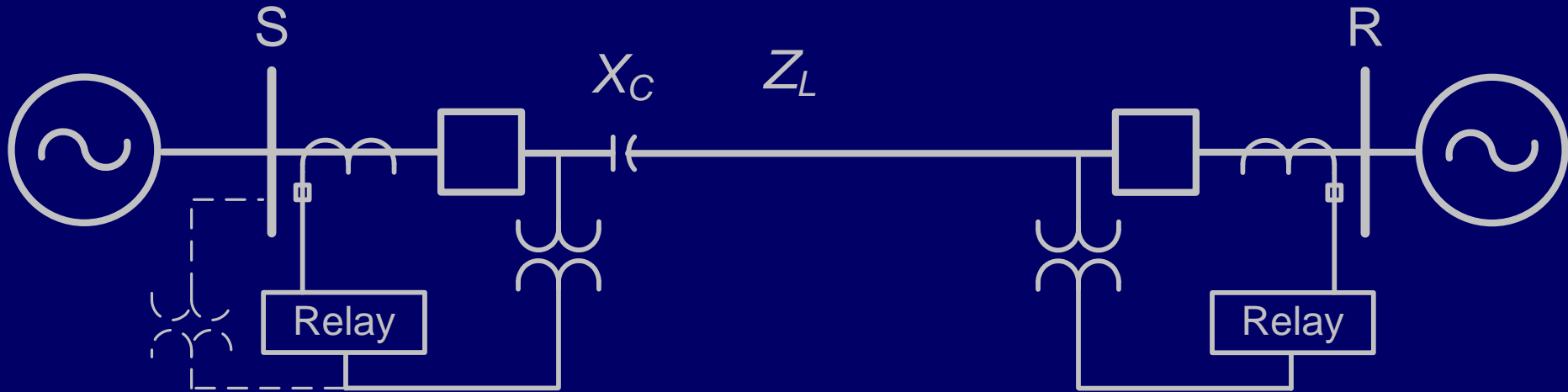


# Directional Element Offset Mid-Line Cap



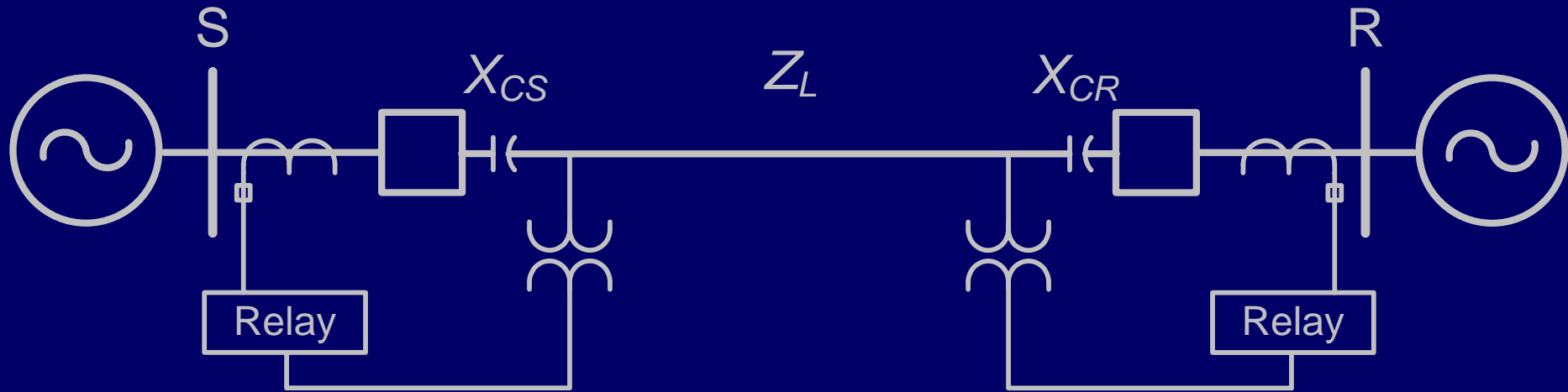
# Directional Element Offset

## End-of-Line Cap, Bus PT

