Improvements in the Operation of a Distance Relay During Resistive Faults

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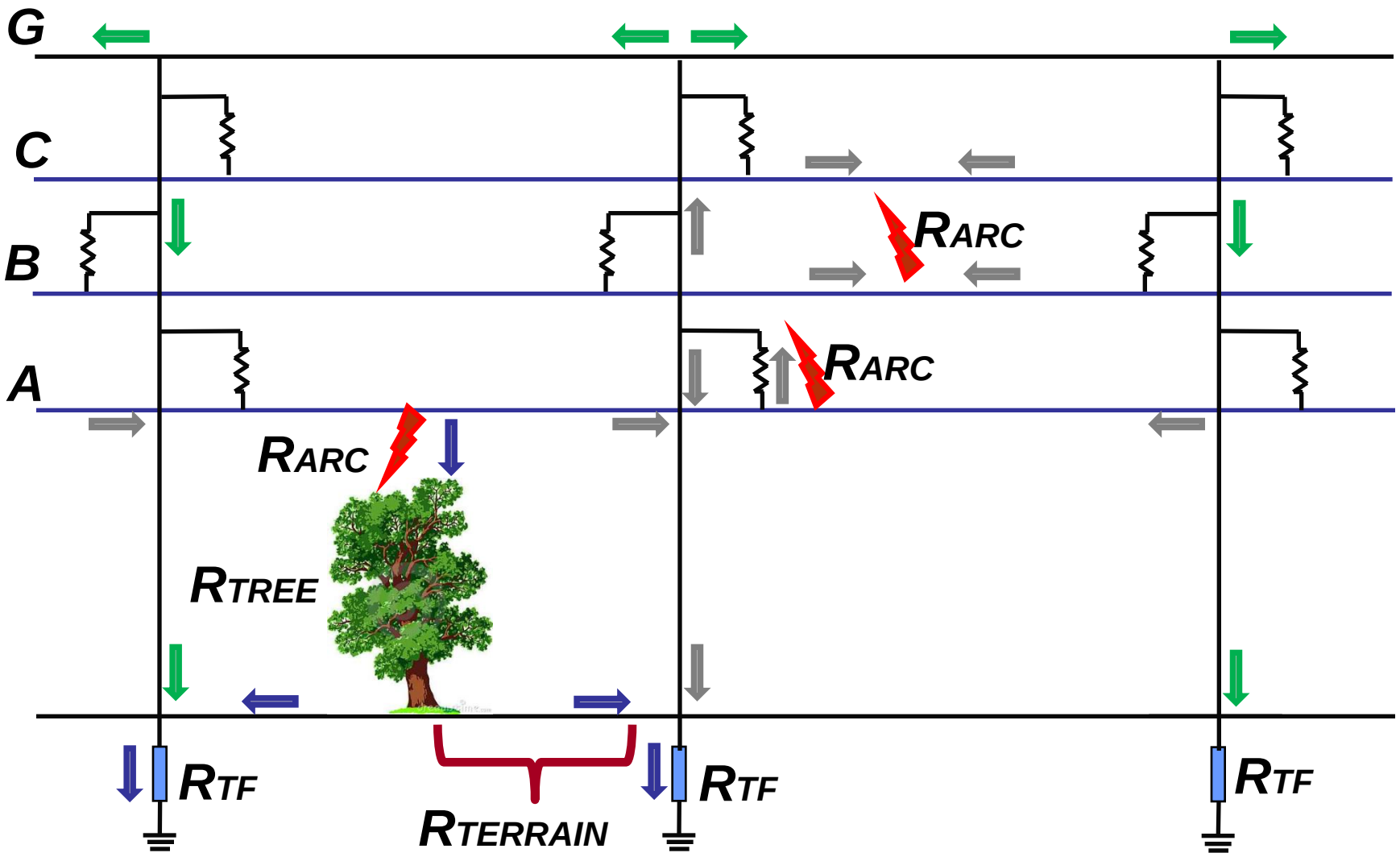
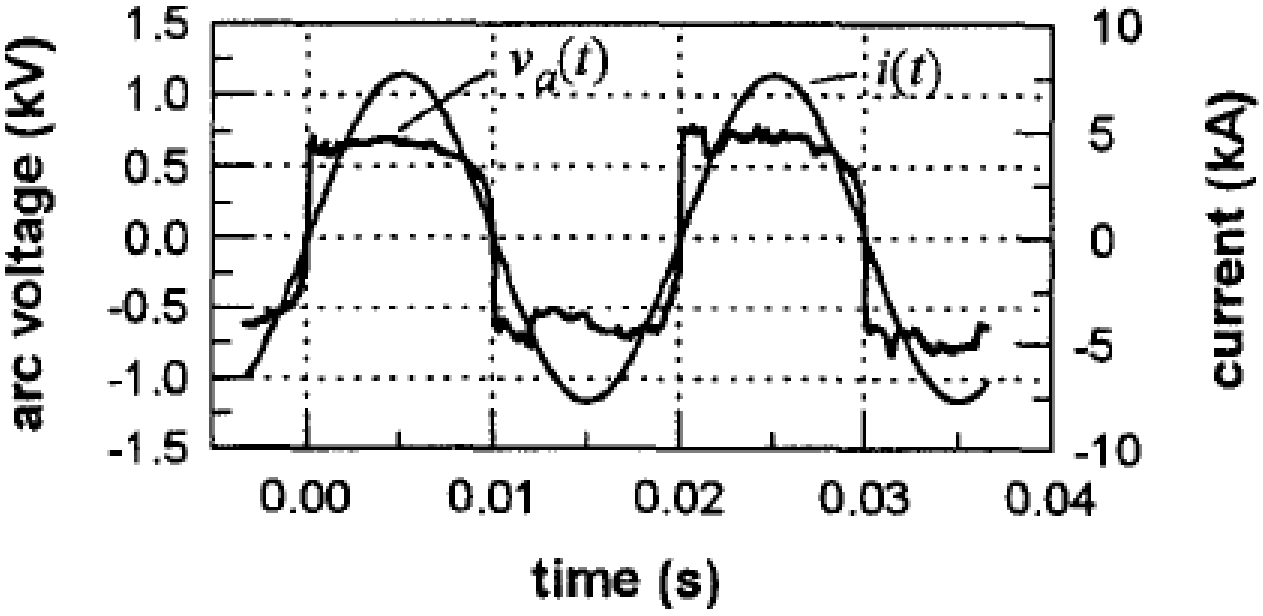
Overview

- Fault resistance
- Influence on Mho and Quadrilateral characteristics
- Special conditions affecting the polarization of the ground reactance line
  - Ground fault during open pole
  - Phase-phase-ground fault
- Resistive reach calculation
- RTDS simulations

Fault Resistances and Current Flow



Arc Resistance

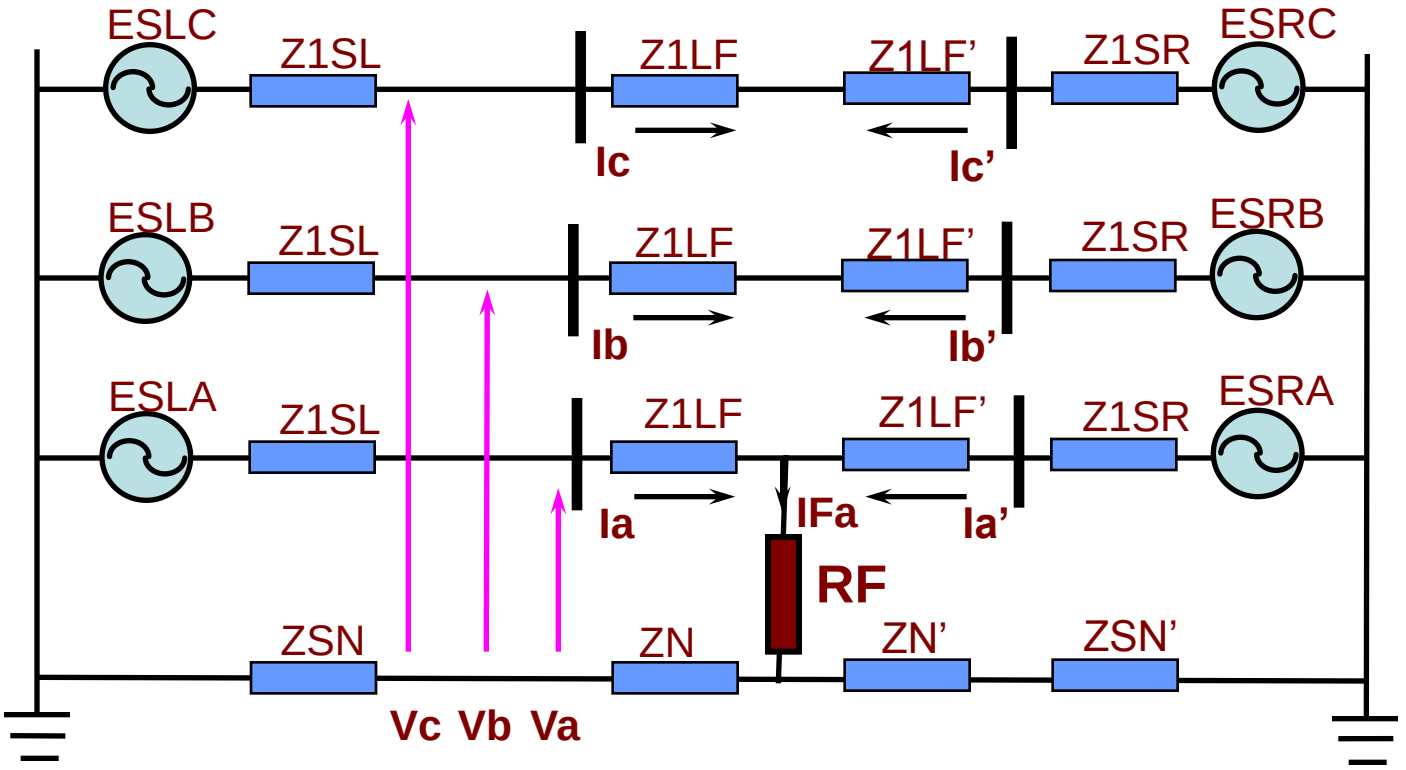


$$R_{arc} = K \cdot \frac{L_{arc}}{I_{arc}^{\ n}} \qquad n \geq 1$$

AG Fault Loop

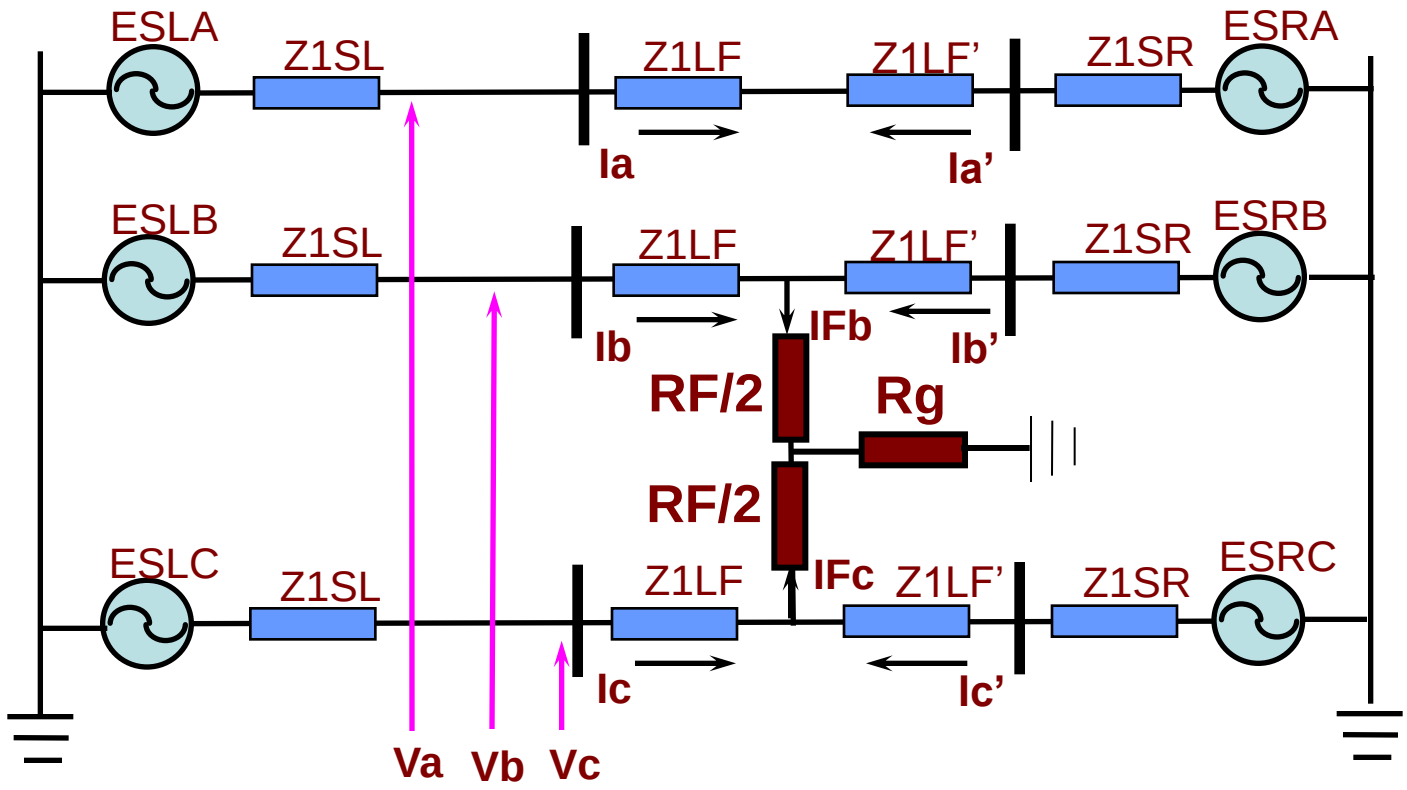
$$Va = Iaeq \cdot Z1LF + IFa \cdot RF \qquad Iaeq = Ia + I0 \cdot K0$$

$$K0 = \frac{ZL0 - ZL1}{ZL1}$$



BC Fault Loop

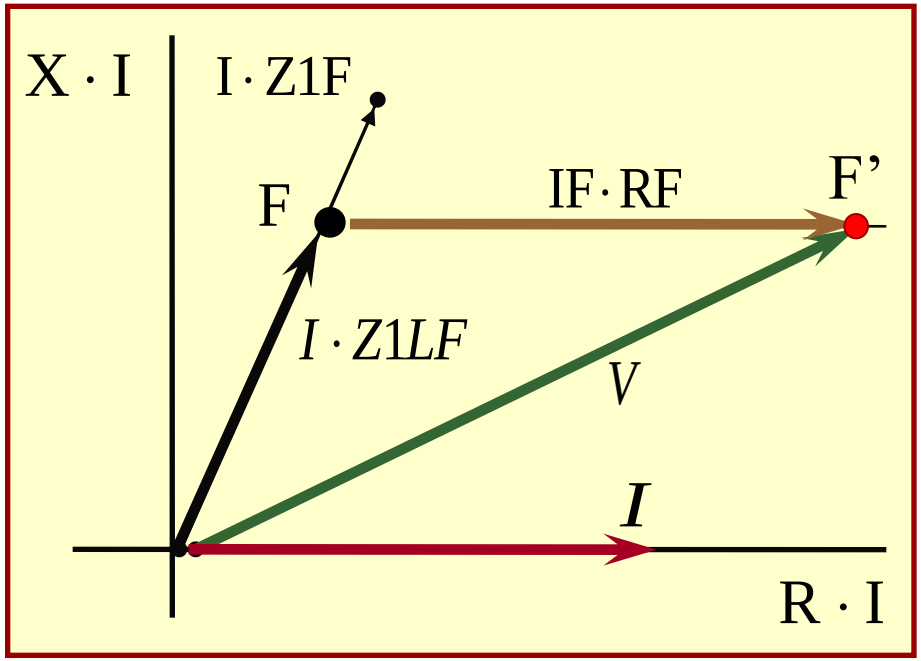
$$Vbc = Ibc \cdot Z1LF + IFbc \cdot RF/2 \qquad IFbc = IFb - IFc$$

