Understanding the Dynamic Mho Distance Characteristic

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Overview

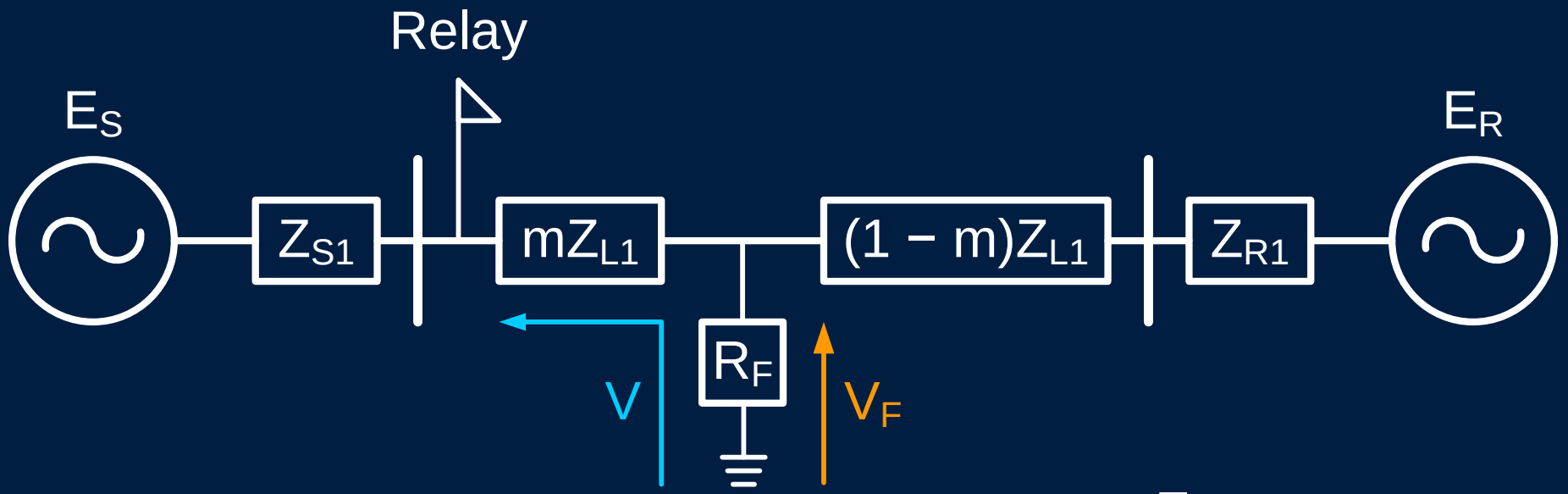
- Introduction
- Self-polarized mho
- Polarization
- Dynamic expansion
- Load flow
- Testing
- Expansion and security
- Conclusions

Why Revisit the Mho Circle?

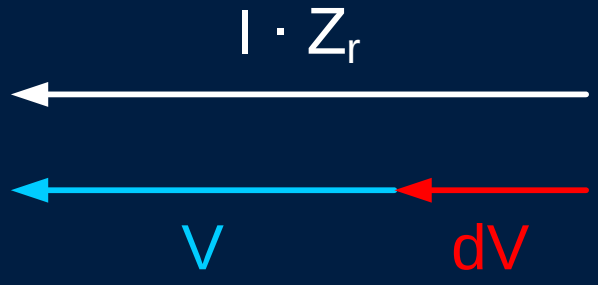
- Dynamic mho : source of confusion
- Improvements in software animation
  - Simplify understanding
  - Visualize the change in a system parameter
- Dispel modern mho misconceptions : clear up common myths

Self-Polarized Mho

Voltage

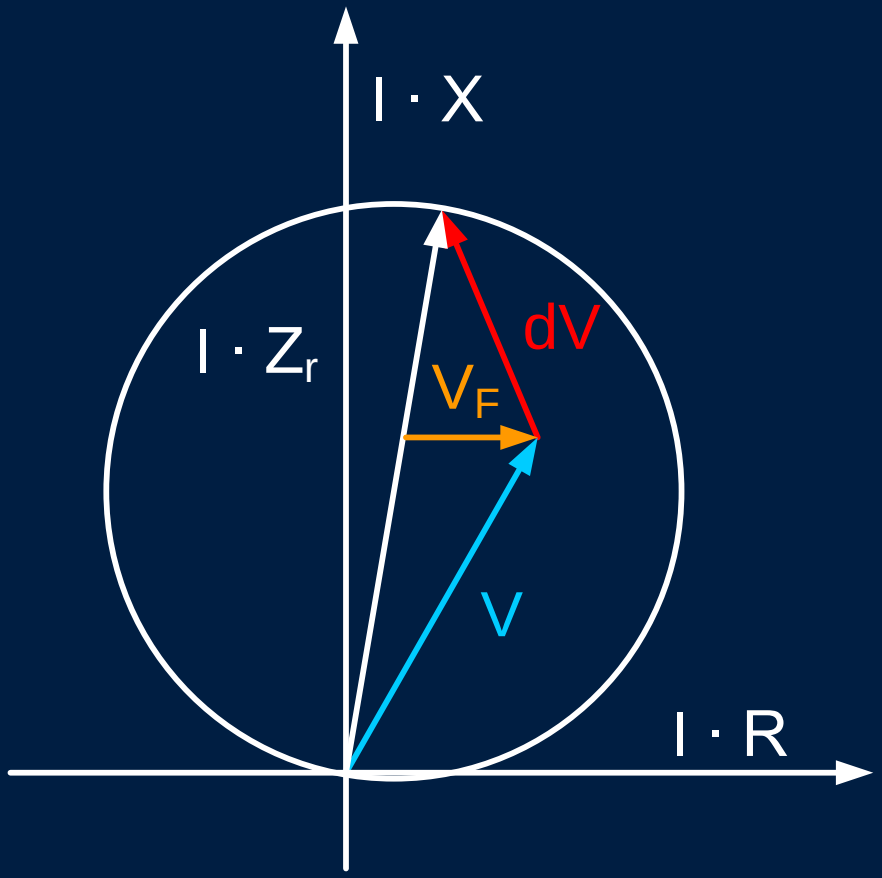


dV = Operating quantity
Z_r = Relay reach
I = Loop current
V = Measured voltage
V_F = Fault voltage