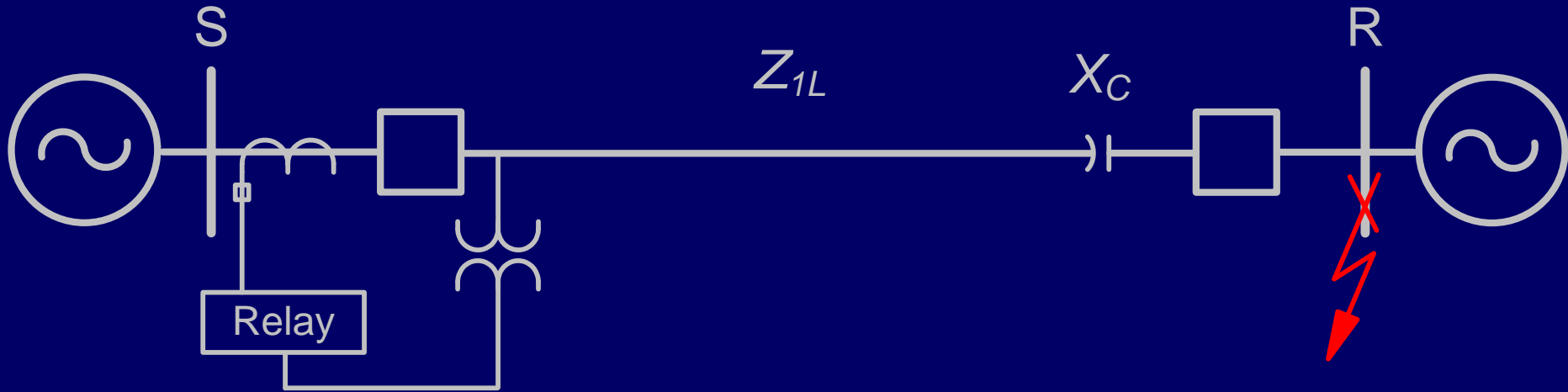


# Directional Element Offset

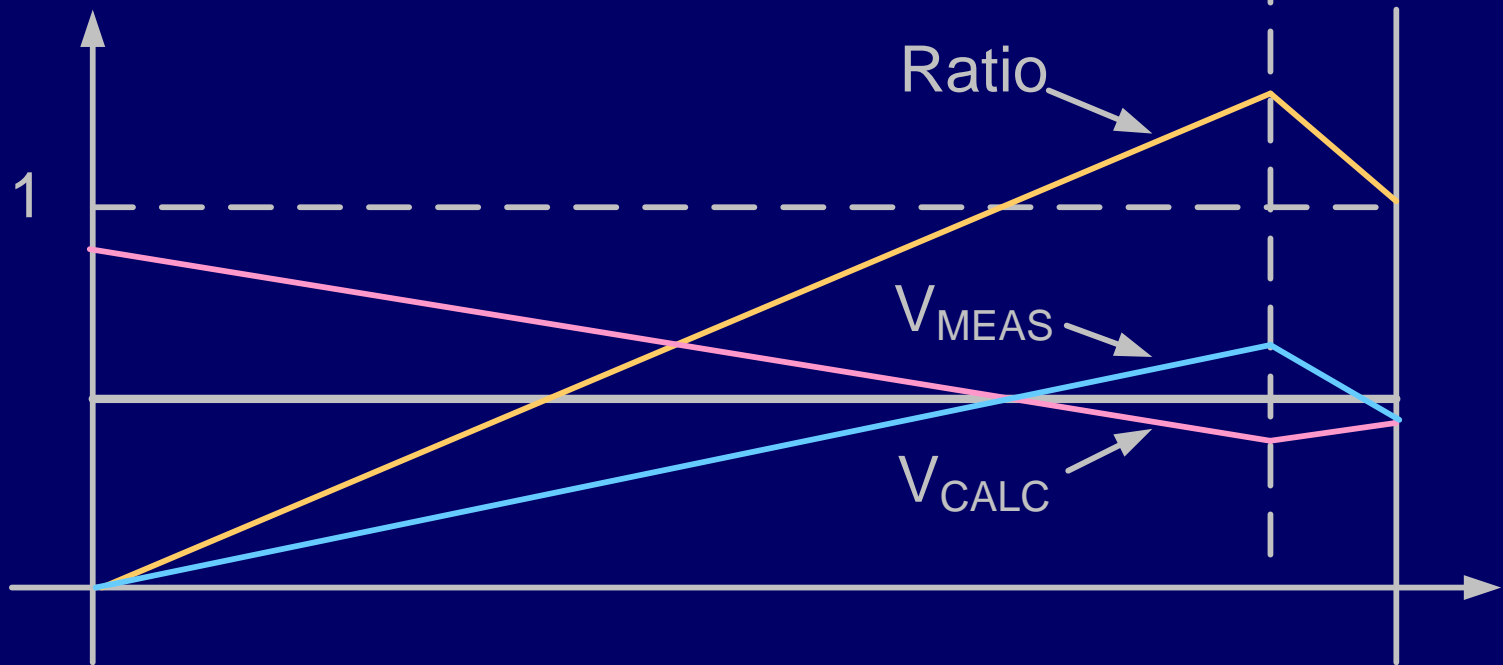
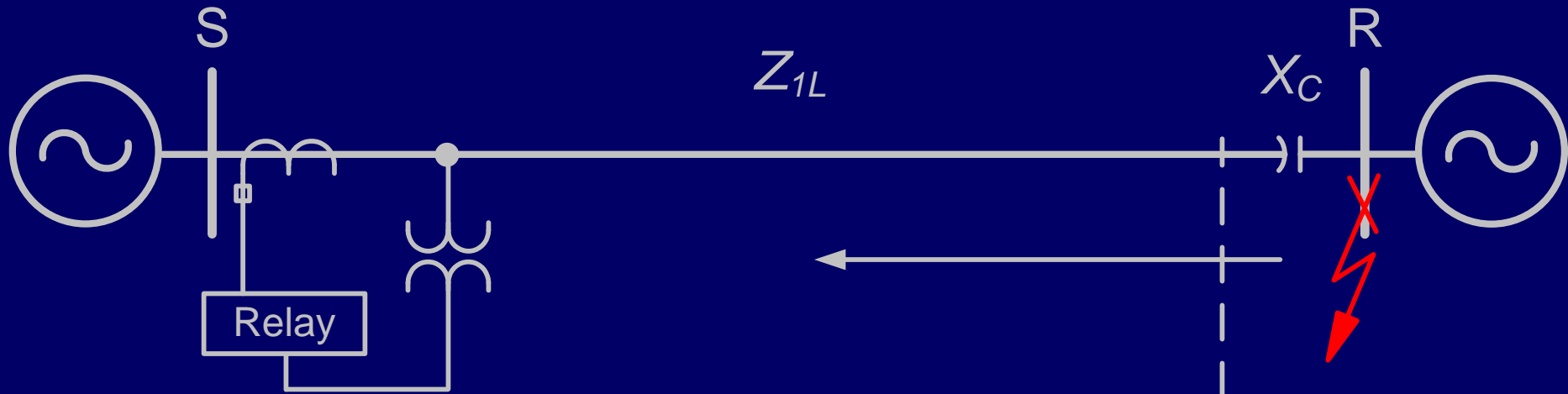
## End-of-Line Cap, Line Side PT