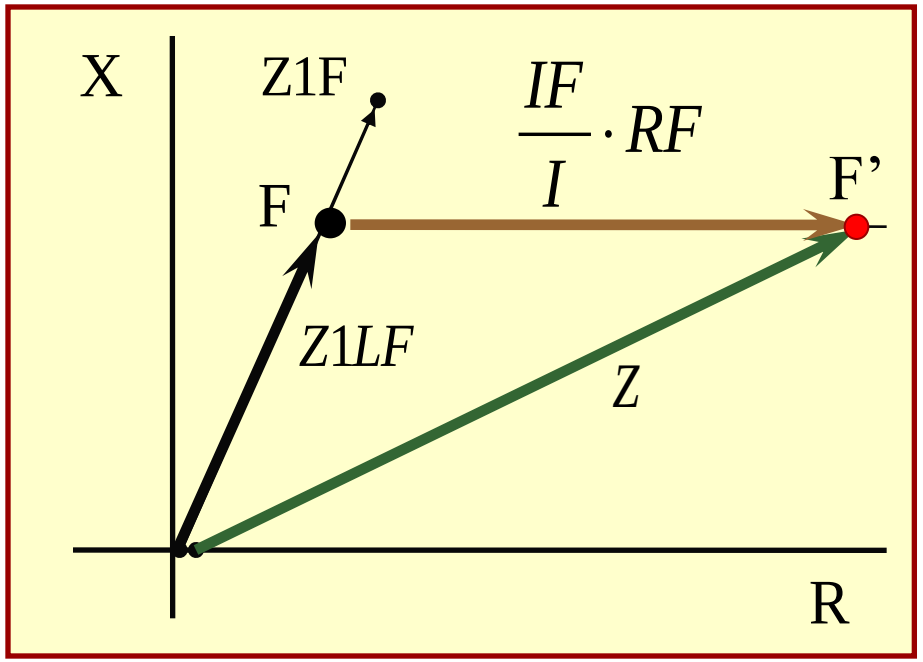


Apparent Fault Resistance

$$V = I \cdot Z1LF + IF \cdot RF$$

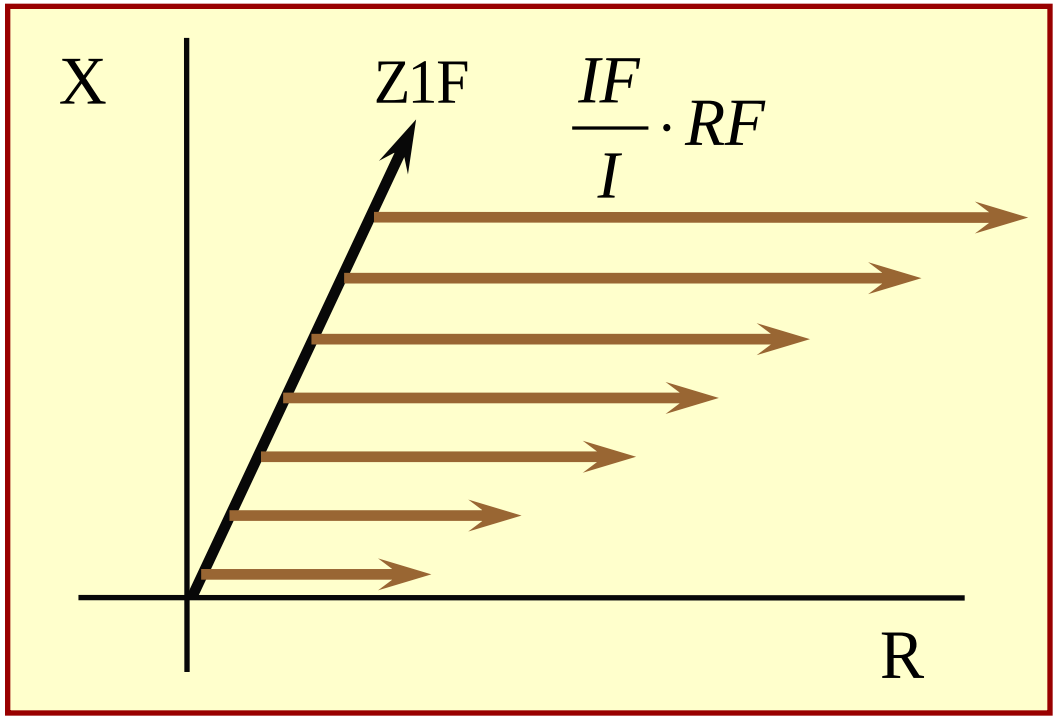
$$Z = Z1LF + \frac{IF \cdot RF}{I}$$



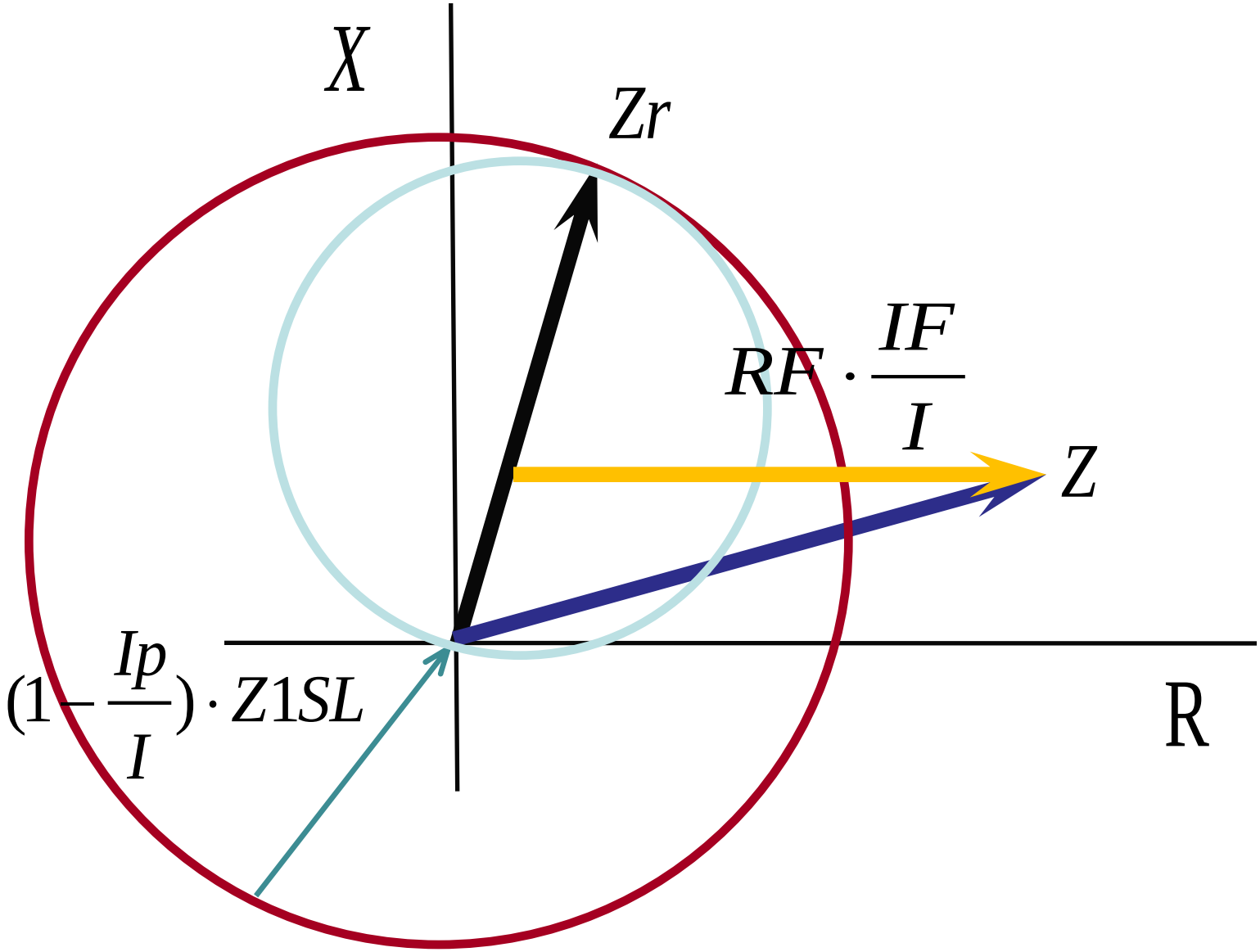


Infeed on Apparent Fault Resistance

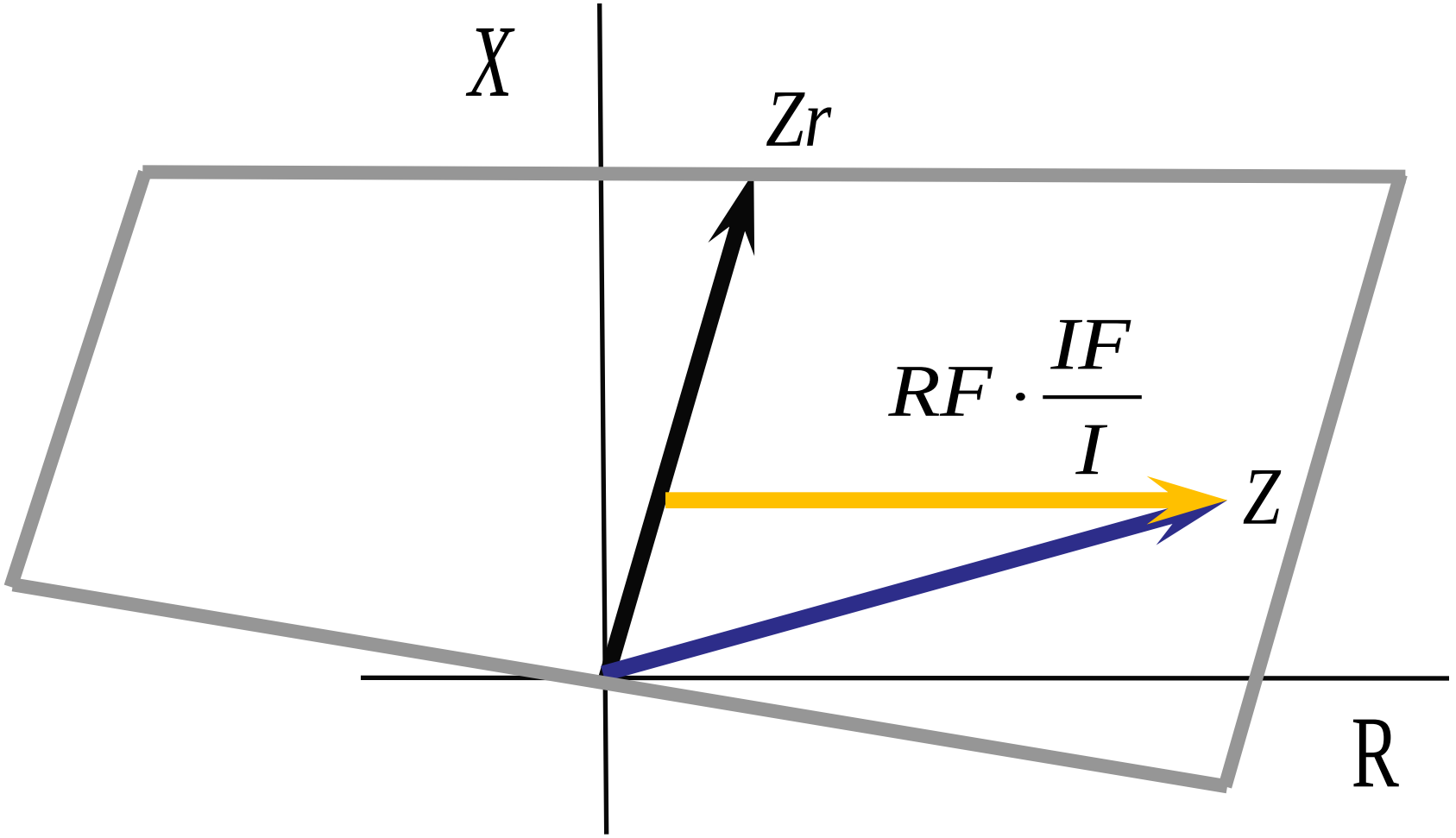
- Amplification of the apparent fault resistance
- Not applicable for arc resistances