Self-Polarized Mho

Voltage



dV = Operating quantity
Z_r = Relay reach
I = Loop current
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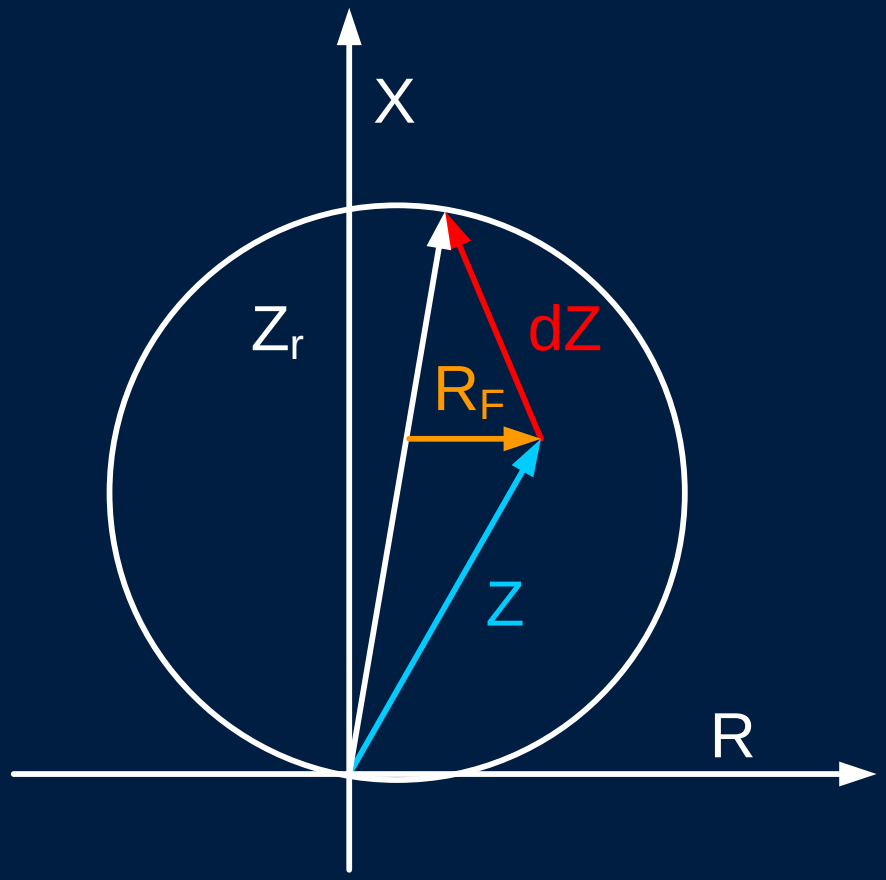
Self-Polarized Mho

Impedance



dZ = Operating quantity
Z_r = Relay reach
Z = Measured impedance
R_F = Fault impedance

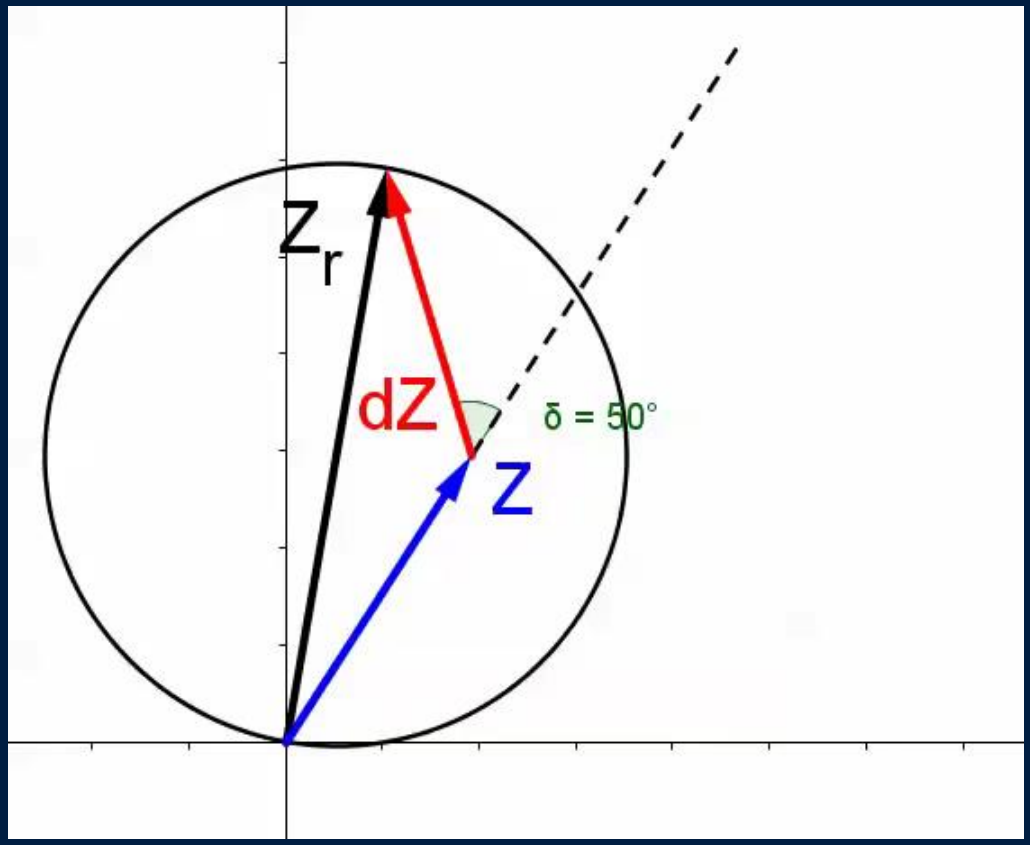
Self-Polarized Mho

Cosine Comparator

Restrain cos (δ) < 0

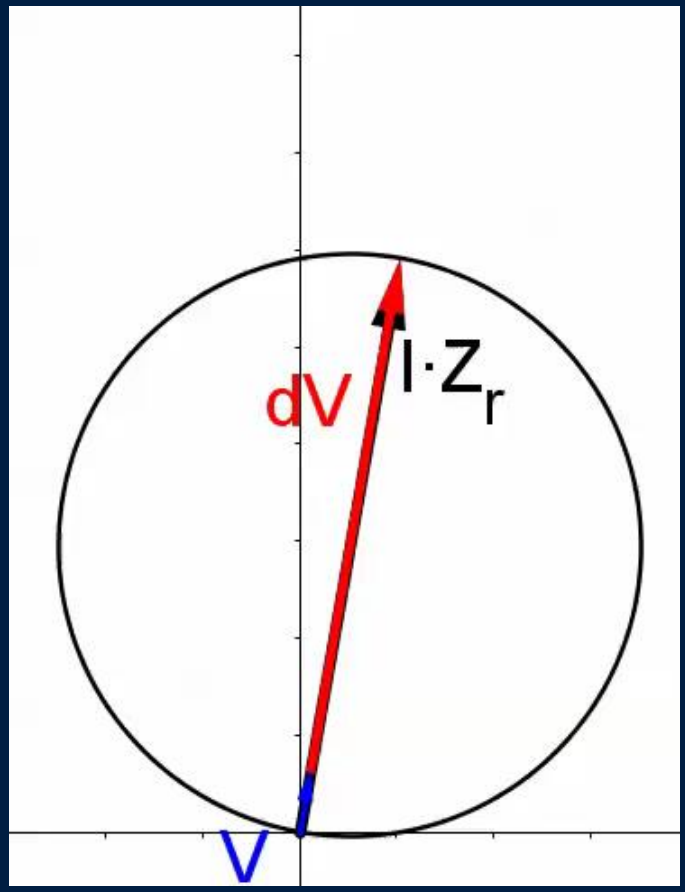
Operate cos (δ) > 0

On circle cos (δ) = 0



Polarization

- Polarization provides a reference for the operating quantity
- Polarizing quantity must be
  - Stable
  - Reliable