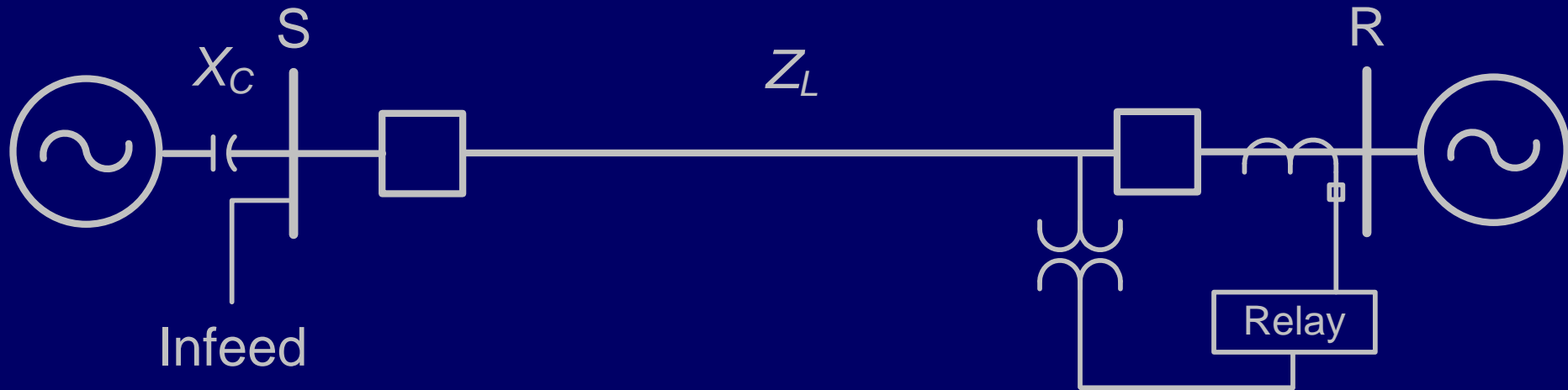
# Out-of-Section Fault Beyond Cap



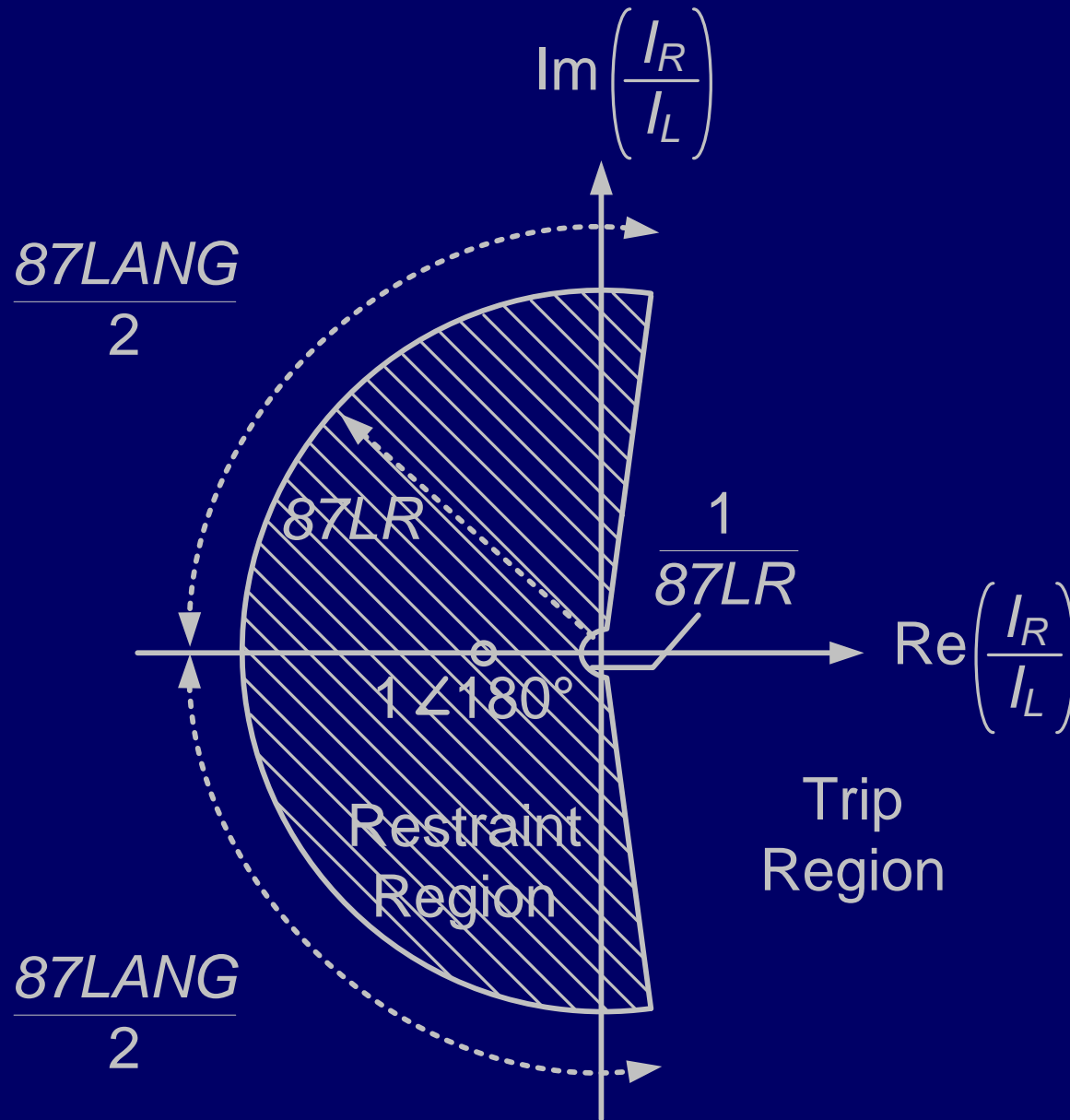