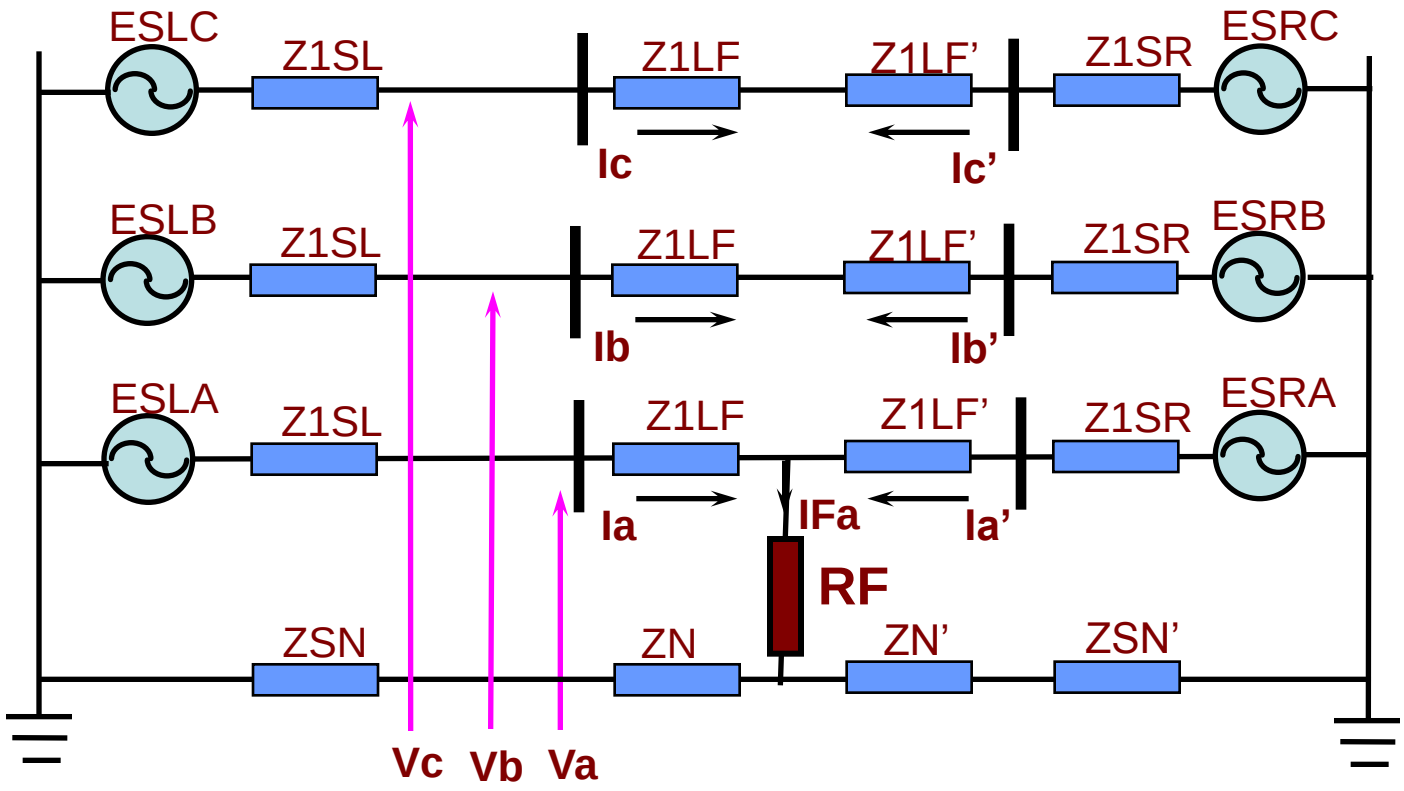
Influence on Mho Characteristic



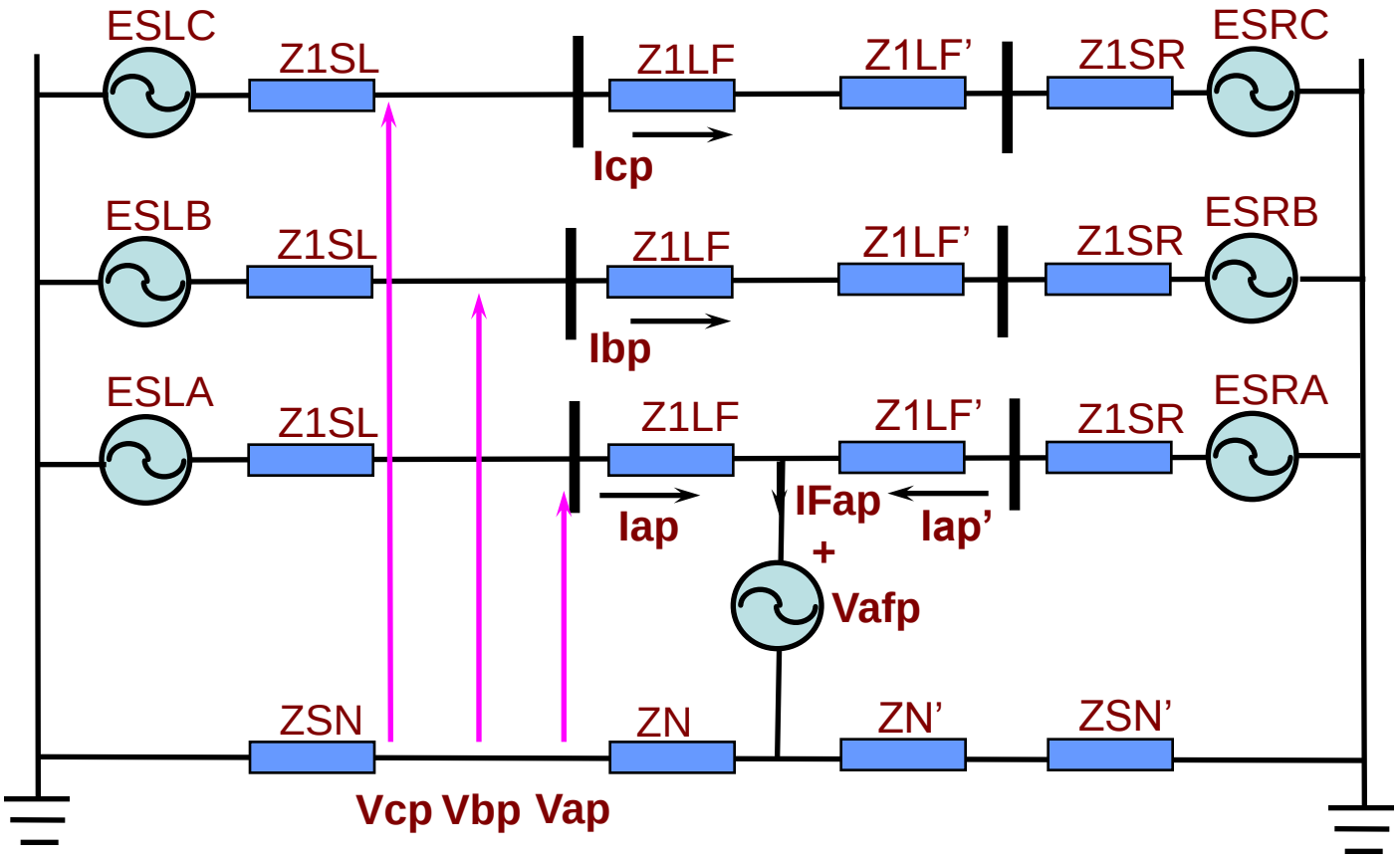
Influence on Quadrilateral Characteristic