Quantity shown

dV = Operating, ***V*** = Polarizing

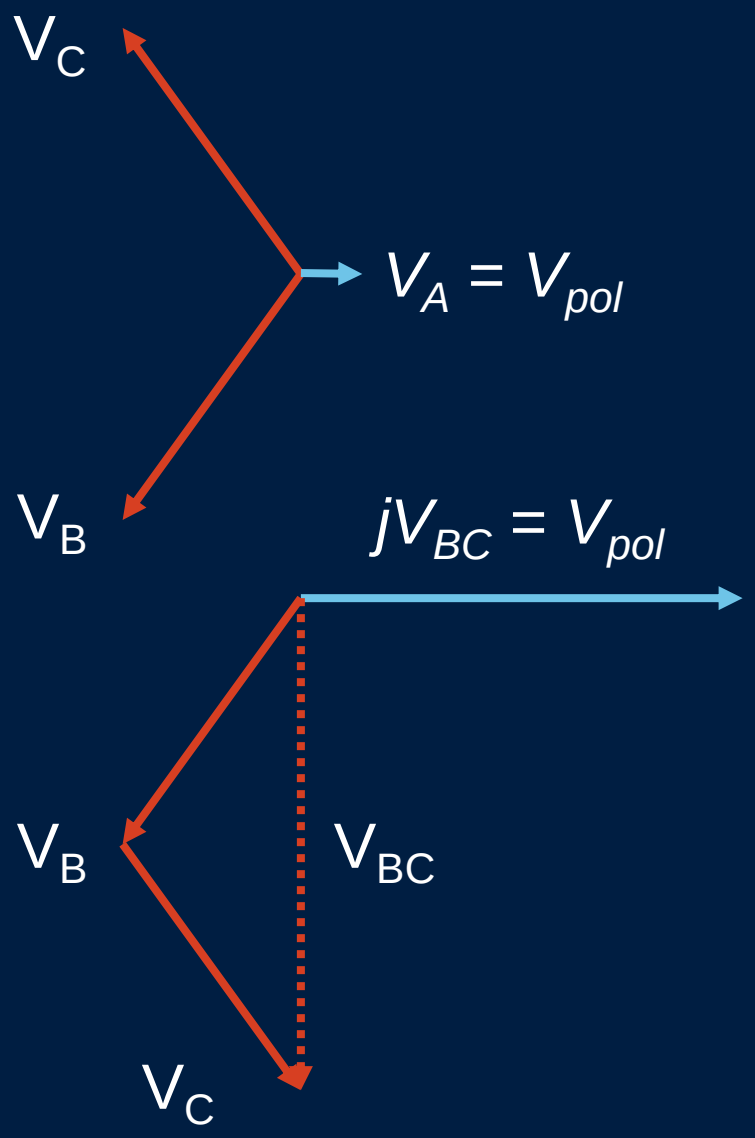
Polarization

Self-polarization

- Voltage of faulted phase(s)
- Poor for close-in faults

Cross-polarization

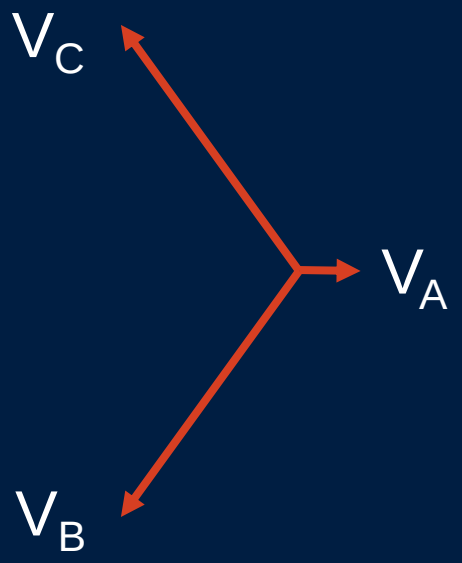
- Voltage of unfaulted phase(s)
- Poor for close-in 3PH faults
- Investigate open-pole security



Polarization

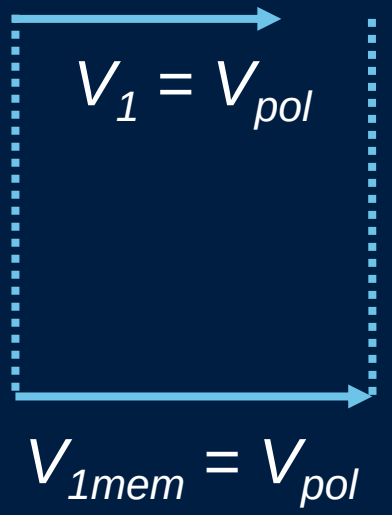
Positive-sequence polarization

- Positive-sequence voltage
- Excellent open-pole security
- Poor for close-in 3PH faults