# Voltage Ratio Check Secures Zone 1



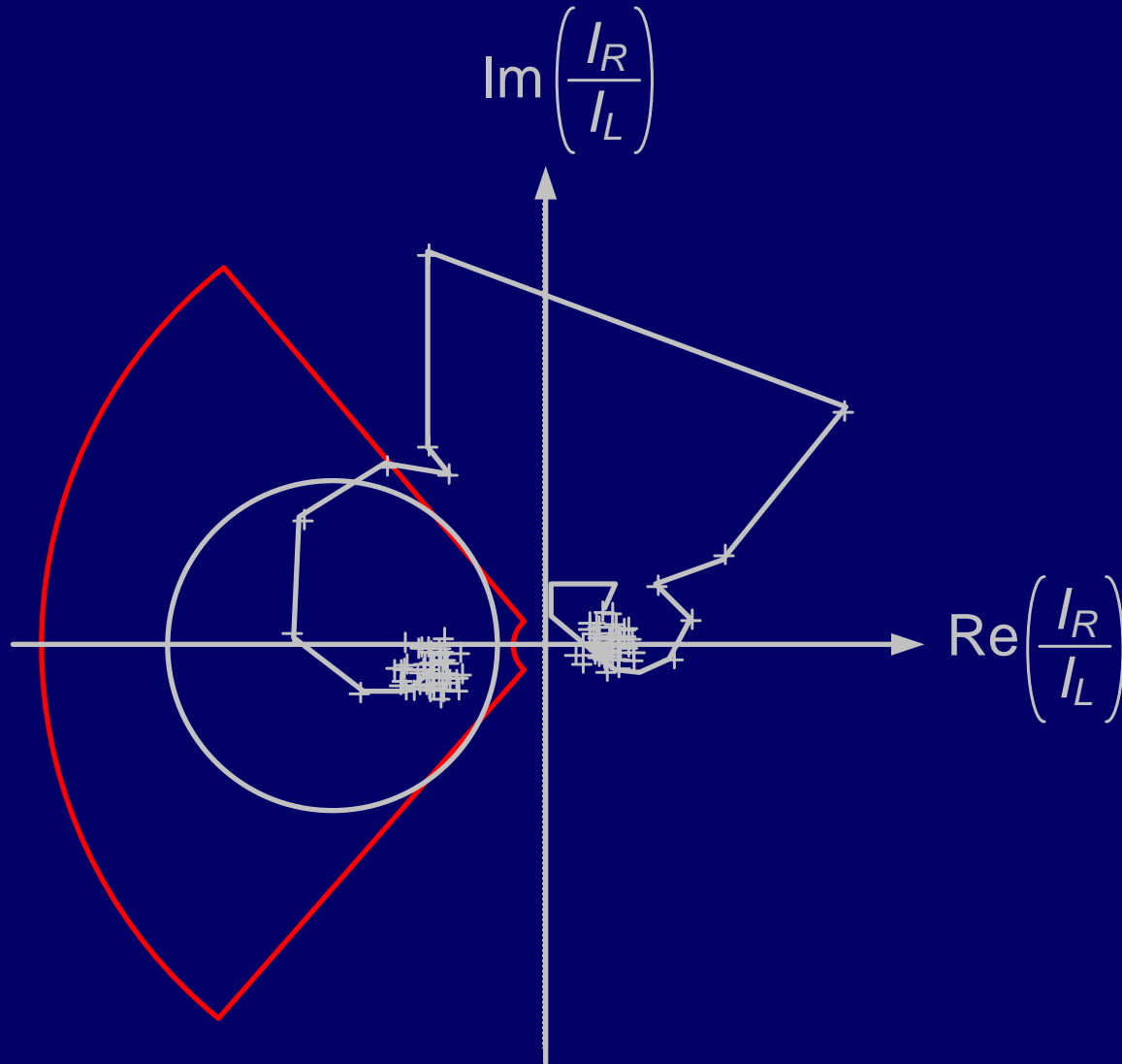
# Infeed Affect Increases Apparent Capacitive Reactance



# Alpha-Plane