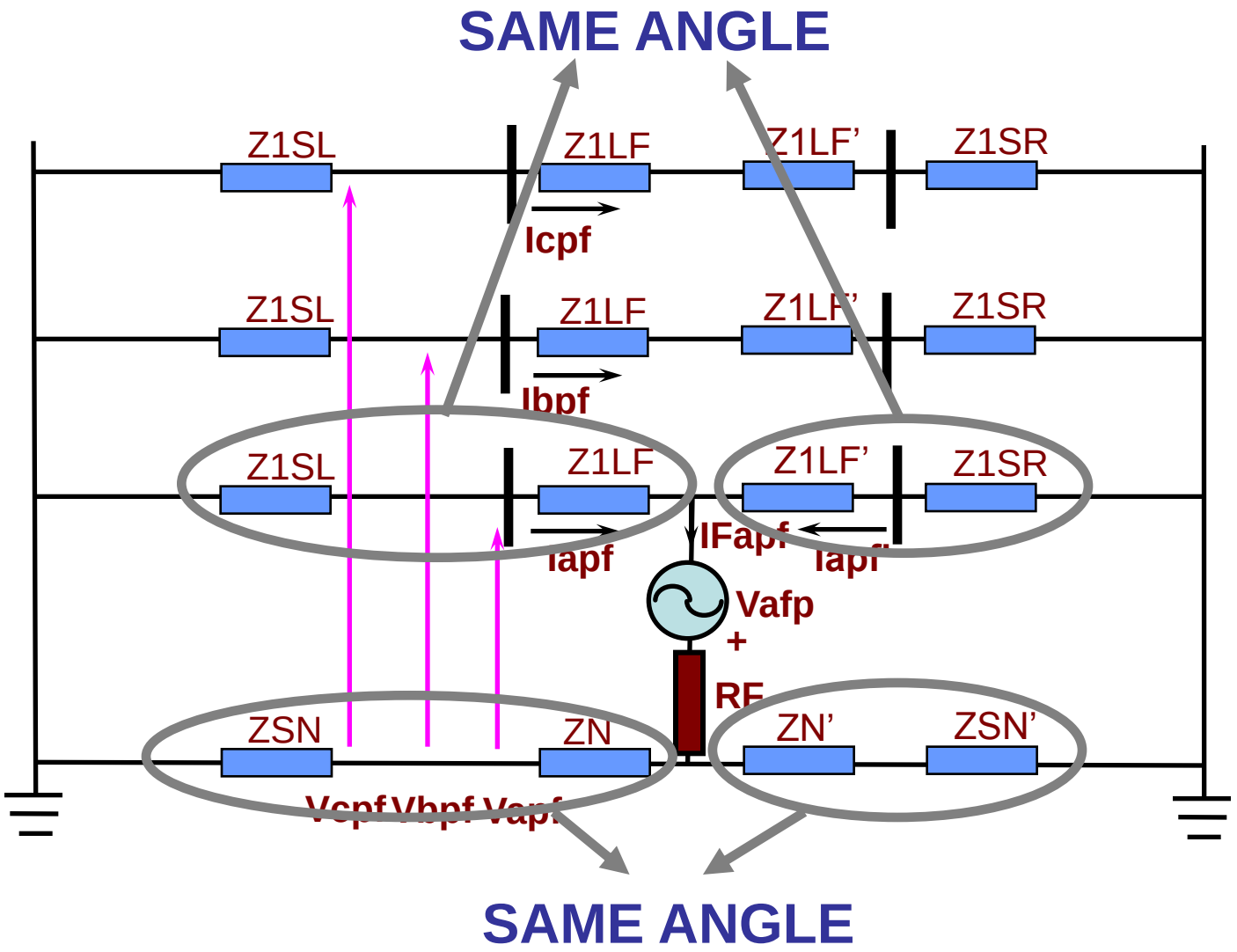
Load Flow Effect: Fault



Load Flow Effect: Prefault

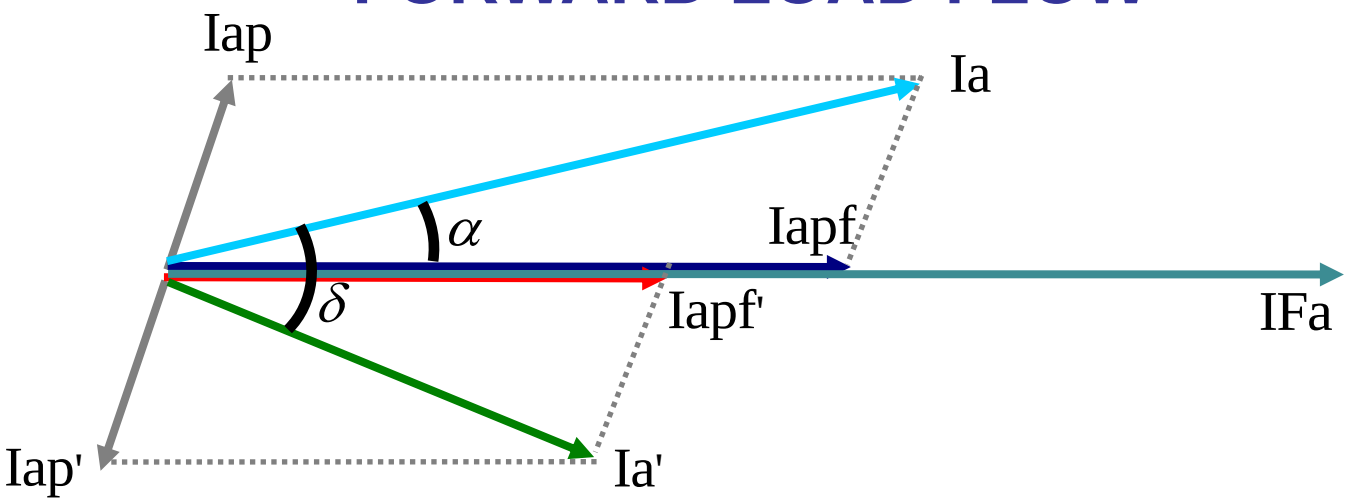


Load Flow Effect: Pure Fault

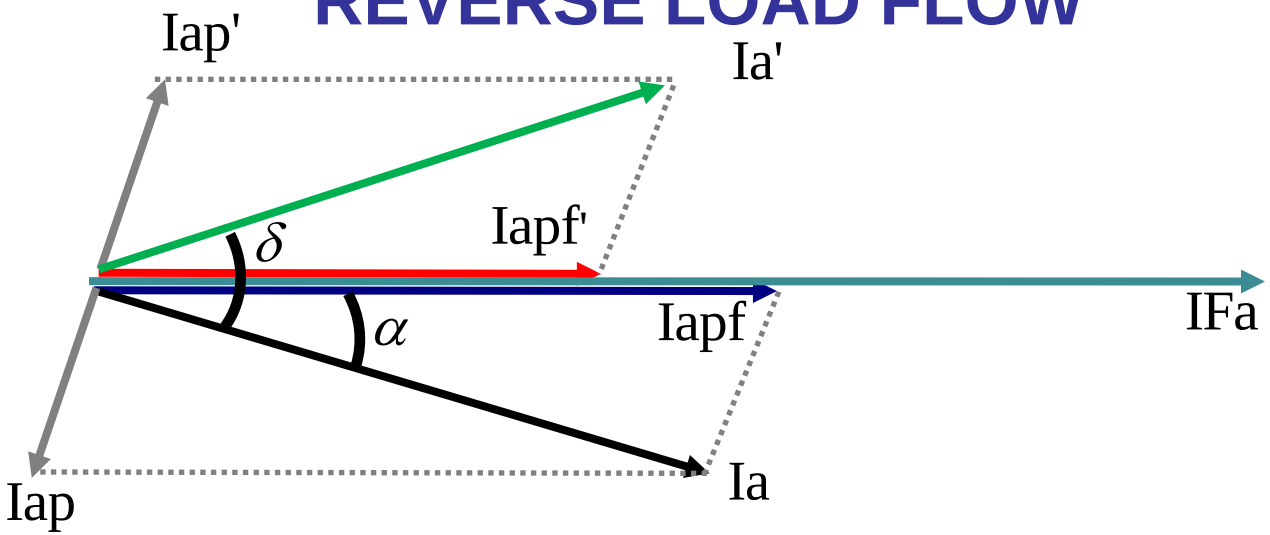


Load Flow Effect

FORWARD LOAD FLOW



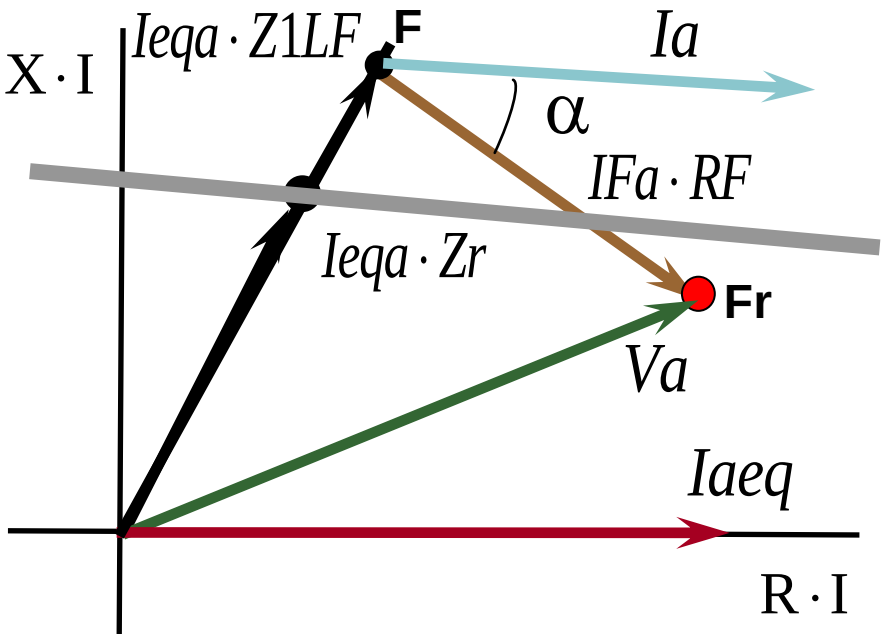
REVERSE LOAD FLOW



Quadrilateral Characteristic: Phase Polarization

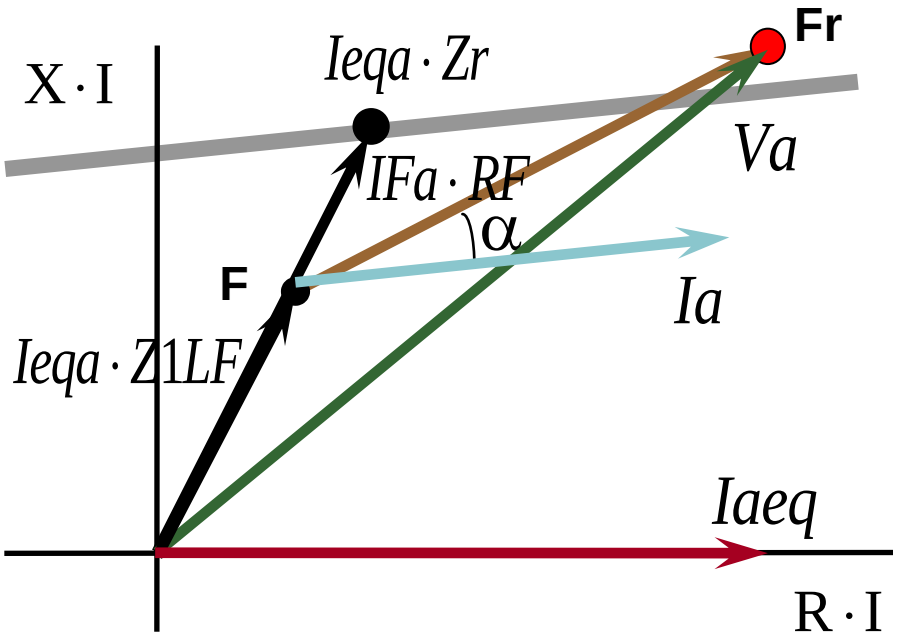
FORWARD LOAD FLOW

OVERREACHING



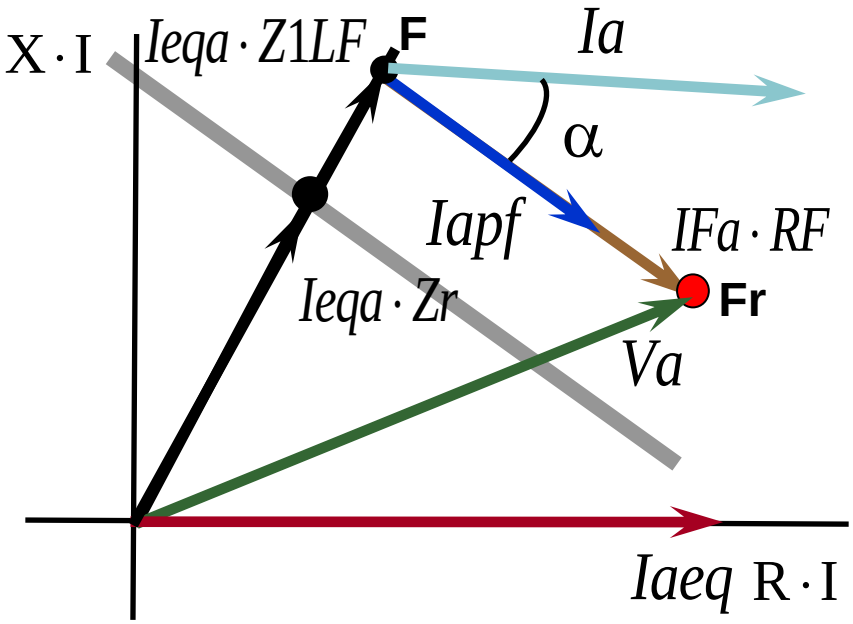
REVERSE LOAD FLOW

UNDERREACHING

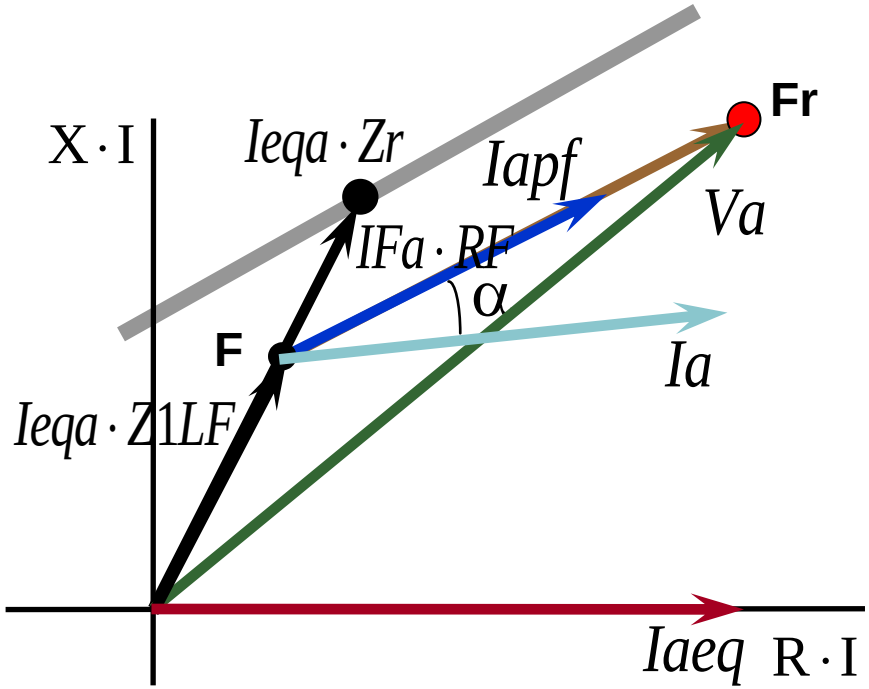


Quadrilateral Characteristic: Pure Fault Phase Polarization

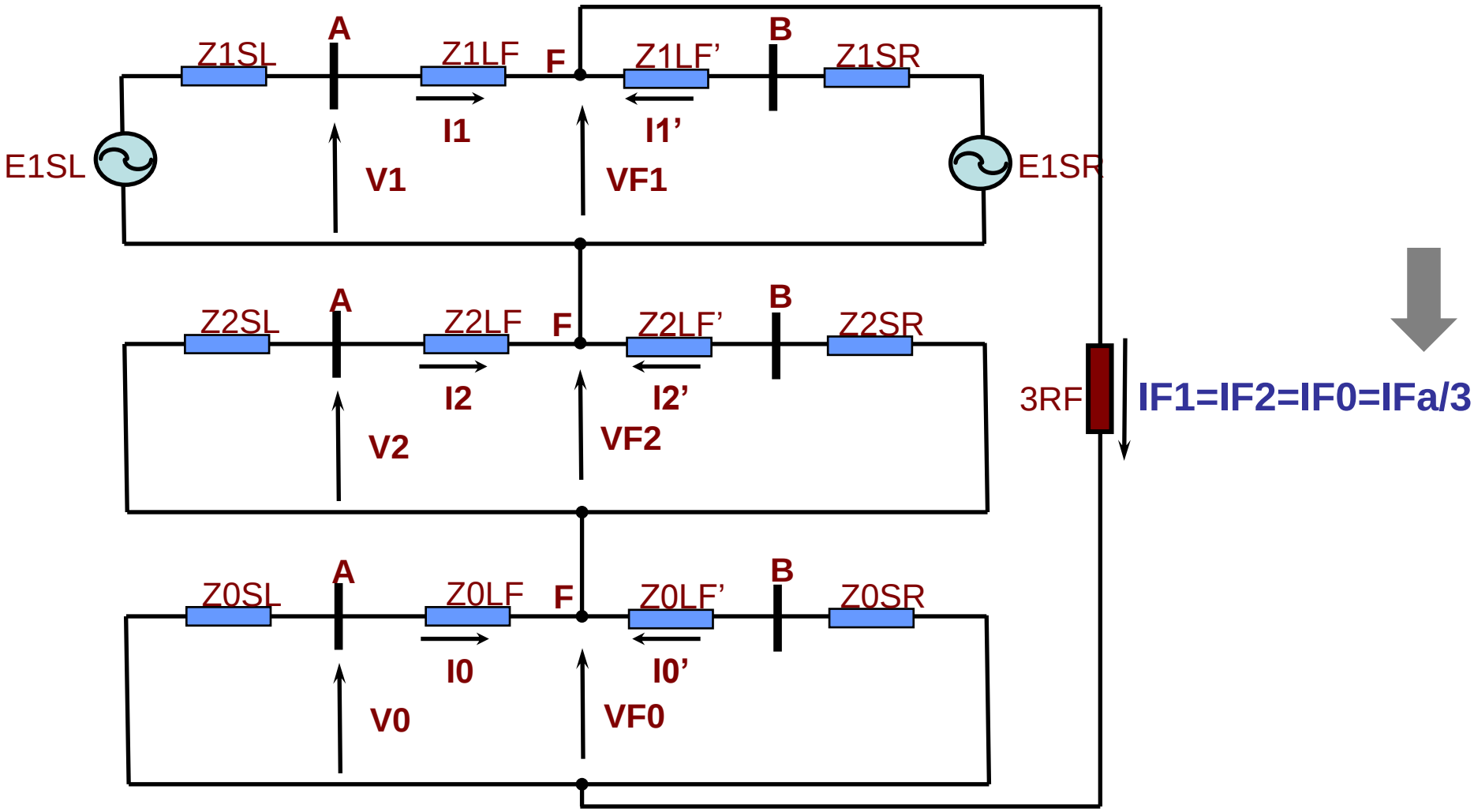
FORWARD LOAD FLOW



REVERSE LOAD FLOW

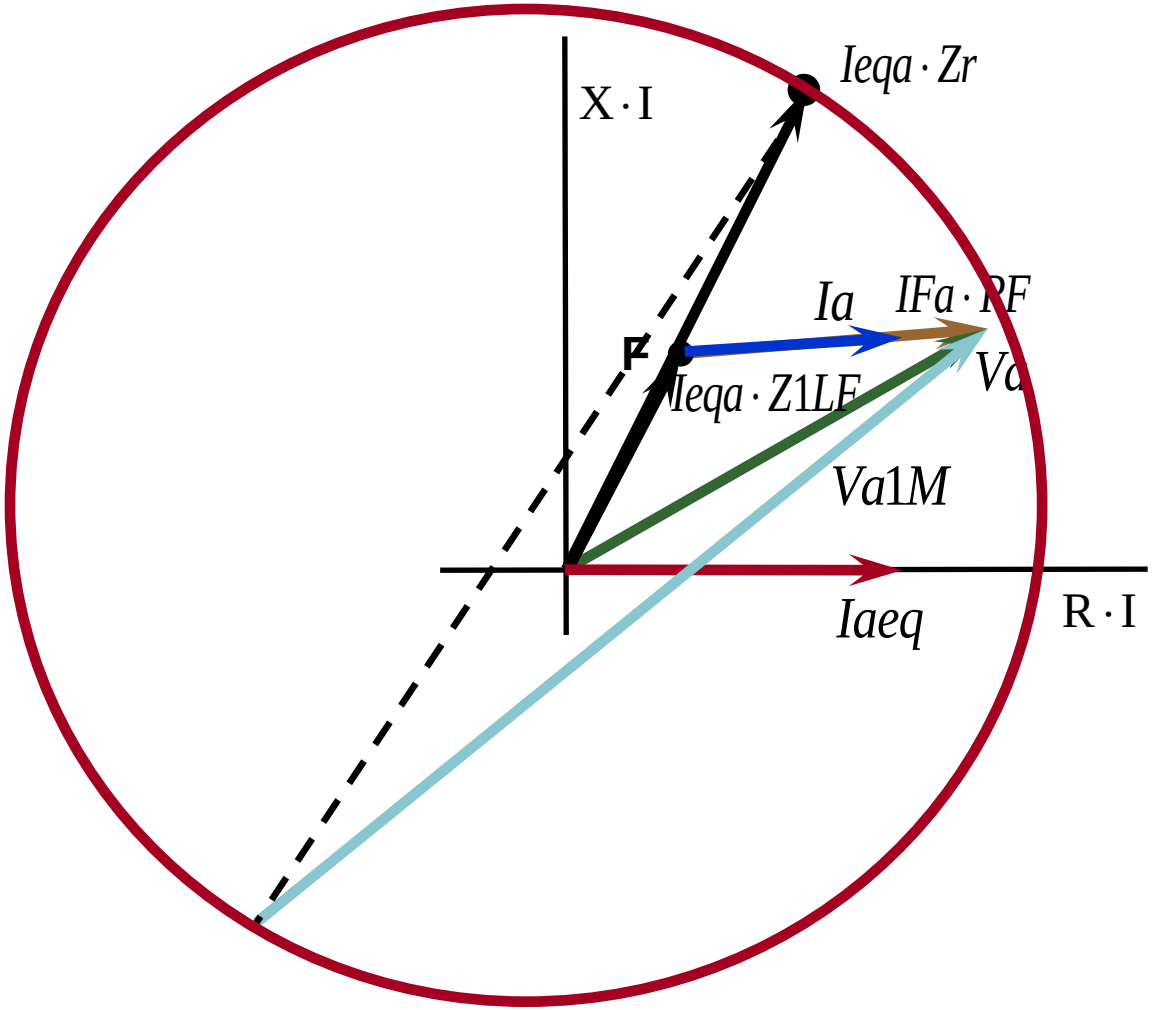