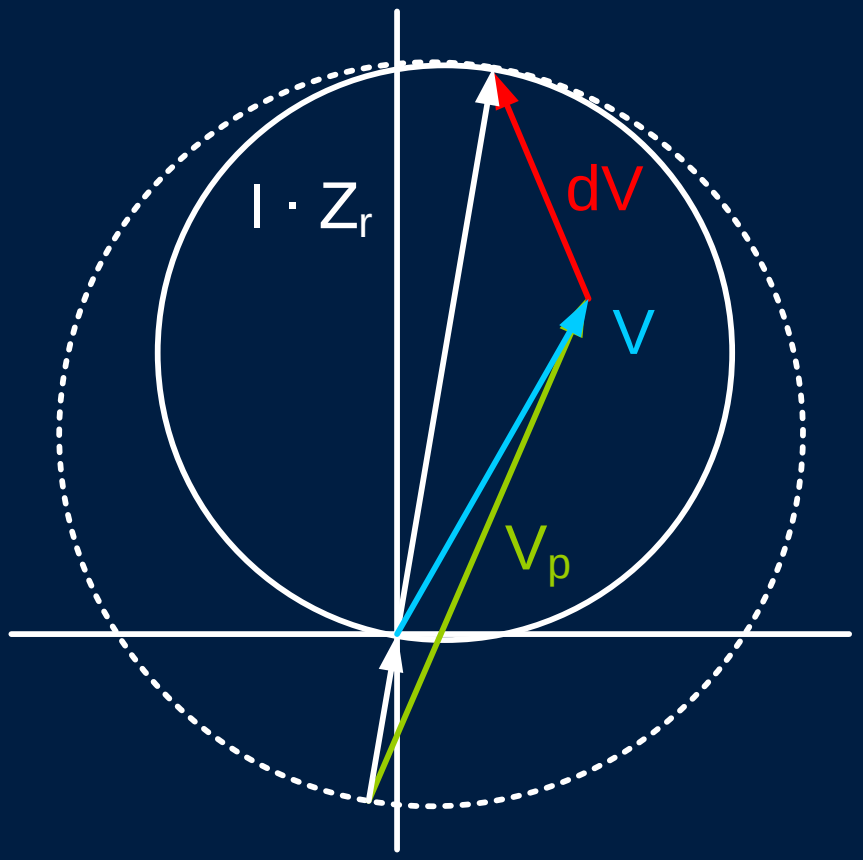
Polarization memory filter

- Polarization maintained
- Reliable for close-in 3PH faults

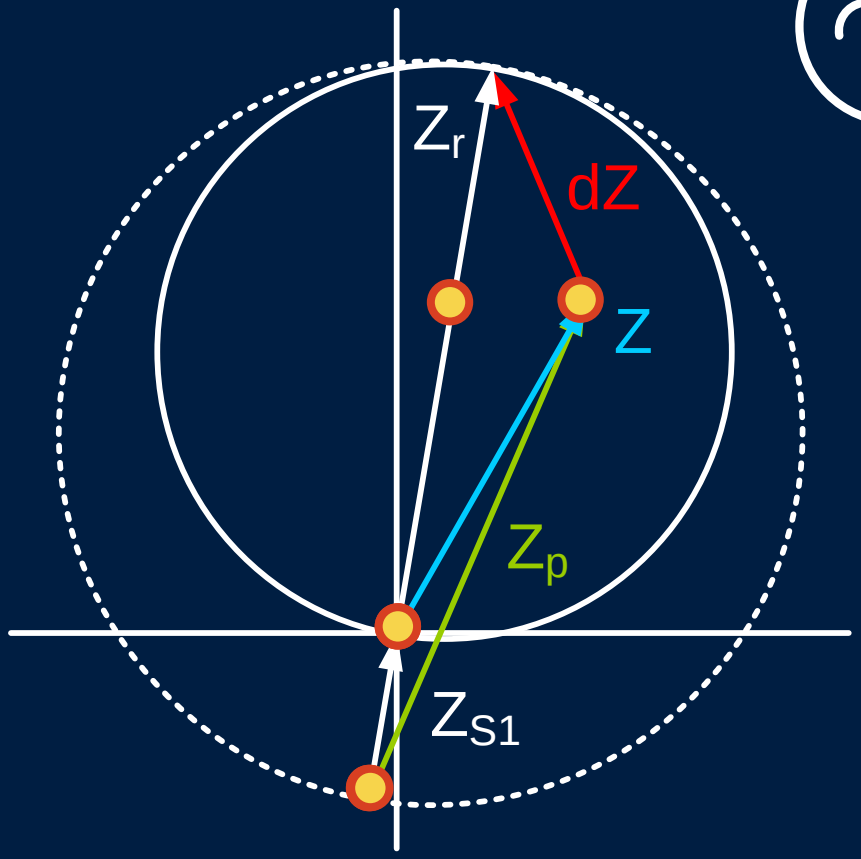


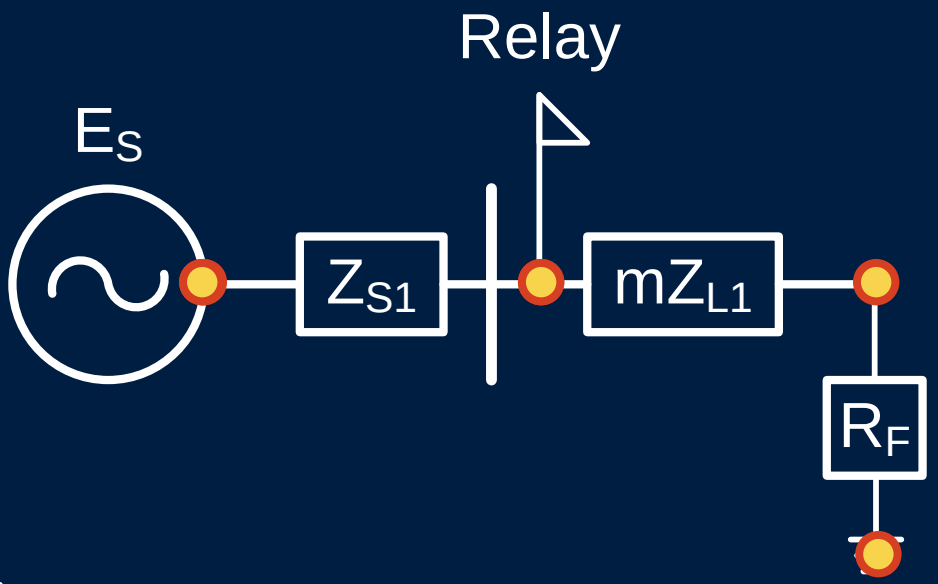
Polarization and Dynamic Expansion

- Polarization causes mho expansion
  - $| V_p | \geq | V |$
  - δ is between V_p and dV
  - Choice of V_p affects expansion
- Memory voltage decays : expansion shrinks