Differential Characteristic



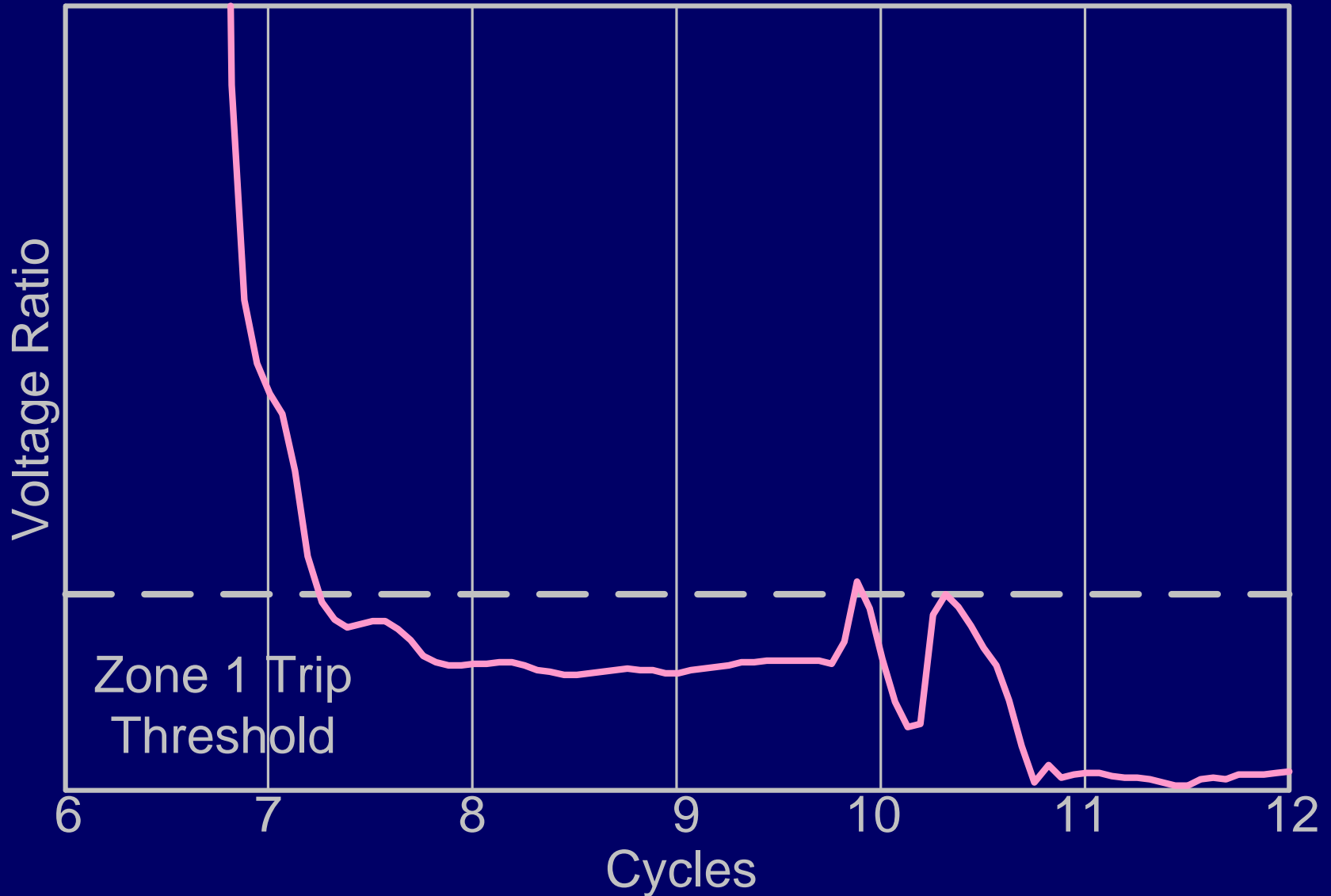
# Differential Element Response to an Internal Fault