Quadrilateral Characteristic: I2 and I0 Polarization



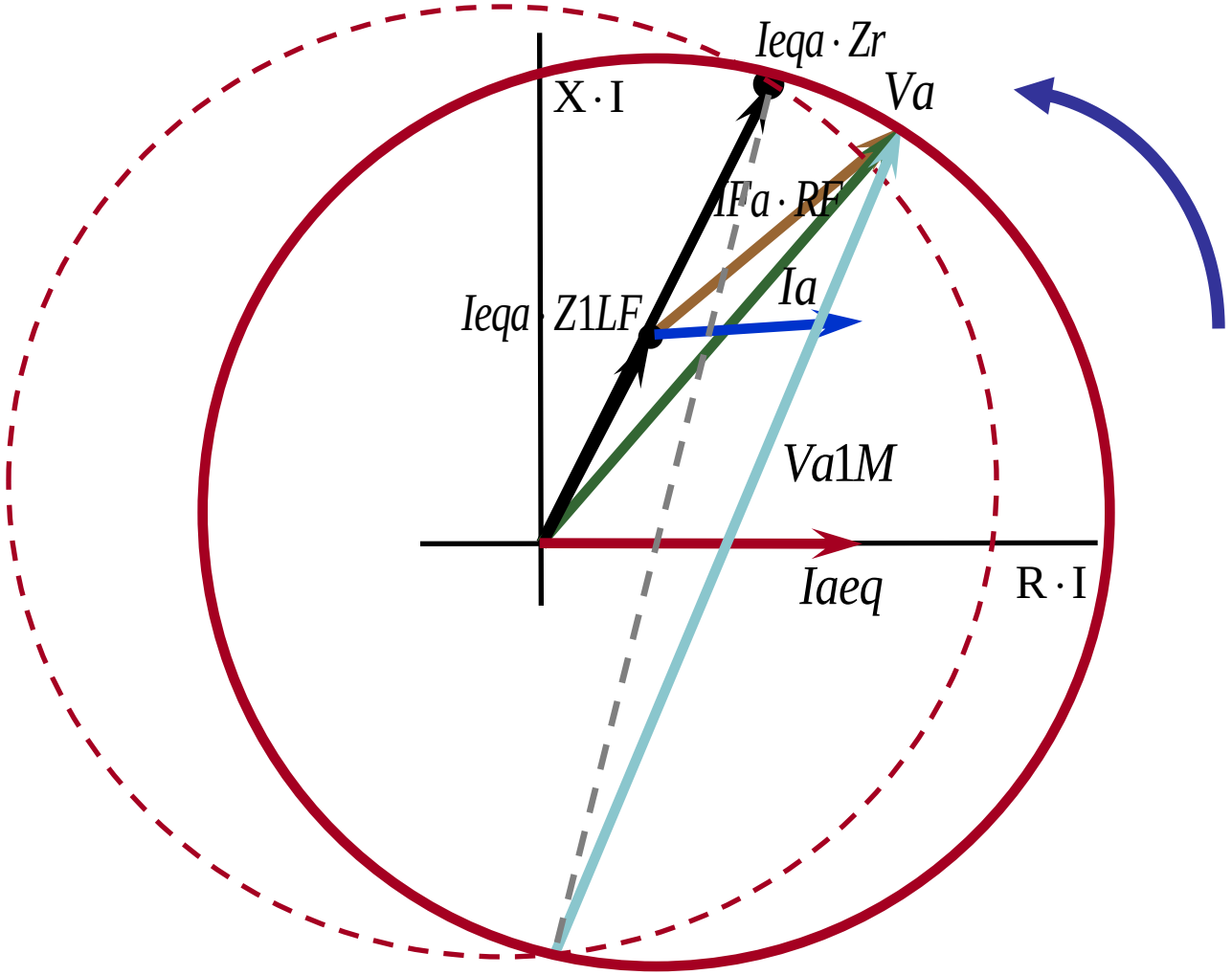
Mho Characteristic

NO LOAD FLOW



Mho Characteristic

REVERSE LOAD FLOW



System Non-Homogeneity

$$K1 = \frac{1}{3 \cdot (1 + \frac{Z0X}{Z0Y})}$$

$$\arg(\frac{Ia_{pf}}{IFa}) = \arg(\frac{Z1X + (-Z1X \cdot K1 + Z0X \cdot K1 - Z0Y \cdot K2 + Z1Y \cdot K2)}{Z1X + Z1Y})$$

$$\arg(\frac{Ia2}{IFa}) = \arg(\frac{Z1X}{Z1X + Z1Y})$$

$$K2 = K1 \cdot \frac{Z0X}{Z0Y}$$

$$\arg(\frac{I0}{IFa}) = \arg(\frac{Z0X}{Z0X + Z0Y})$$

ZX: Z AT THE LEFT OF THE FAULT

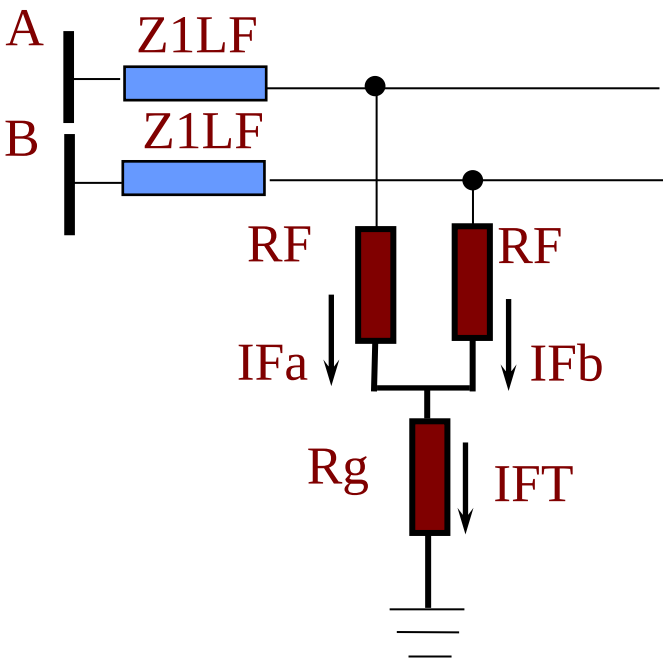
ZY: Z AT THE RIGHT OF THE FAULT

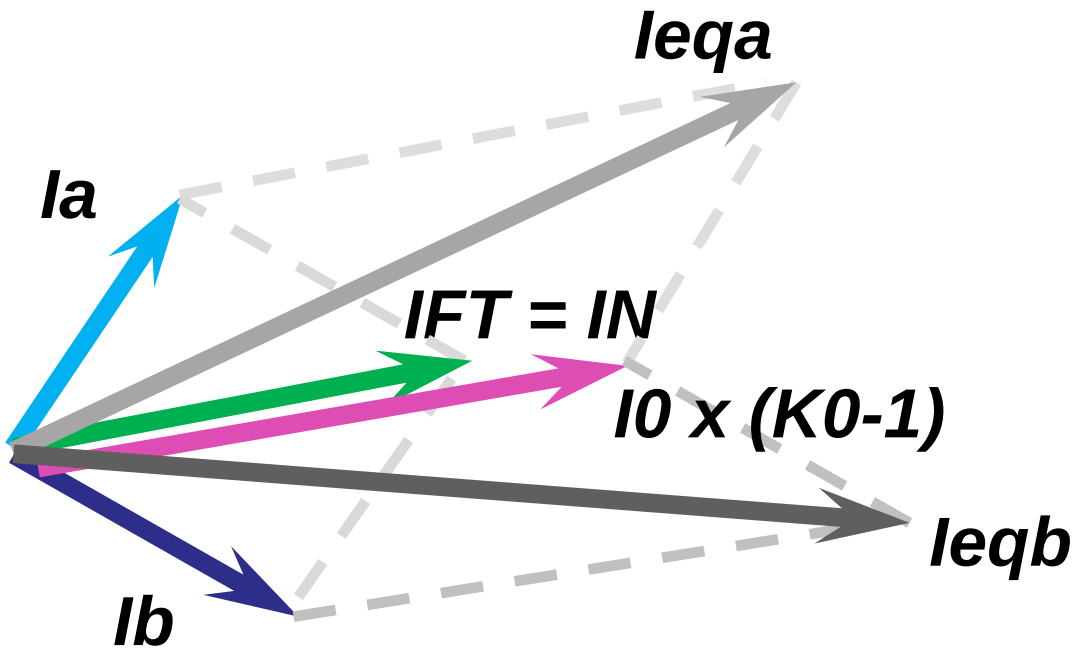
- I2 is preferable than Ia_{pf} and I0
- Tilt angle can be used