Dynamic Expansion

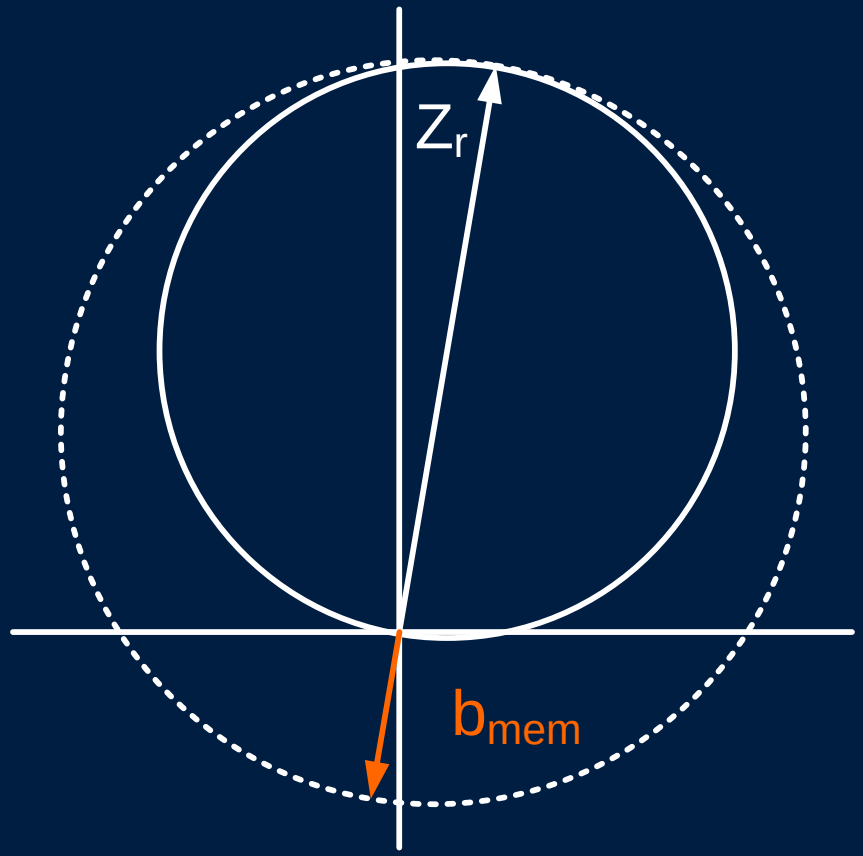


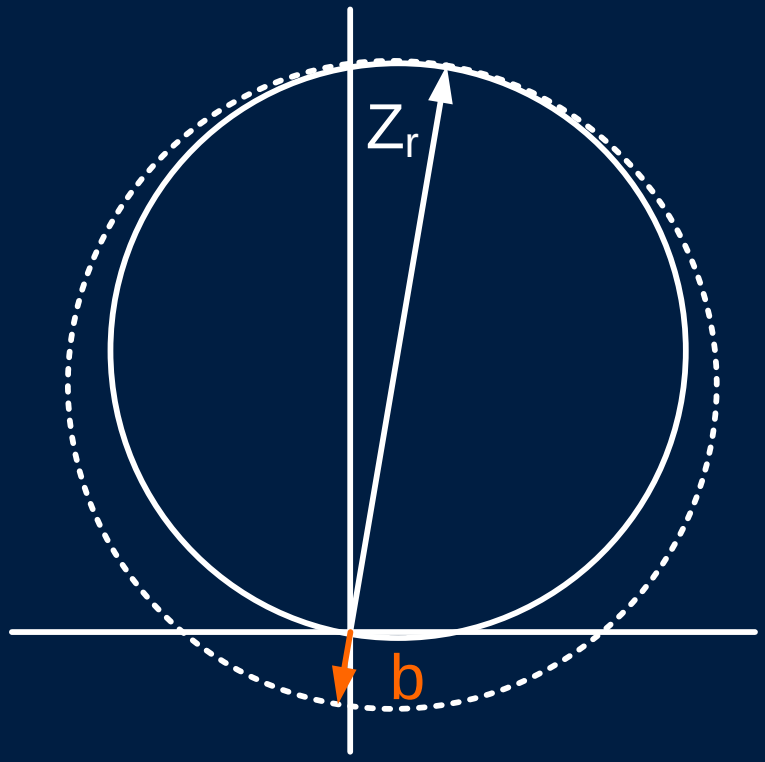


Dynamic Expansion

Expansion described by b and b_{mem}

- b_{mem} : maximum expansion after fault
- b : steady state



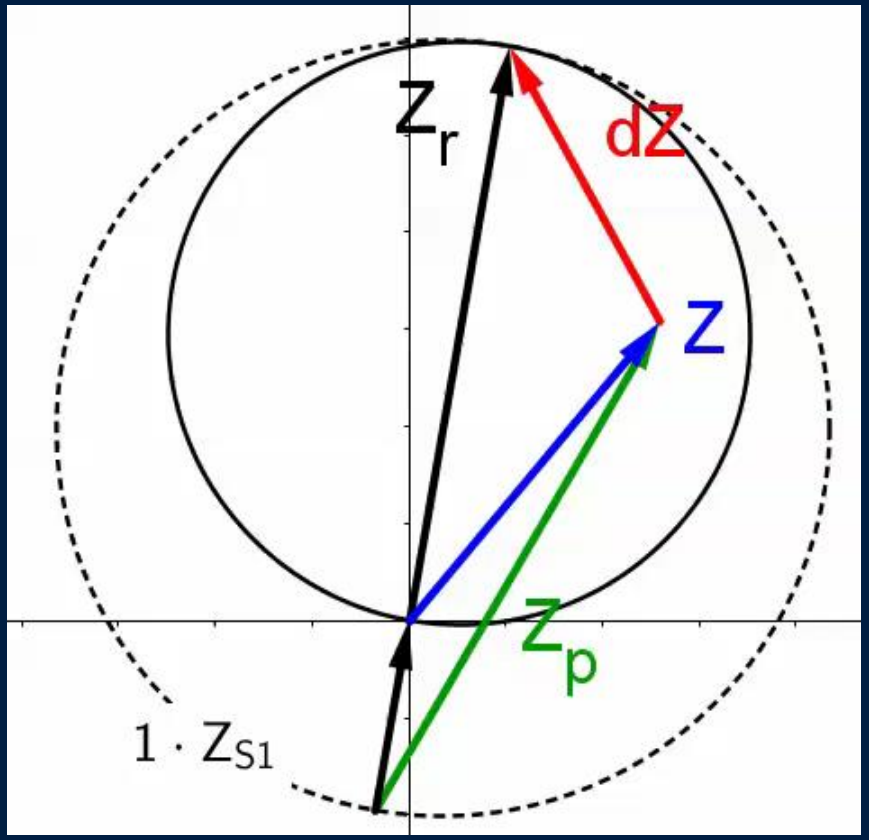


Dynamic Expansion

3PH Fault

$$b = 0$$

$$b_{mem} = -Z_{S1}$$

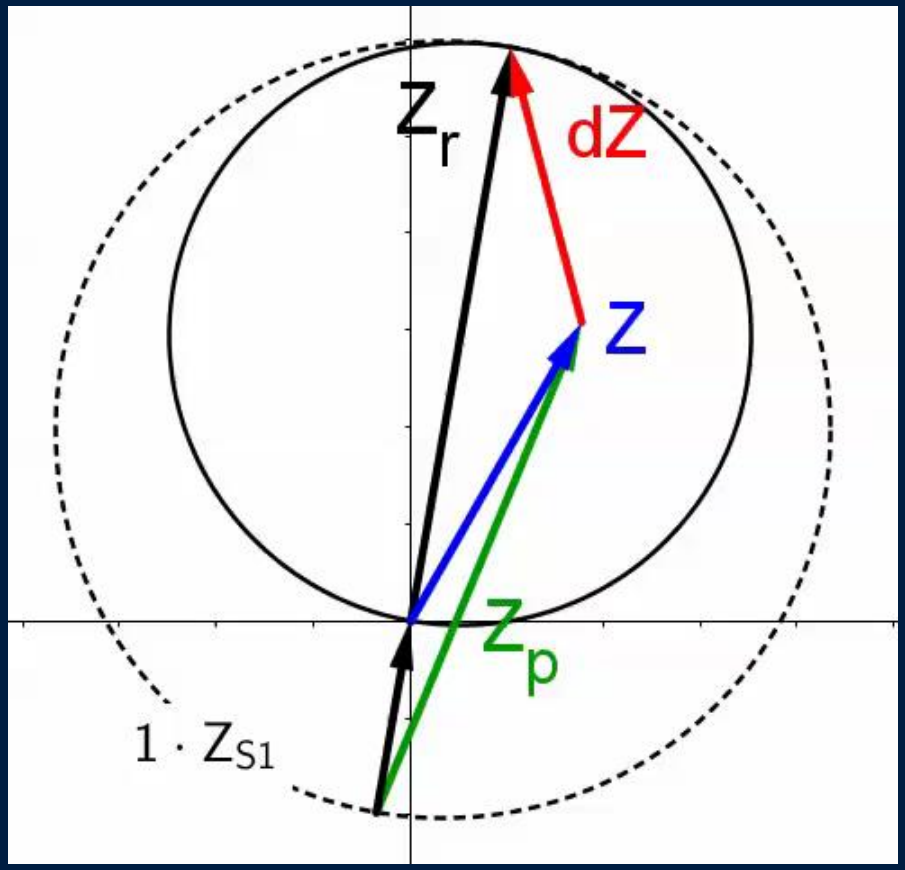


Dynamic Expansion

SLG Fault

$$b = -Z_{S1}\left[\frac{1+\frac{Z_{S0}}{Z_{S1}}}{2+\frac{Z_{L0}}{Z_{L1}}}\right]$$

$$b_{mem} = -Z_{S1}\left[\frac{2+\frac{Z_{S0}}{Z_{S1}}}{2+\frac{Z_{L0}}{Z_{L1}}}\right]$$