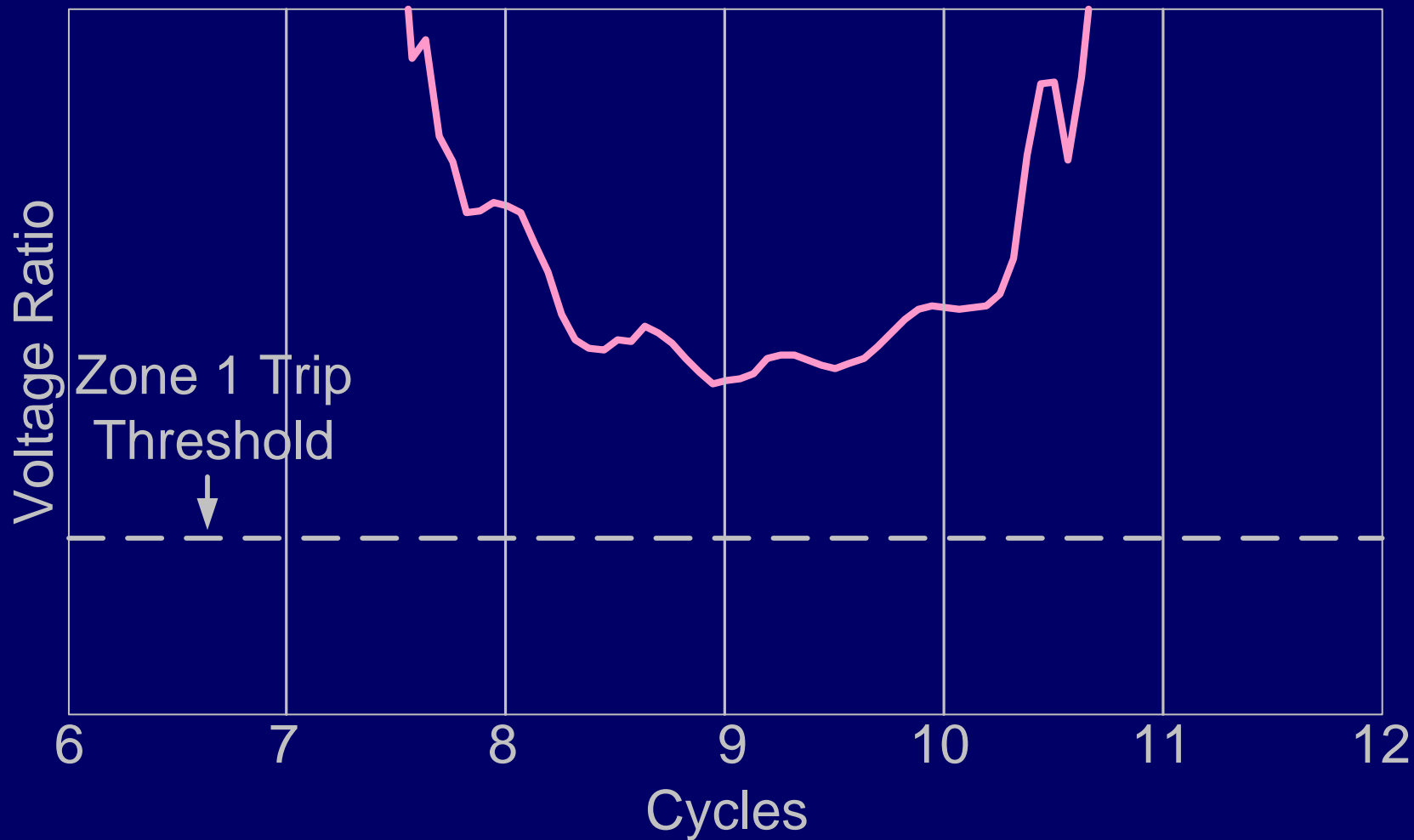
# Analysis of Field Events

- Parallel 500 kV lines with 70% compensation
- Internal fault on 500 kV line
- Internal fault on 345 kV line with bus side PTs