Single-Phase Fault with Open Pole

- I2 is not reliable
- Pure fault phase current is chosen

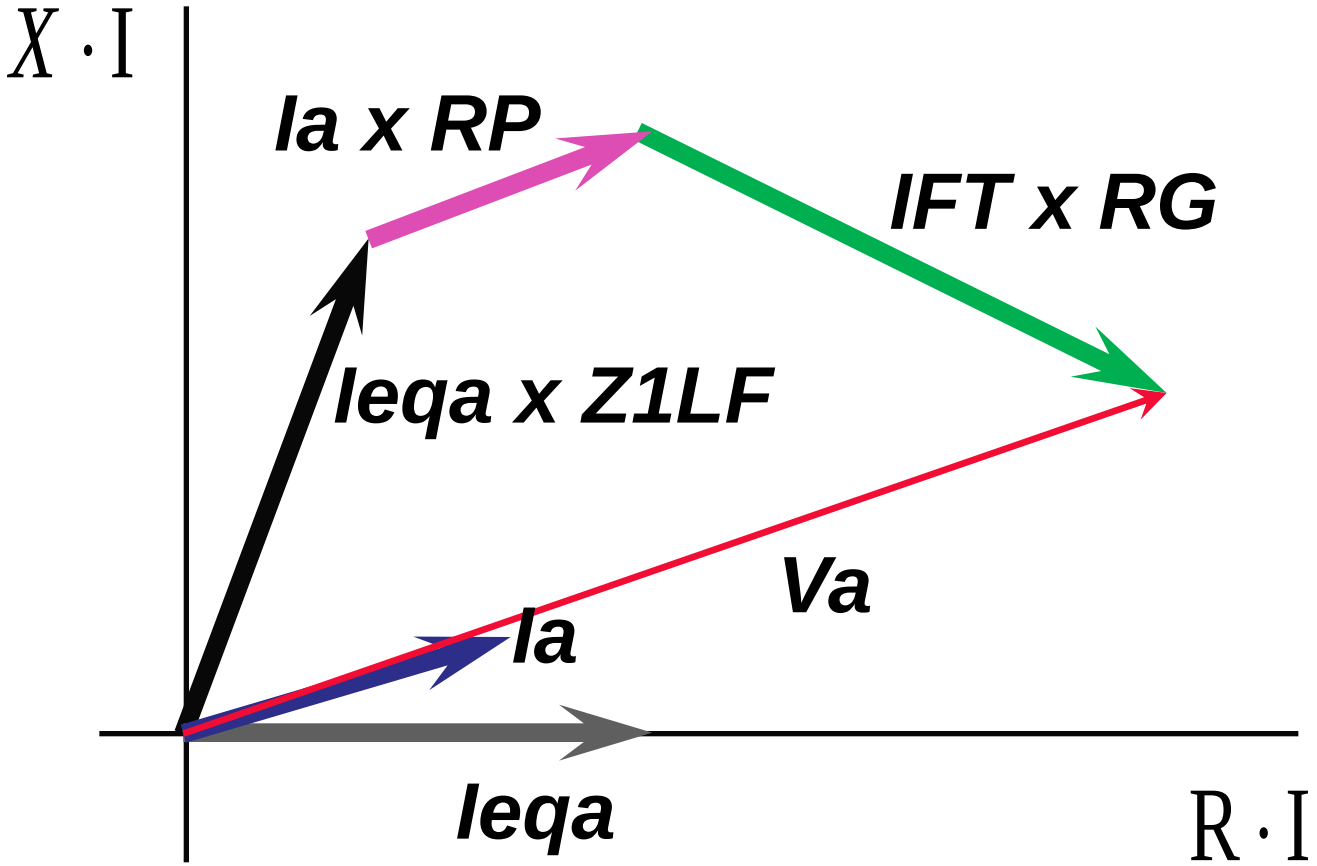
Phase-Phase-Ground Fault





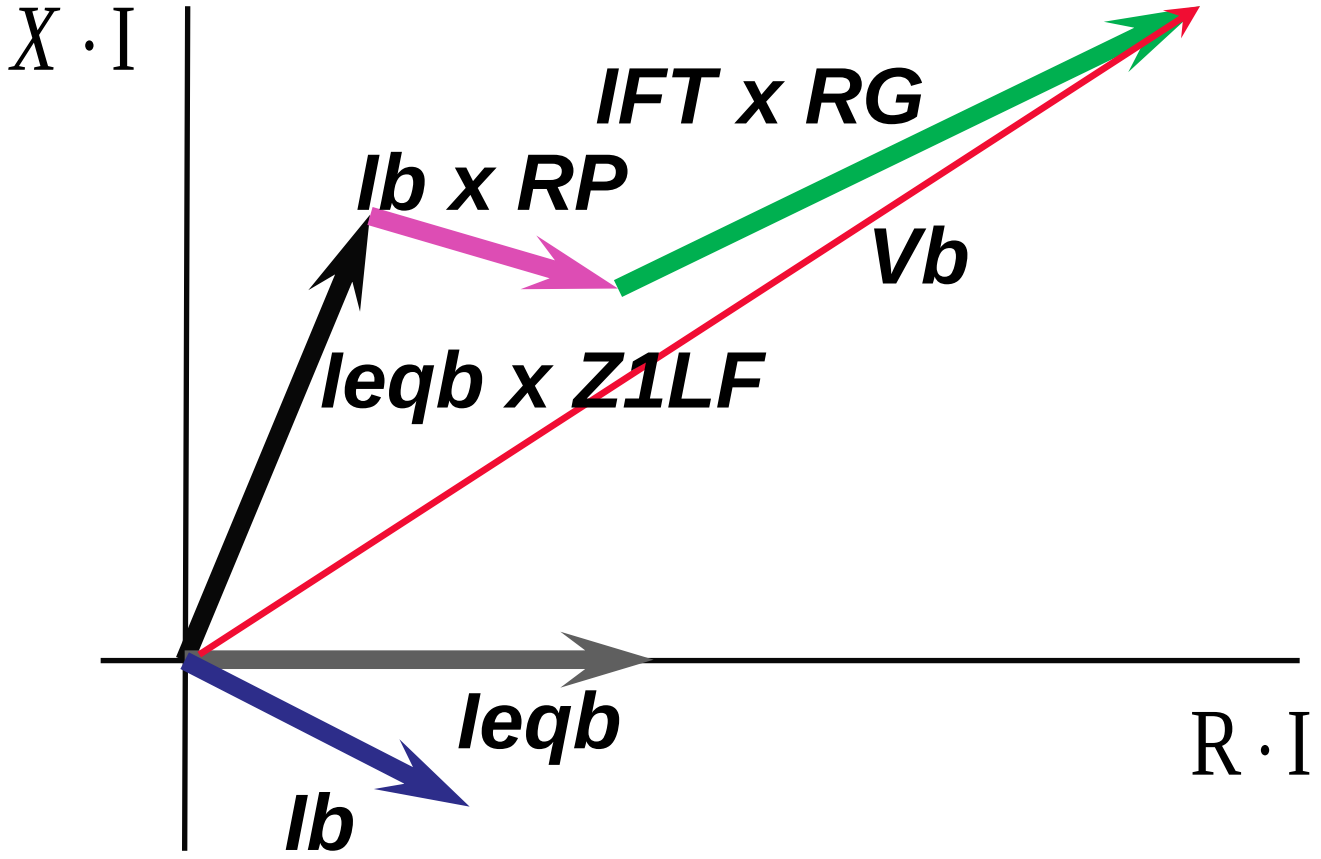
Phase-Phase-Ground Fault

LEADING PHASE (A): OVERREACHES

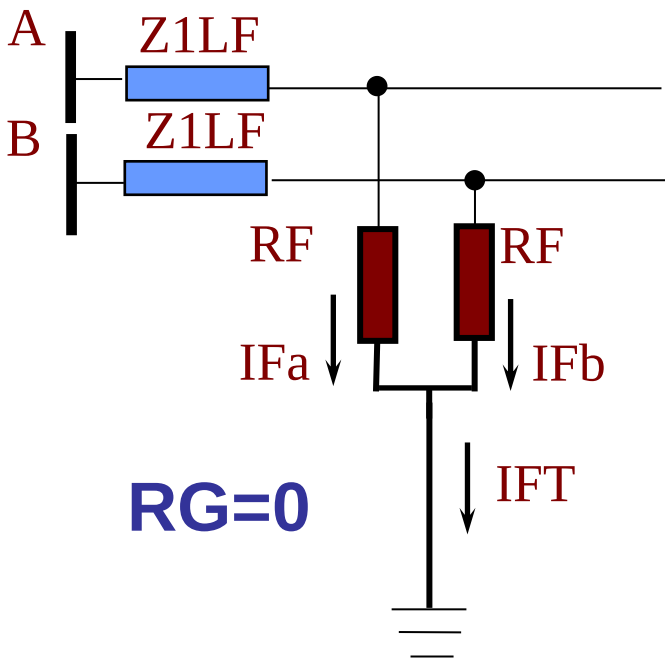


Phase-Phase-Ground Fault

LAGGING PHASE (B): UNDERREACHES



Simultaneous Phase-Ground Faults



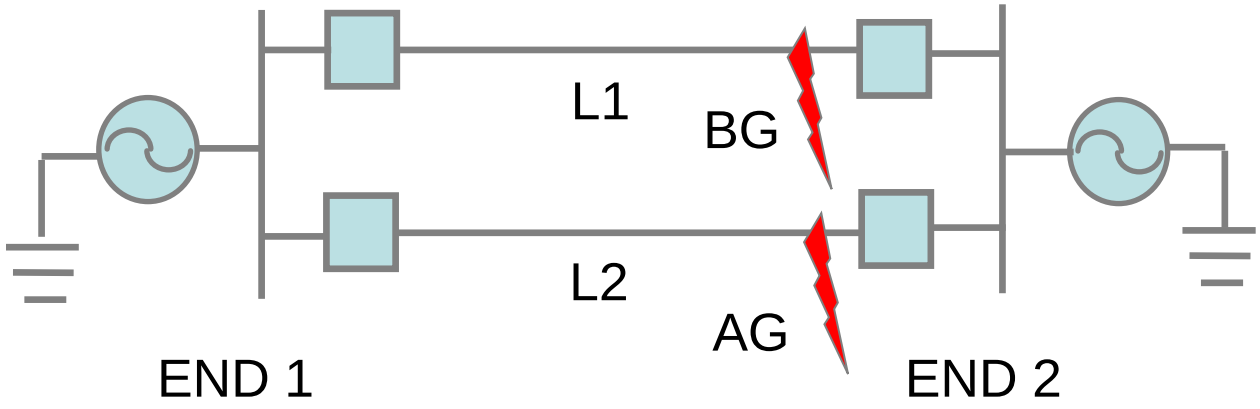
AG DOES NOT OVERREACH

BG DOES NOT UNDERREACH

- I2 polarization is not reliable
- Pure fault phase current polarization must be used

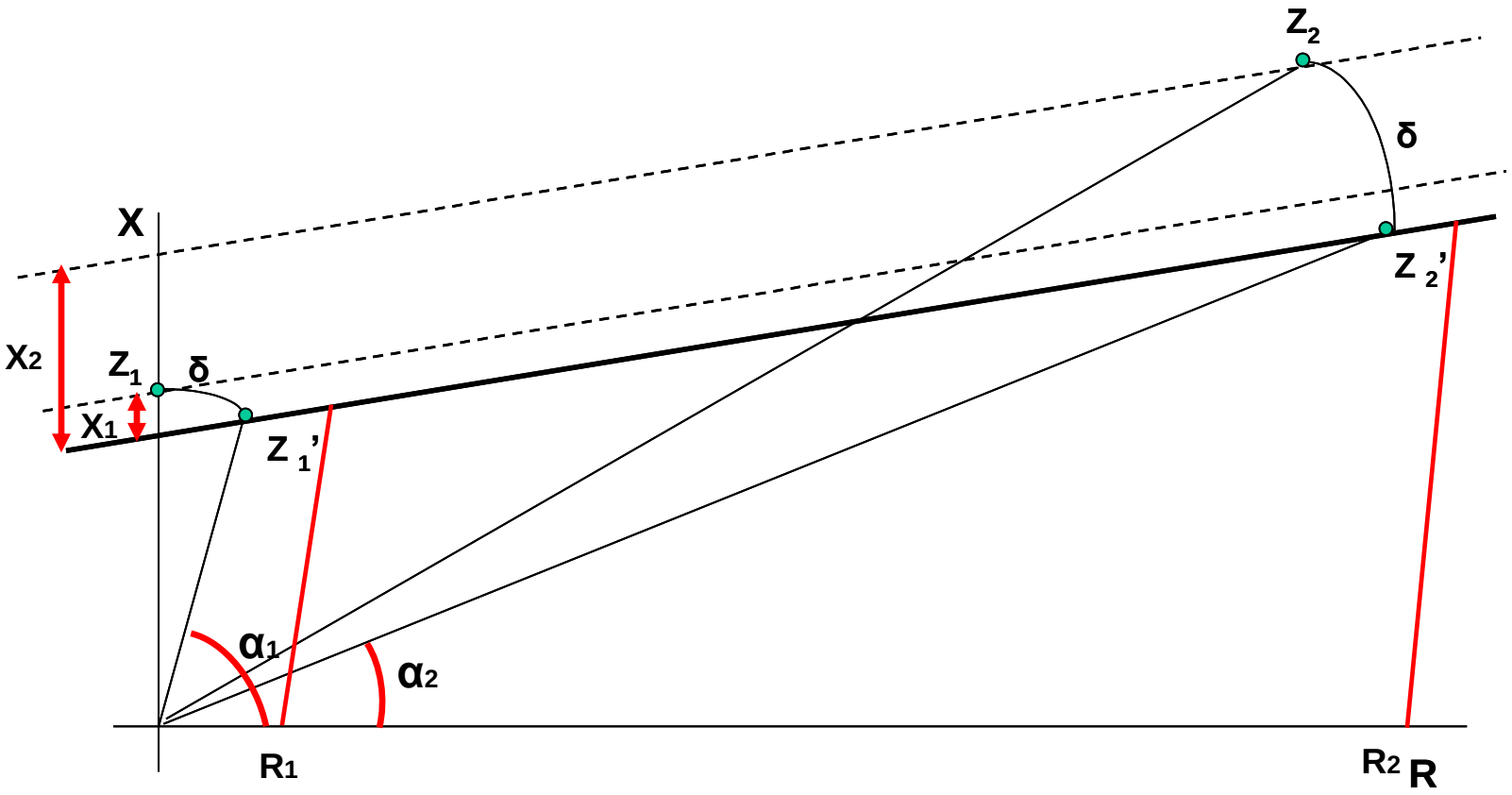
Phase Selector Indicating Single-Phase-Ground Fault During Two-Phase-Ground Fault

- Evolving Fault from Single-Phase-Ground: detection based on a phase selector using the angle between I2 and I1pf
- Cross-Country Fault

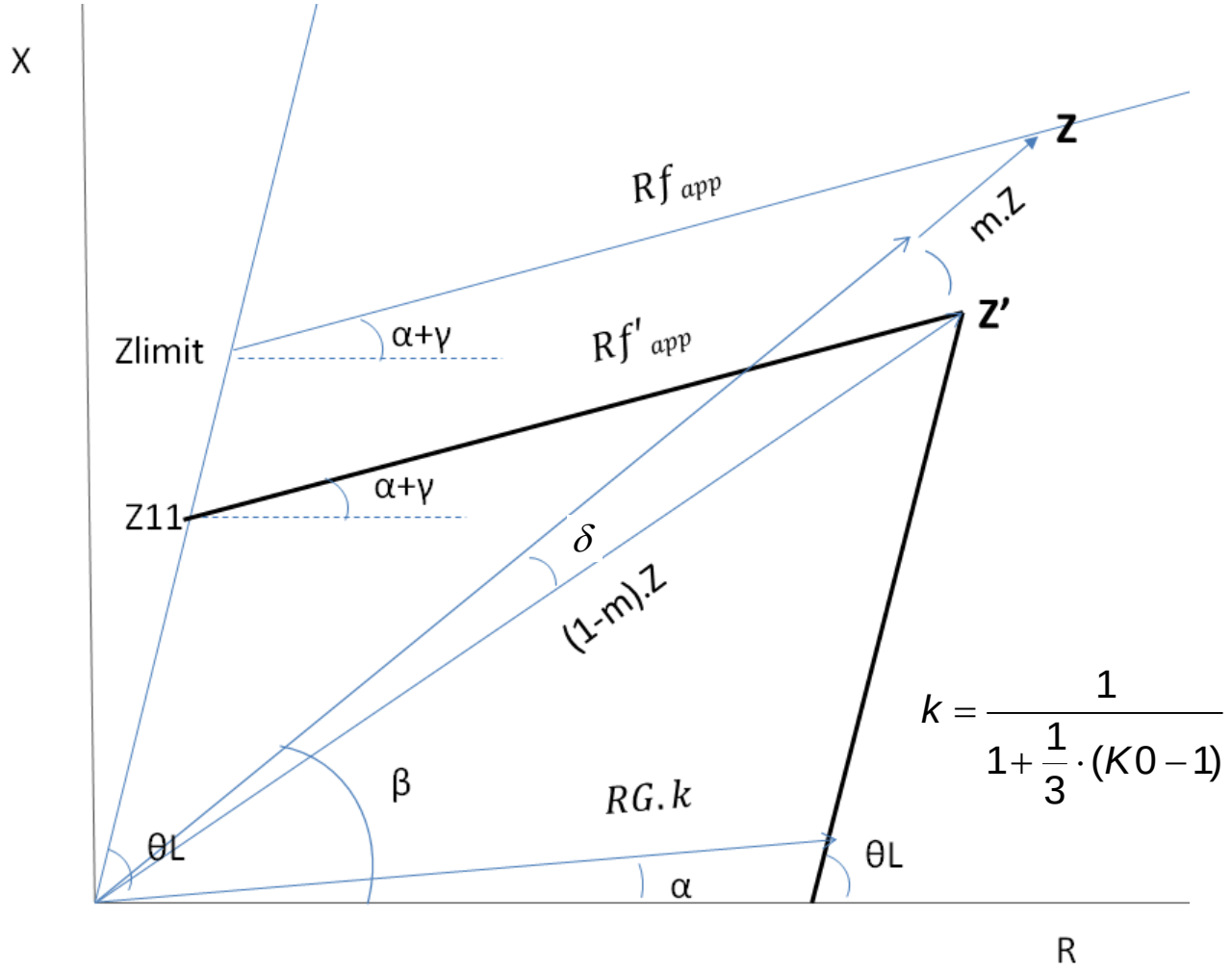


Resistive Reach Calculation

- The higher the resistive reach the lower the impedance angle → the higher the overreach with the same angle error (δ)