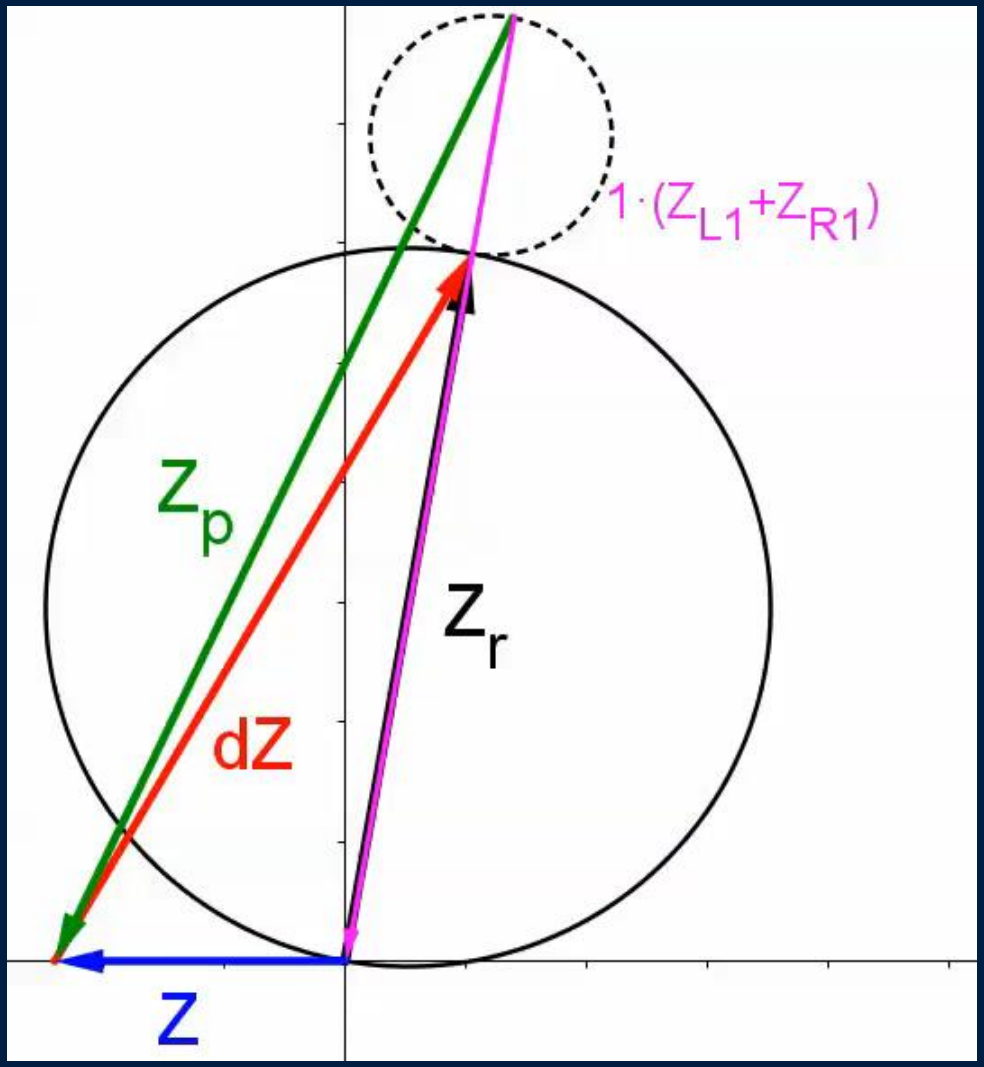


Dynamic Expansion
Reverse Fault

- Special case of mho expansion
  - Current reverses
  - V_{1mem} similar to forward fault
  - Impedance-to-source includes Z_L *and* Z_R
- Mho shrinks : enhanced security

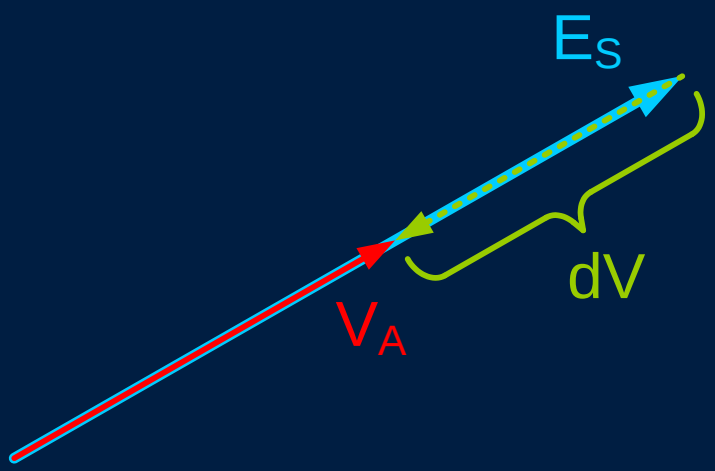
Dynamic Expansion

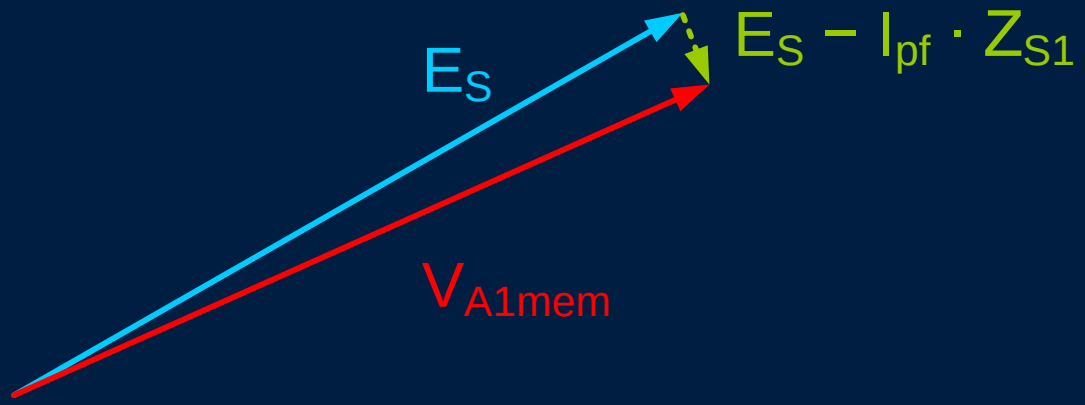
Reverse Fault



Load Flow
V_{1mem} Polarized

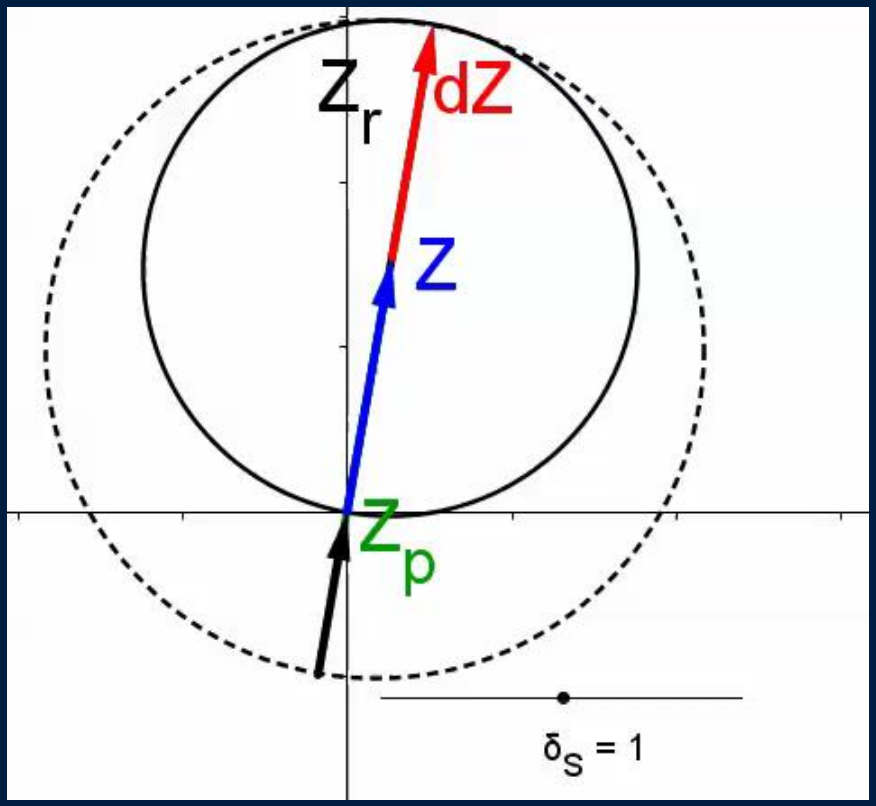
- Example : 3PH fault
  - Prefault current I_{pf} : voltage drop across Z_{S1}
  - $| V_A | < | V_{A1mem} |$
  - V_A and V_{A1mem} (Z and Z_p) separate