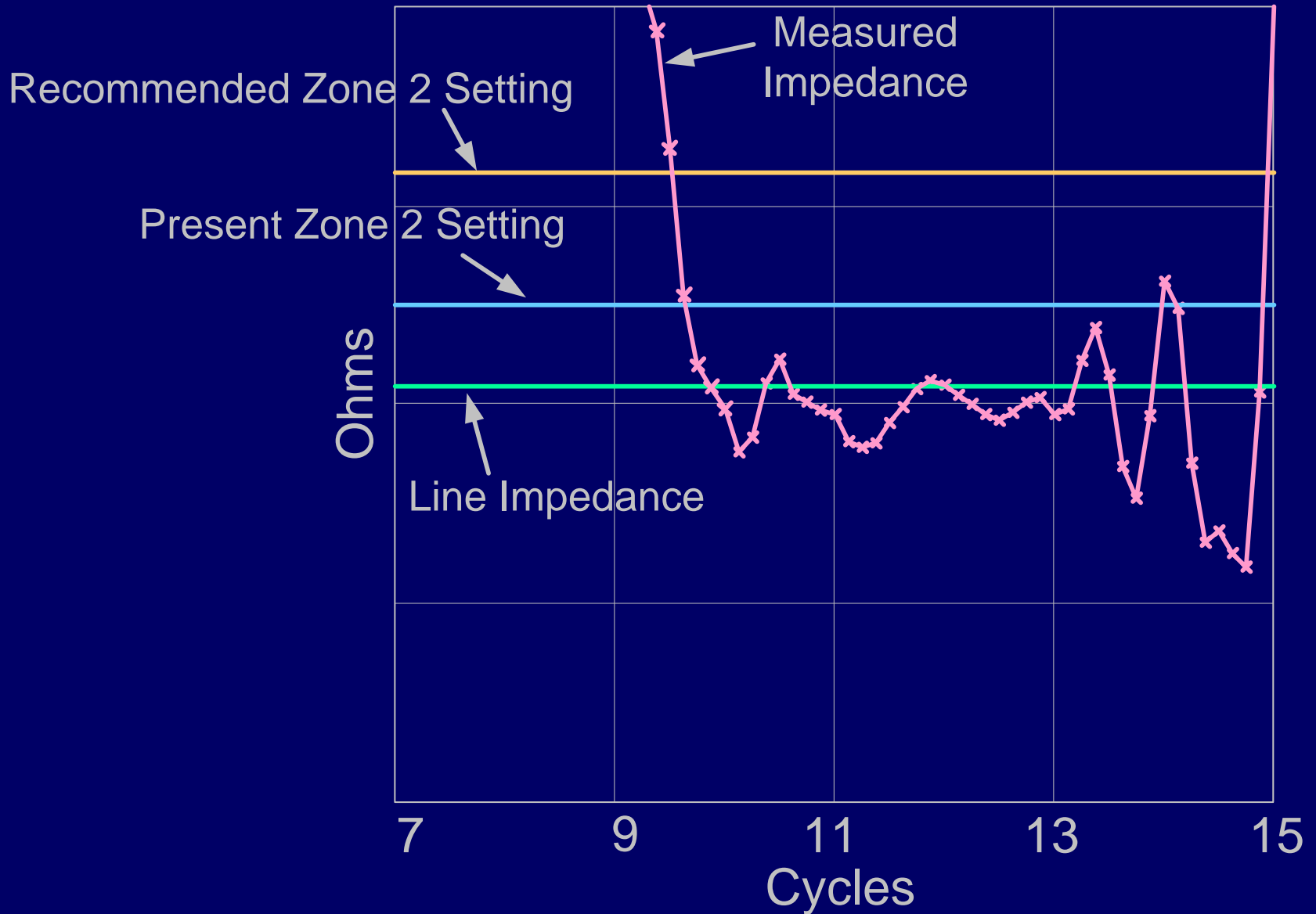
# Voltage Ratio Check – Close-in Fault



# Voltage Ratio Check – Parallel Line



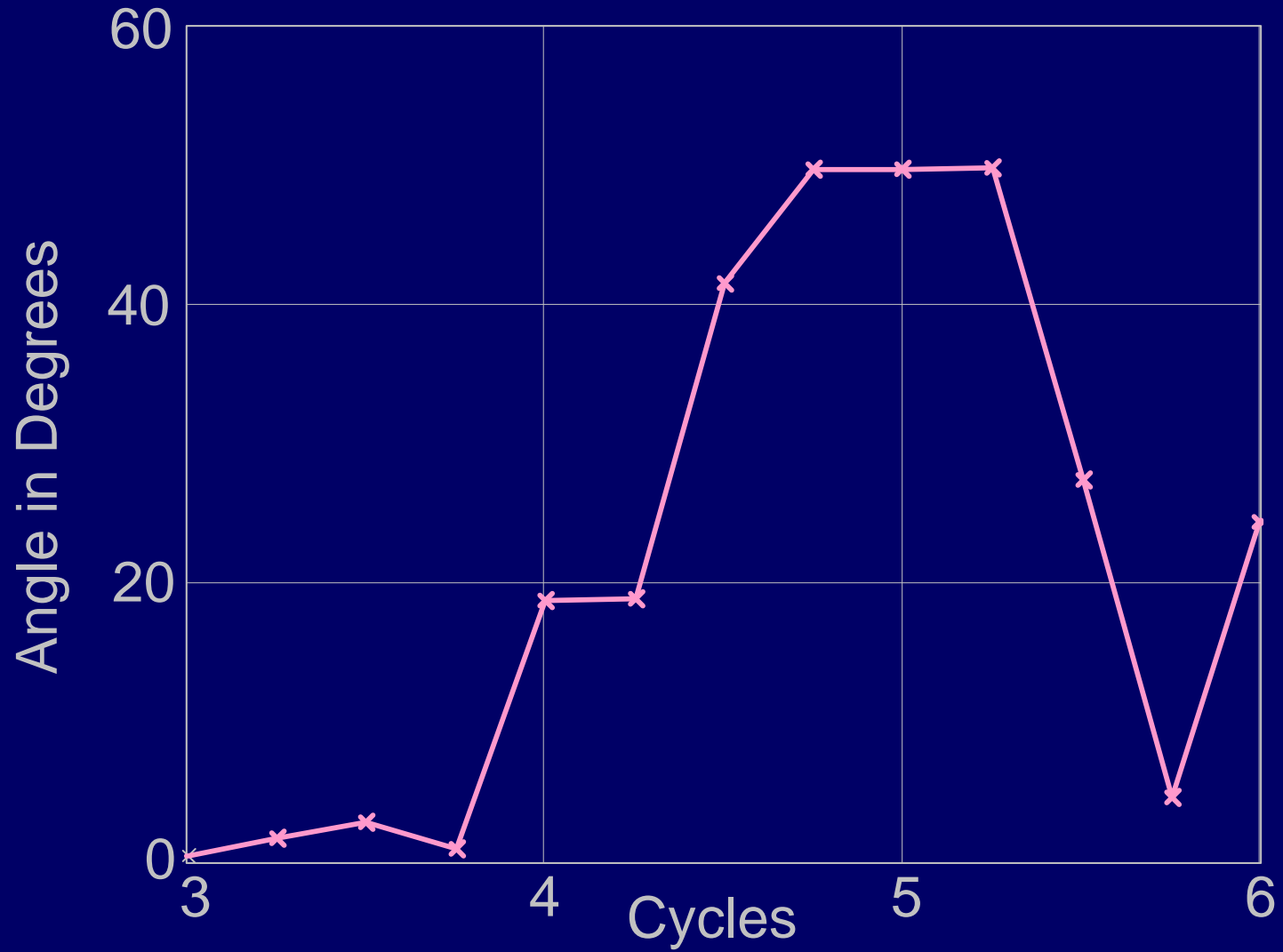
# Internal Fault – Zone 2



# Voltage Inversion – Phase Voltage



# Voltage Inversion – V1



# Conclusions

- Memory polarization and directional element offset address voltage inversion
- Line current differential elements are more tolerant to current inversion

# Conclusions

- Low frequency oscillations can cause overreach and underreach of distance elements
- Transient simulation and testing is strongly recommended