Ground Resistive Reach Calculation

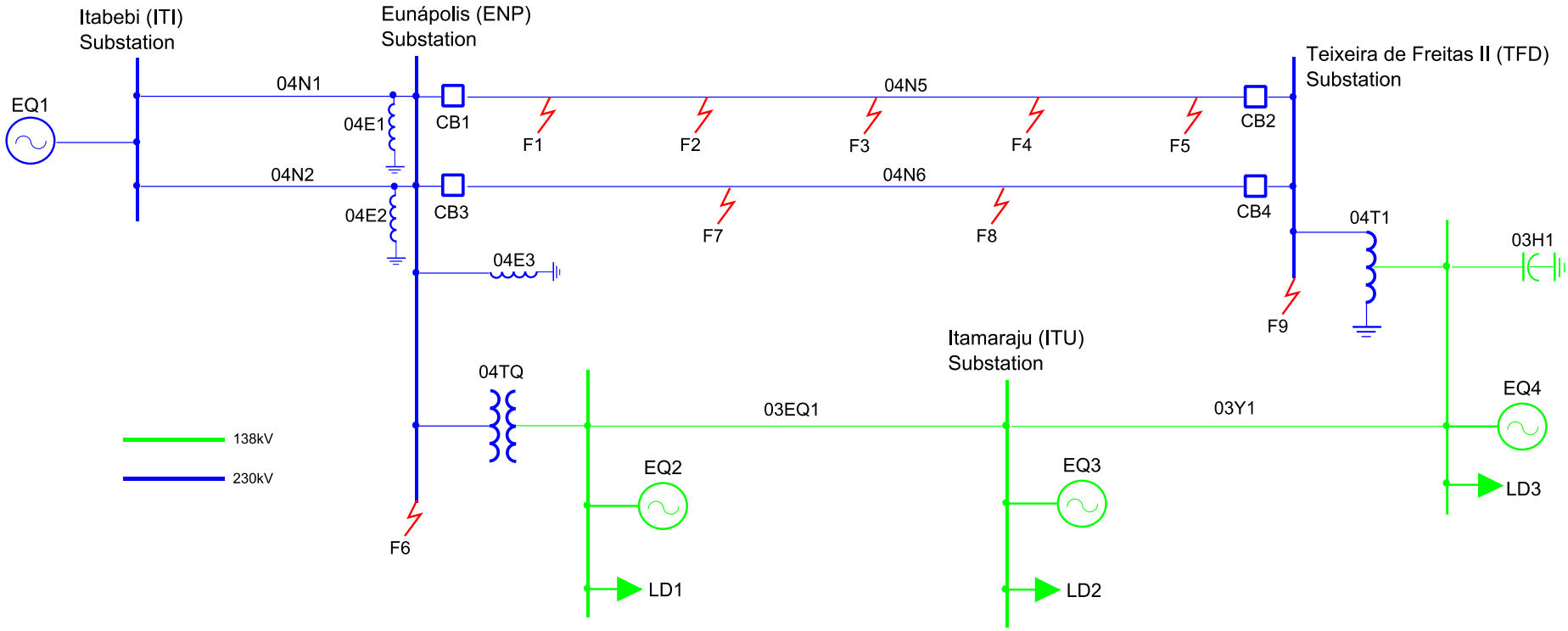


$$k = \frac{1}{1 + \frac{1}{3} \cdot (K0 - 1)}$$

$$RG = \frac{|ZL1| \cdot \left[(1-m) \cdot (Z1\_reach + overreach) \cdot \sin(\theta L - \alpha - \gamma) - Z1\_reach \cdot \sin(\theta L - \alpha - \gamma + \delta) \right]}{\frac{\sin(\theta L - \alpha)}{\sin(\theta L - \alpha - \gamma)} \cdot |k| \cdot \sin(\delta)}$$