Load Flow

Vary Source Angle δ_S

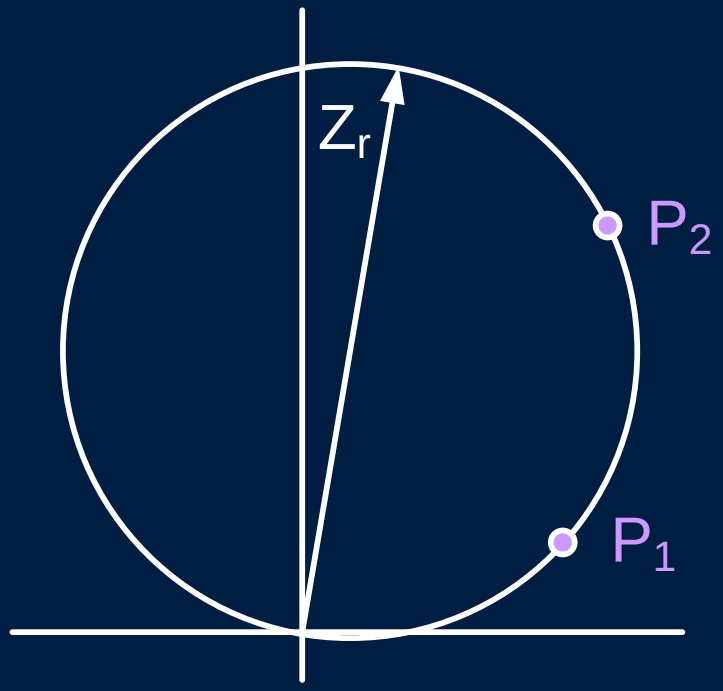


Testing

- Steady state
  - Self-polarized circle
  - Minimum expansion
- Dynamic
  - Difficult (real-time memory decay)
  - Real-time digital simulator

Testing

Does the dynamic circle disappear during steady-state testing?



Testing

Does the dynamic circle disappear during steady-state testing?

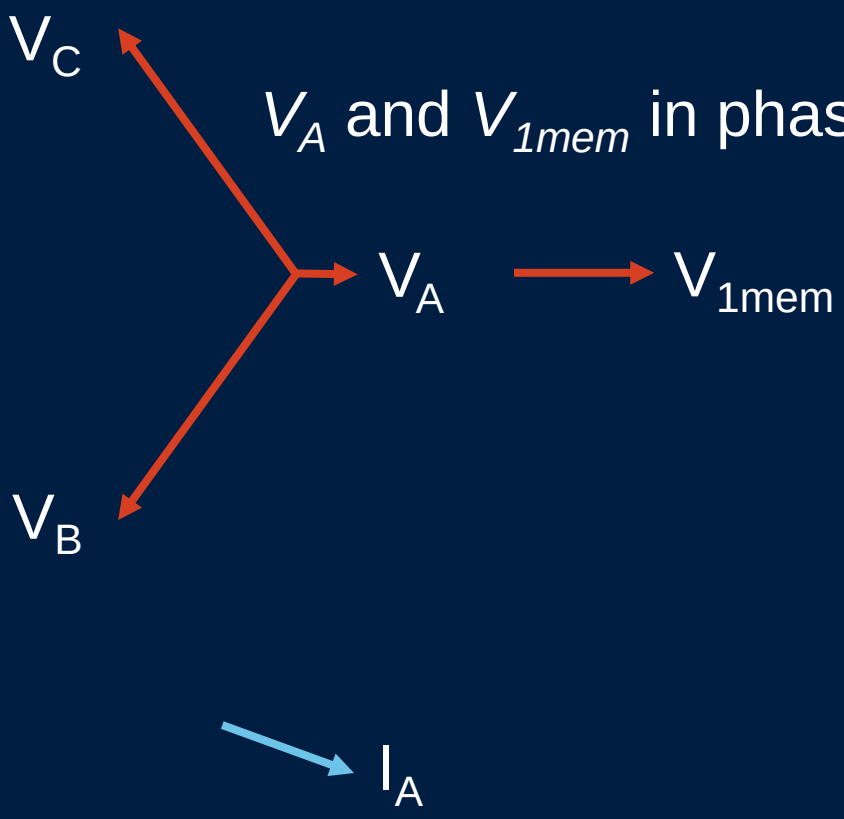
No! Test voltage choice can hide the dynamic mho

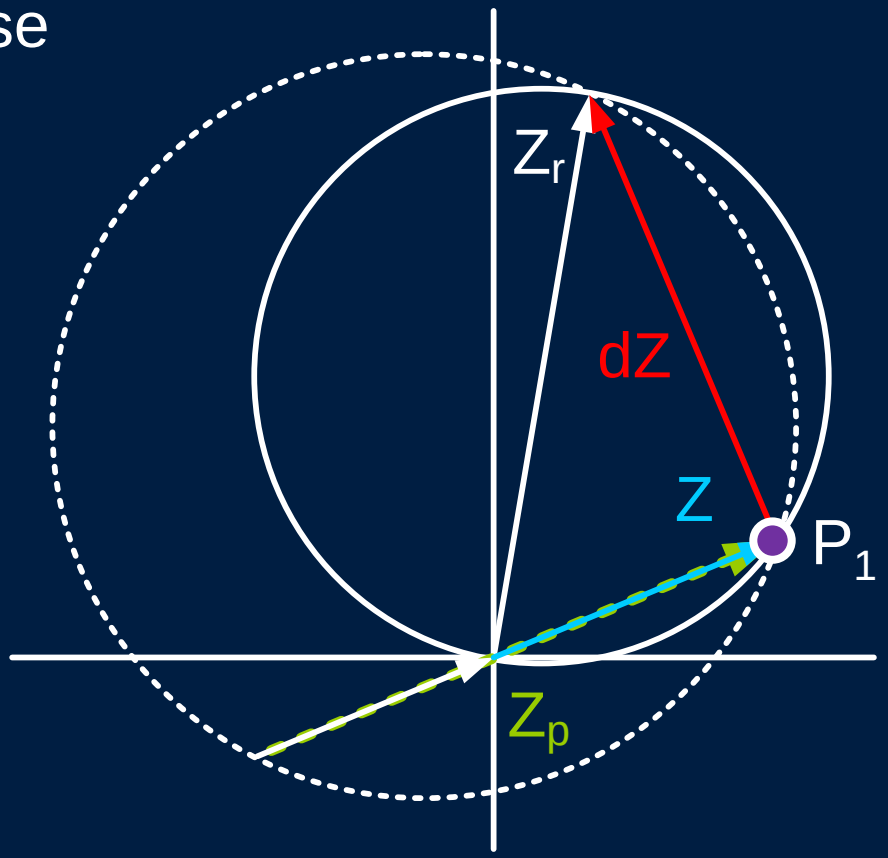
$$Z = \frac{V_A}{I_A + k_0 \cdot I_R}$$

$$Z_P = \frac{V_{1mem}}{I_A + k_0 \cdot I_R}$$

Testing

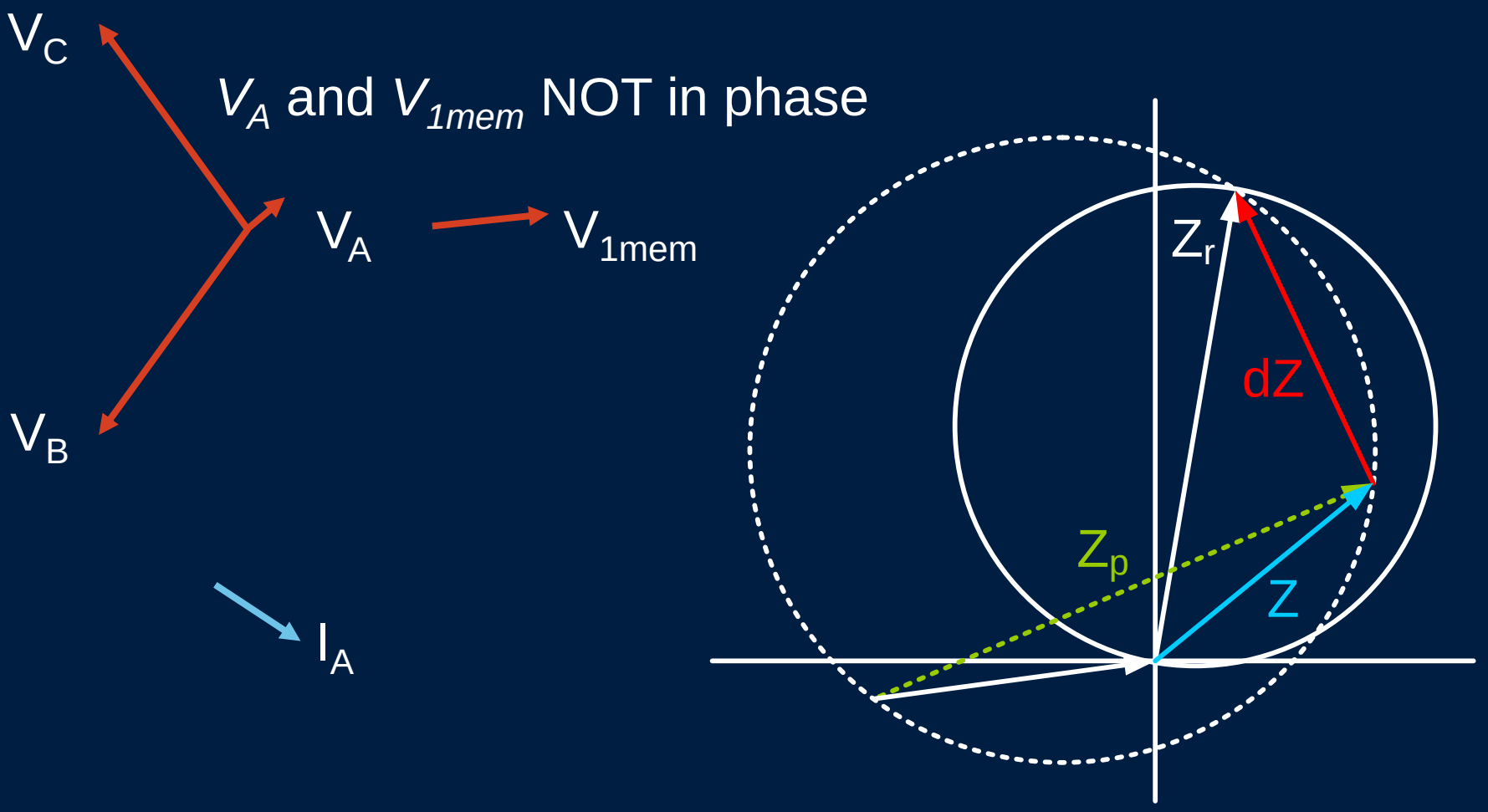
Example Normal Voltages





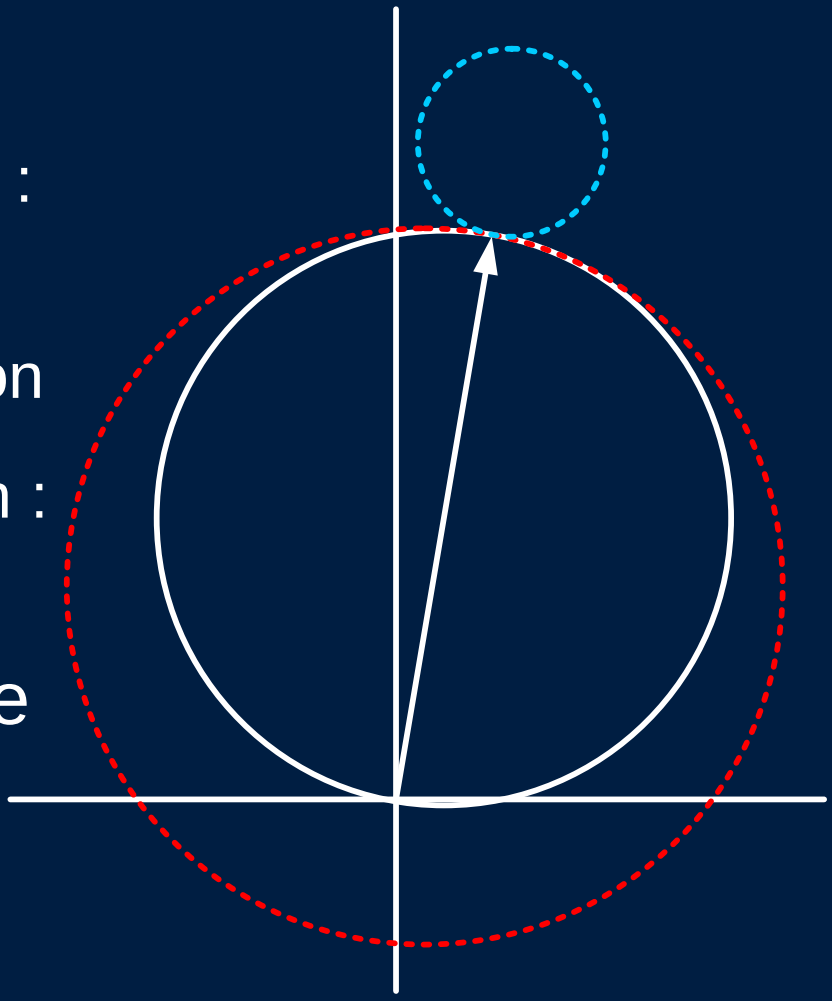
Testing

Example Abnormal Voltages



Expansion and Security

- Dynamic mho security
  - Forward versus reverse faults : expansion versus contraction
  - Directional element supervision
  - Fault identification supervision : block uninvolved phases
- Expansion is crucial for some series-compensated lines



Conclusions

- Dynamic expansion affected by
  - System parameters (including load flow)
  - Fault type and direction
  - Relay algorithm
- Positive-sequence polarization
  - Good expansion
  - Excellent open-pole security

Conclusions

- Testing
  - Test quantities affect expansion
  - Dynamic testing when required
- Software visualization
  - Many free, open-source packages available
  - Keep things simple

Questions?