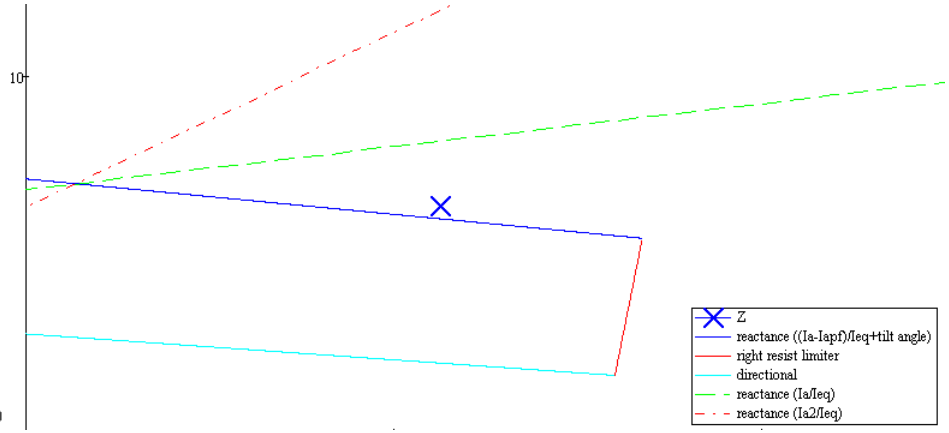
RTDS Simulation

230 kV DOUBLE CIRCUIT LINE

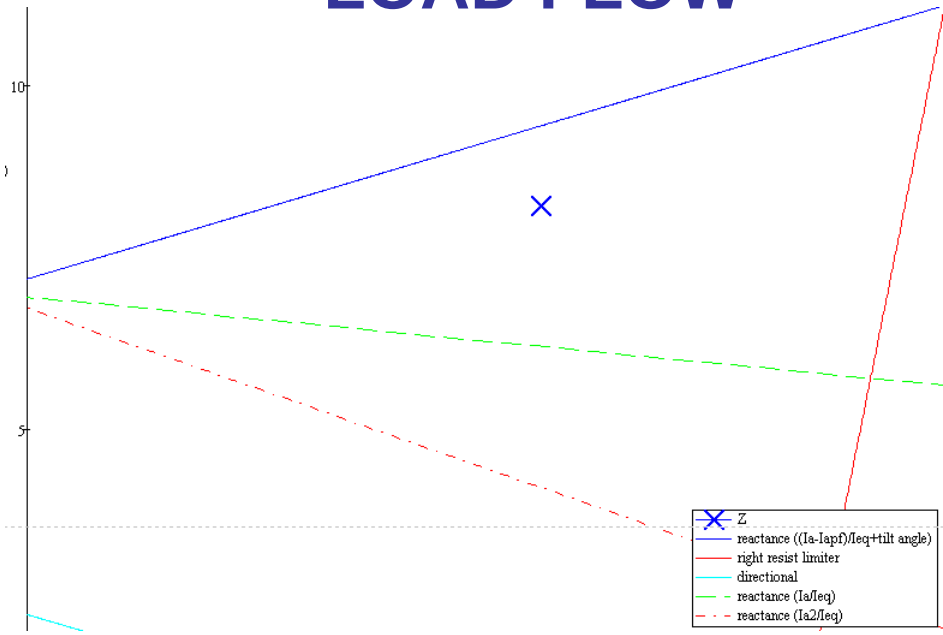


AG Fault with Pole C Open

AT 90% FORWARD LOAD FLOW



AT 70% REVERSE LOAD FLOW



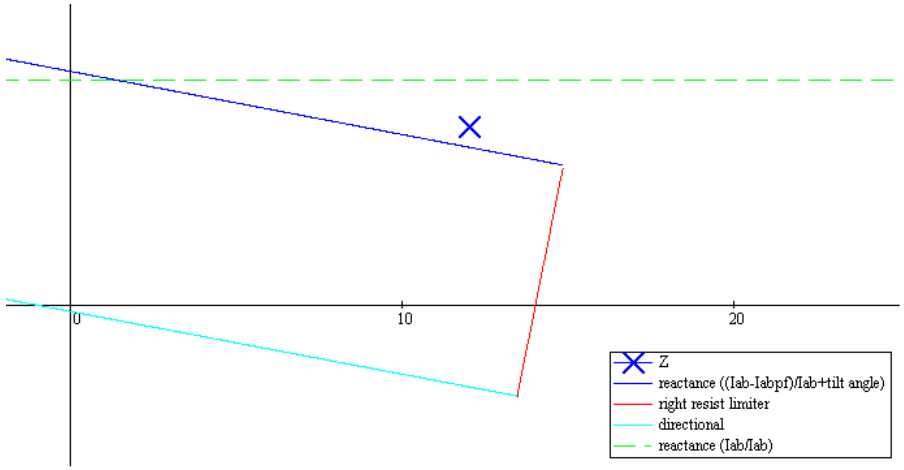
(Ia-Iap)/Iaeq

Ia/Iaeq

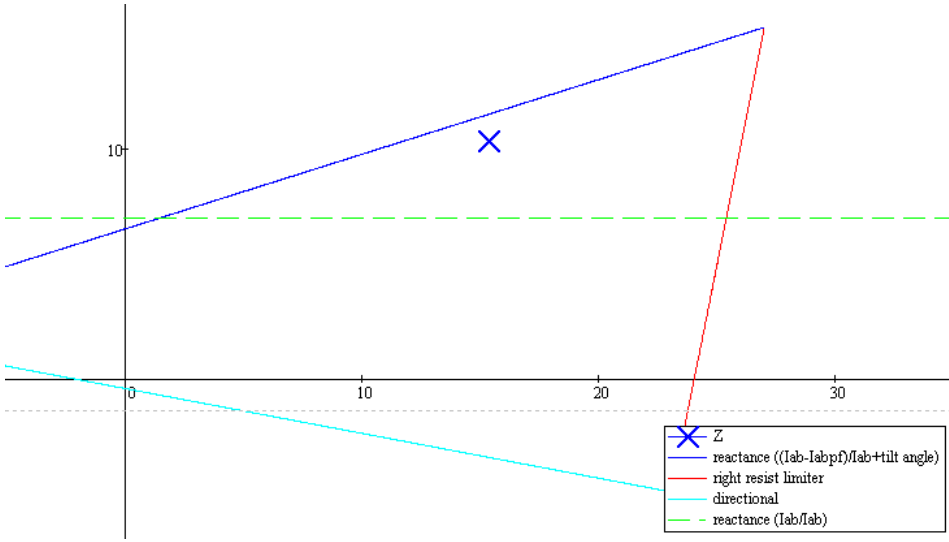
Ia2/Iaeq

Simultaneous Ground Faults (AG BG): AB Unit

AT 90% FORWARD LOAD FLOW



AT 70% REVERSE LOAD FLOW

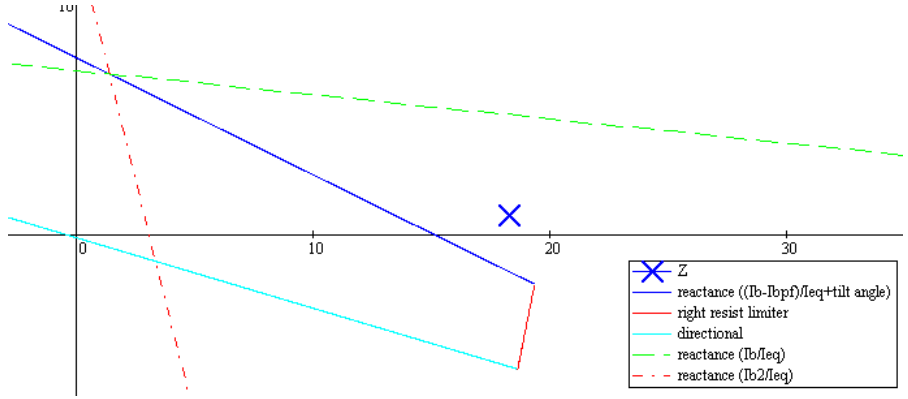


(Iab-Iabp)/Iab

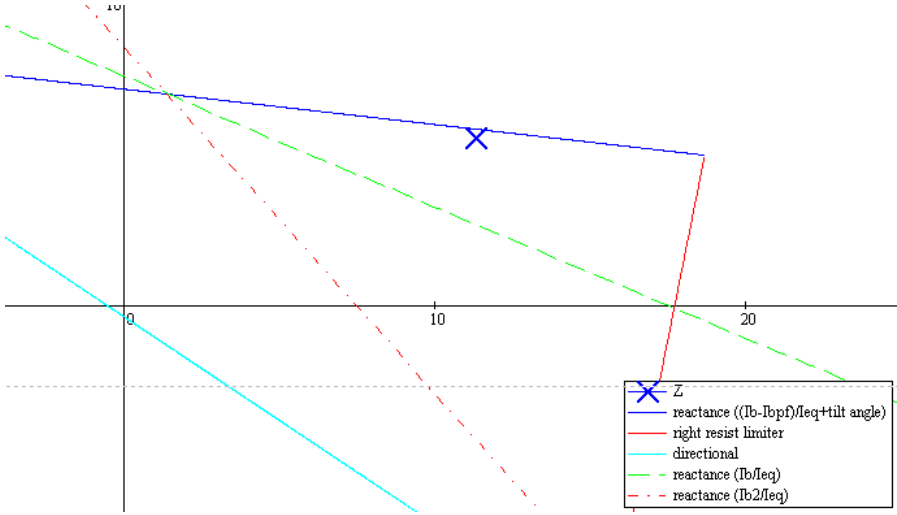
Iab/Iab

Simultaneous Ground Faults (AG BG): BG Unit

AT 90% FORWARD LOAD FLOW



AT 70% REVERSE LOAD FLOW



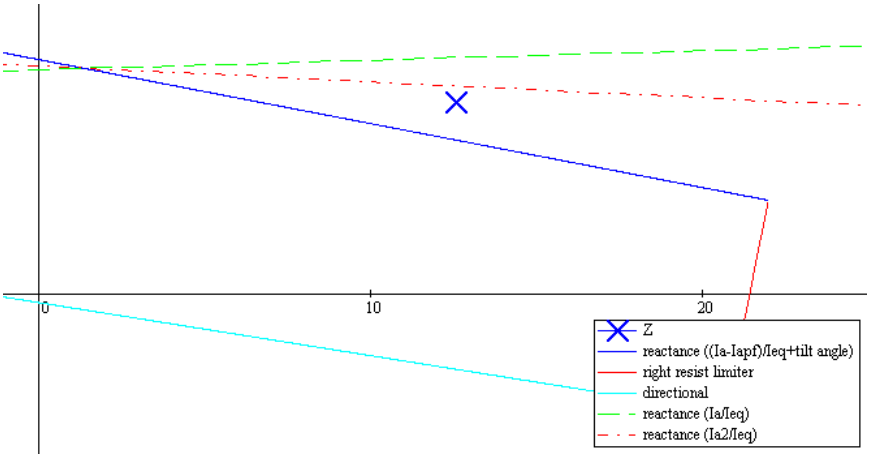
(Ia-Iap)/Iaeq

Ia/Iaeq

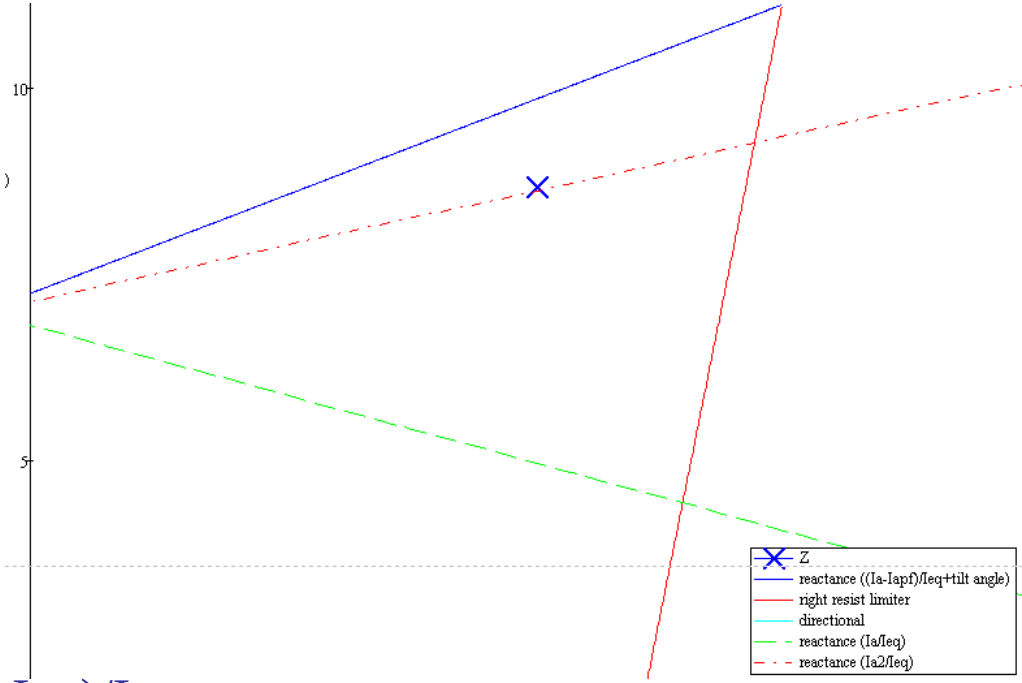
Ia2/Iaeq

Evolving Fault (AG to ABG)

AT 90% FORWARD LOAD FLOW



AT 70% REVERSE LOAD FLOW

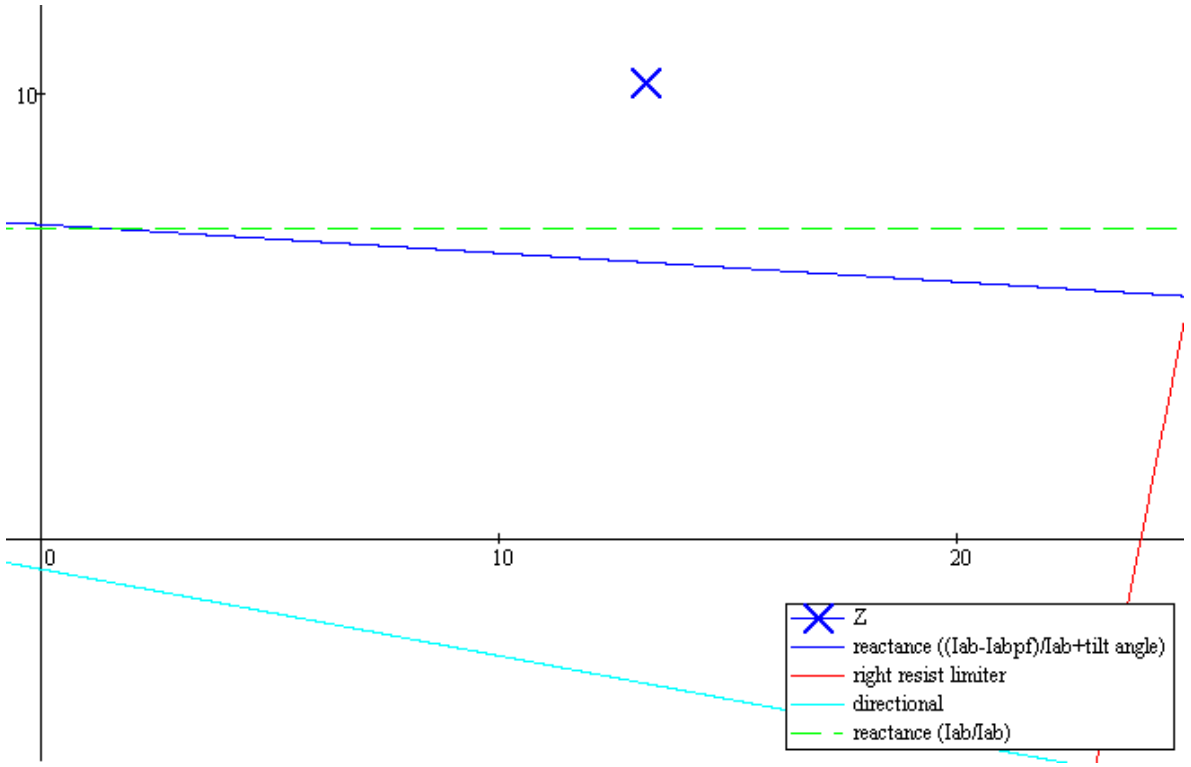


(Ia-Iap)/Iaeq

Ia/Iaeq

Ia2/Iaeq

Cross-Country Fault (Double Circuit): ABG Fault at 70%

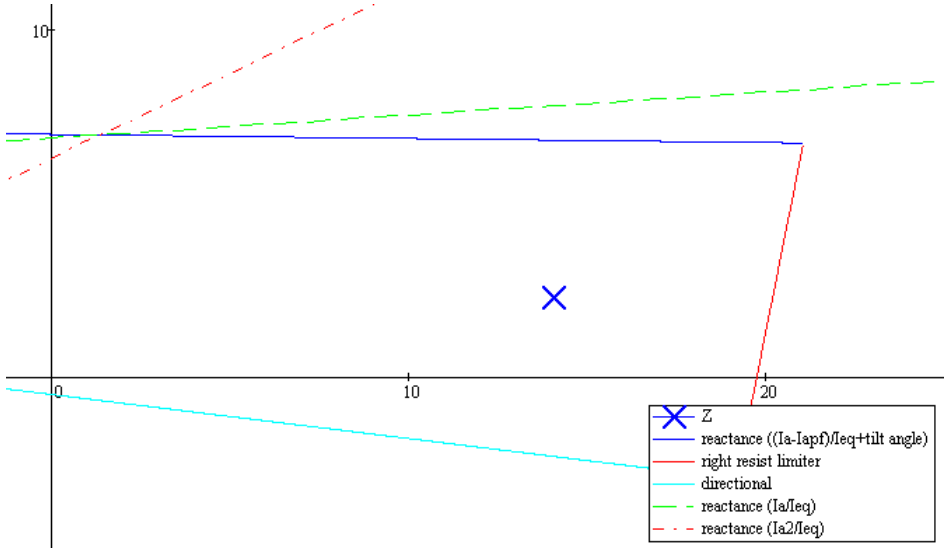


(Iab-Iabp)/Iab

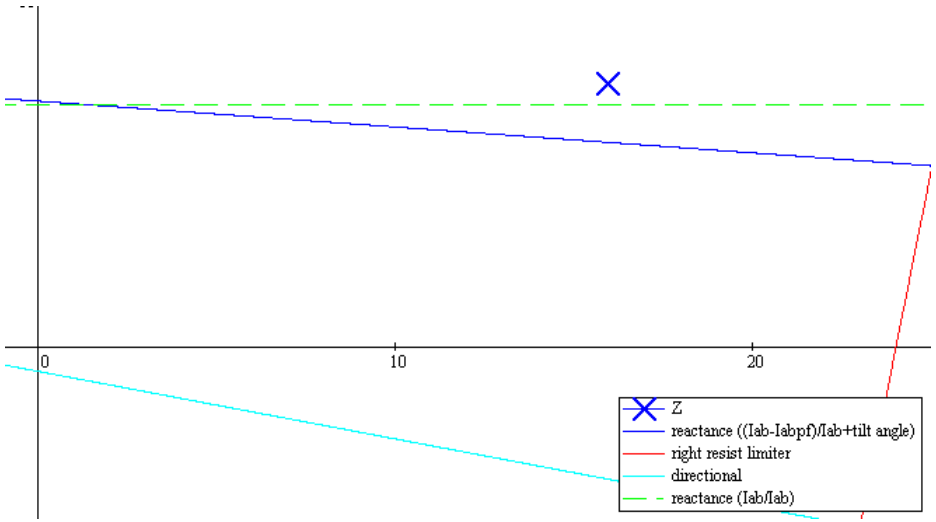
Iab/Iab

Cross-Country Fault (Double Circuit): ABG Fault at 70%

AG FAULT ON PROTECTED LINE



BG FAULT ON PROTECTED LINE



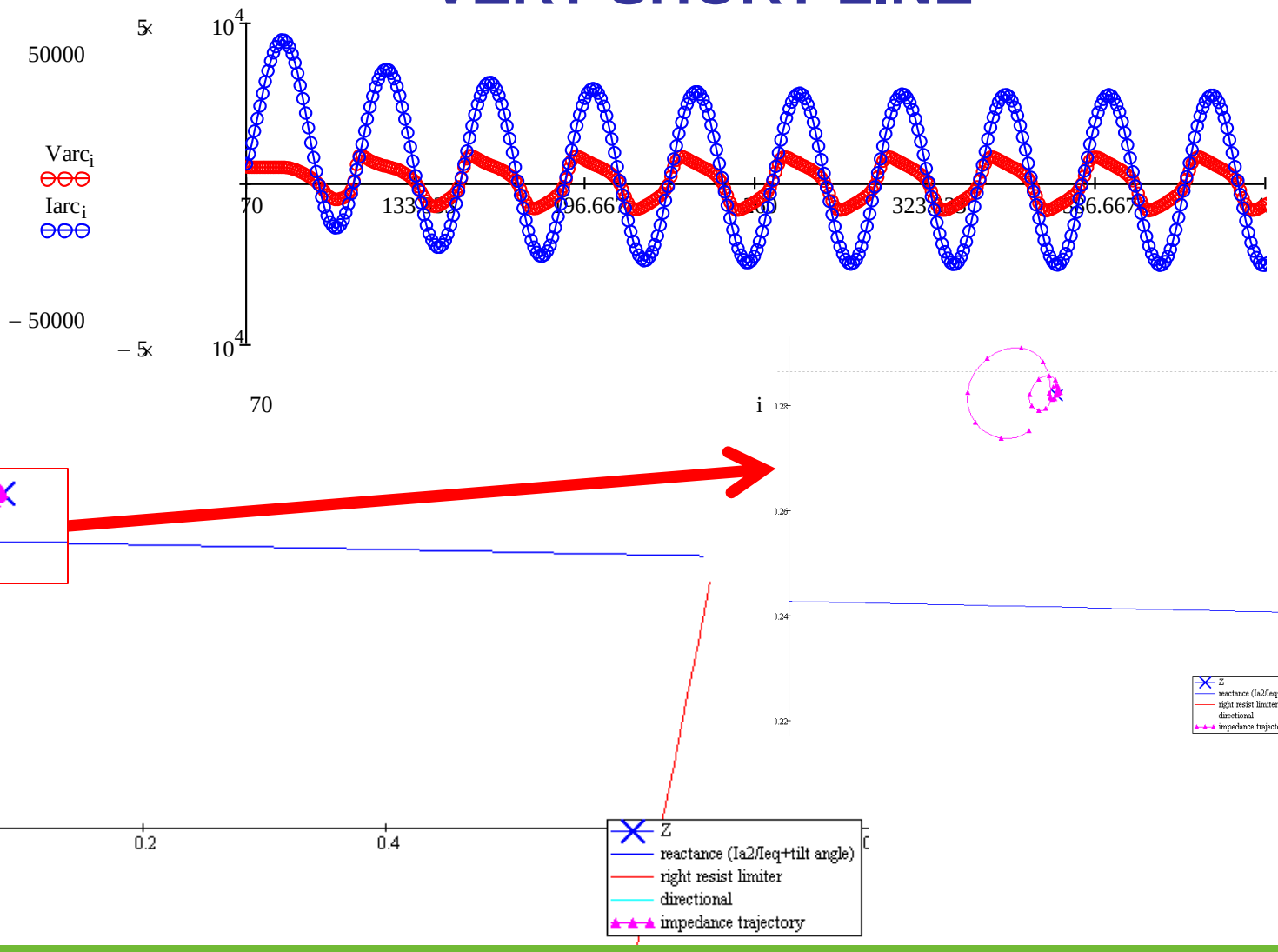
(Ia-Iap)/Iaeq

Ia/Iaeq

Ia2/Iaeq

Fault with Arc Resistance at 90%

VERY SHORT LINE



Conclusions

- The Mho characteristic tends to underreach during resistive faults although its advanced polarization makes it expand and it automatically compensates the load flow effect
- The quadrilateral characteristic has a good resistive coverage, however the reactance line has to be adequately polarized in order to compensate the load flow and the system non-homogeneity
- The polarization phasors chosen are:
  - Ground units:
    - Negative-sequence current during normal single-phase-ground faults
    - Pure fault phase current during open-pole and phase-phase-ground faults
  - Phase units: pure fault phase-phase current

Conclusions

- The use of the ground units during simultaneous ground faults can complement the operation of the phase units, increasing the sensibility
- The system non-homogeneity can be compensated with a tilt angle
- The influence of the arc voltage on distance relays can be considered negligible
- It is important to limit the resistive reach as a function of the reactive reach

Thank you

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