Applying Dependable and Secure Protection With Quadrilateral Distance Elements

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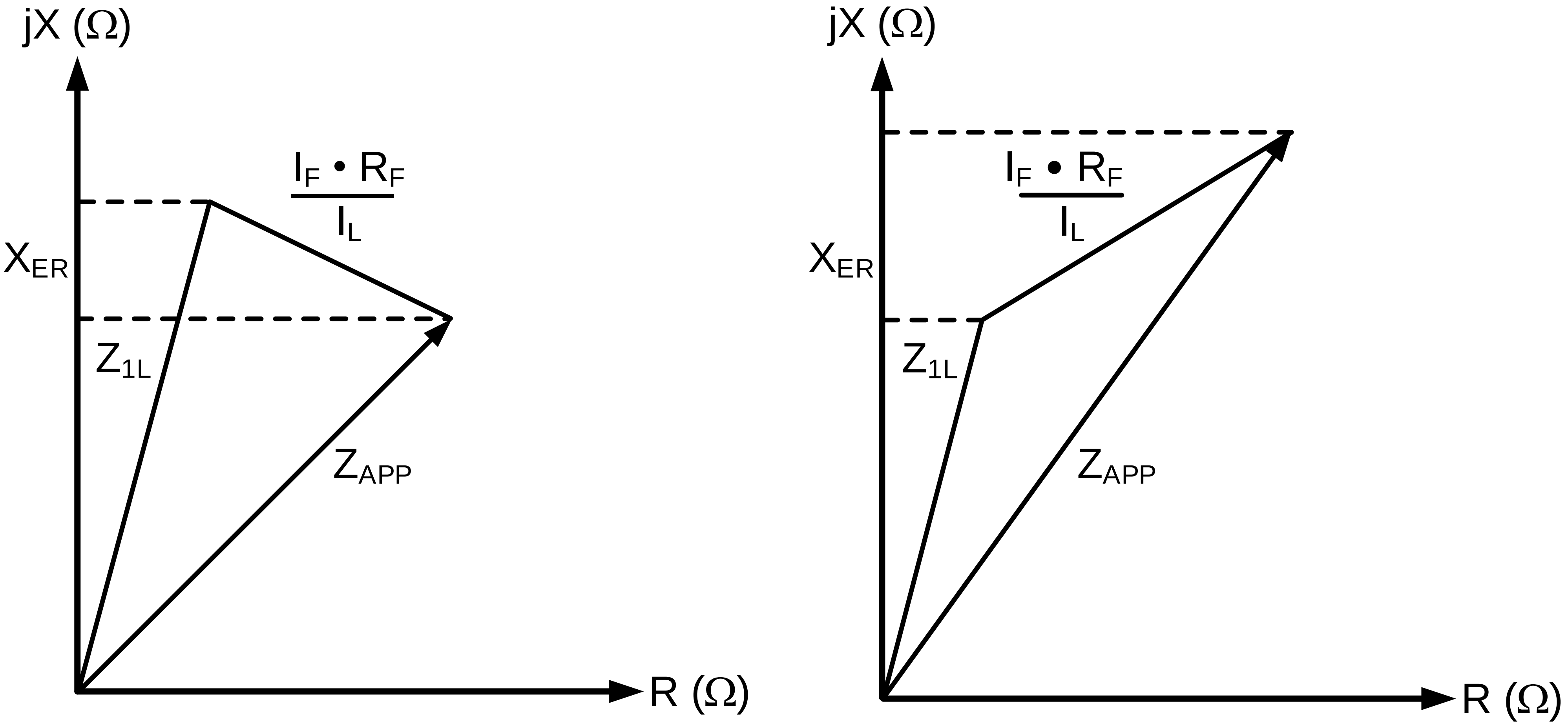
Agenda

- Factors affecting the security of reactance element
  - Nonhomogeneous network correction angle
  - VT and CT steady-state angle errors
  - Line transpositions
  - Line charging currents
  - Unbalance operating conditions
- Determining the best tilt angle and corresponding R_{SET}

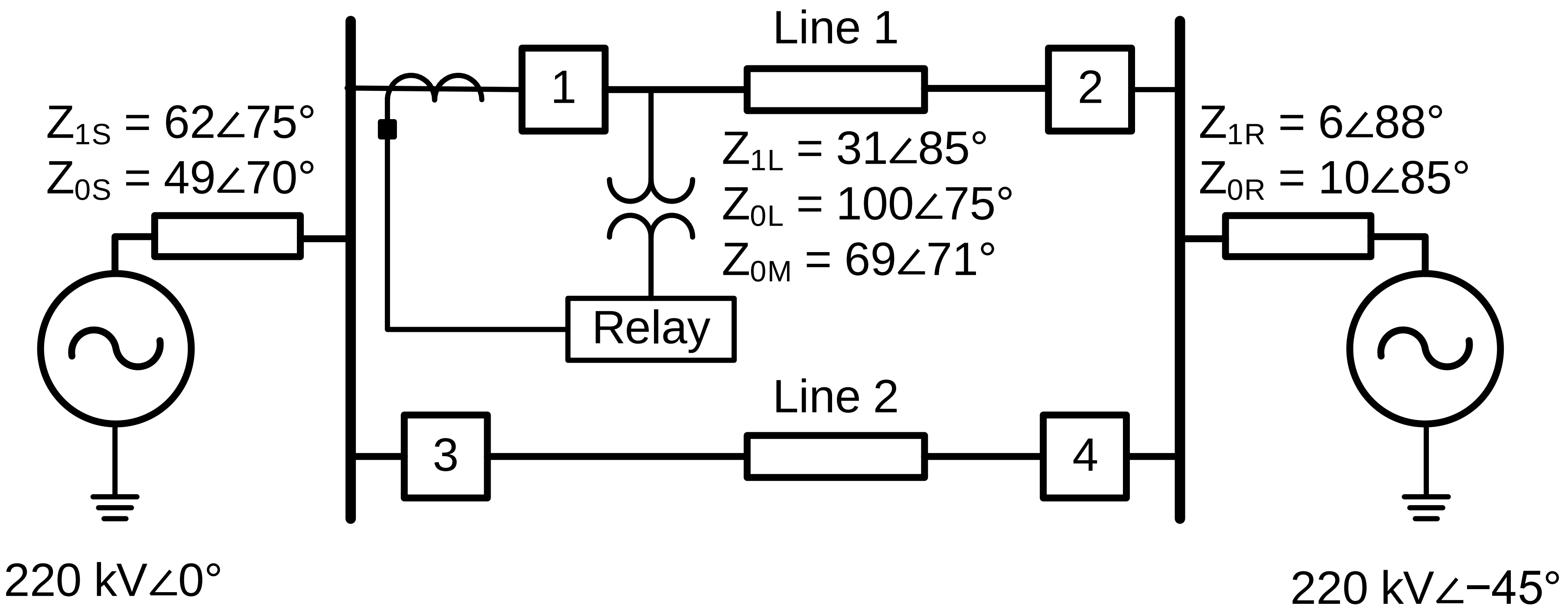
Power flow direction affects apparent impedance



Outgoing power flow

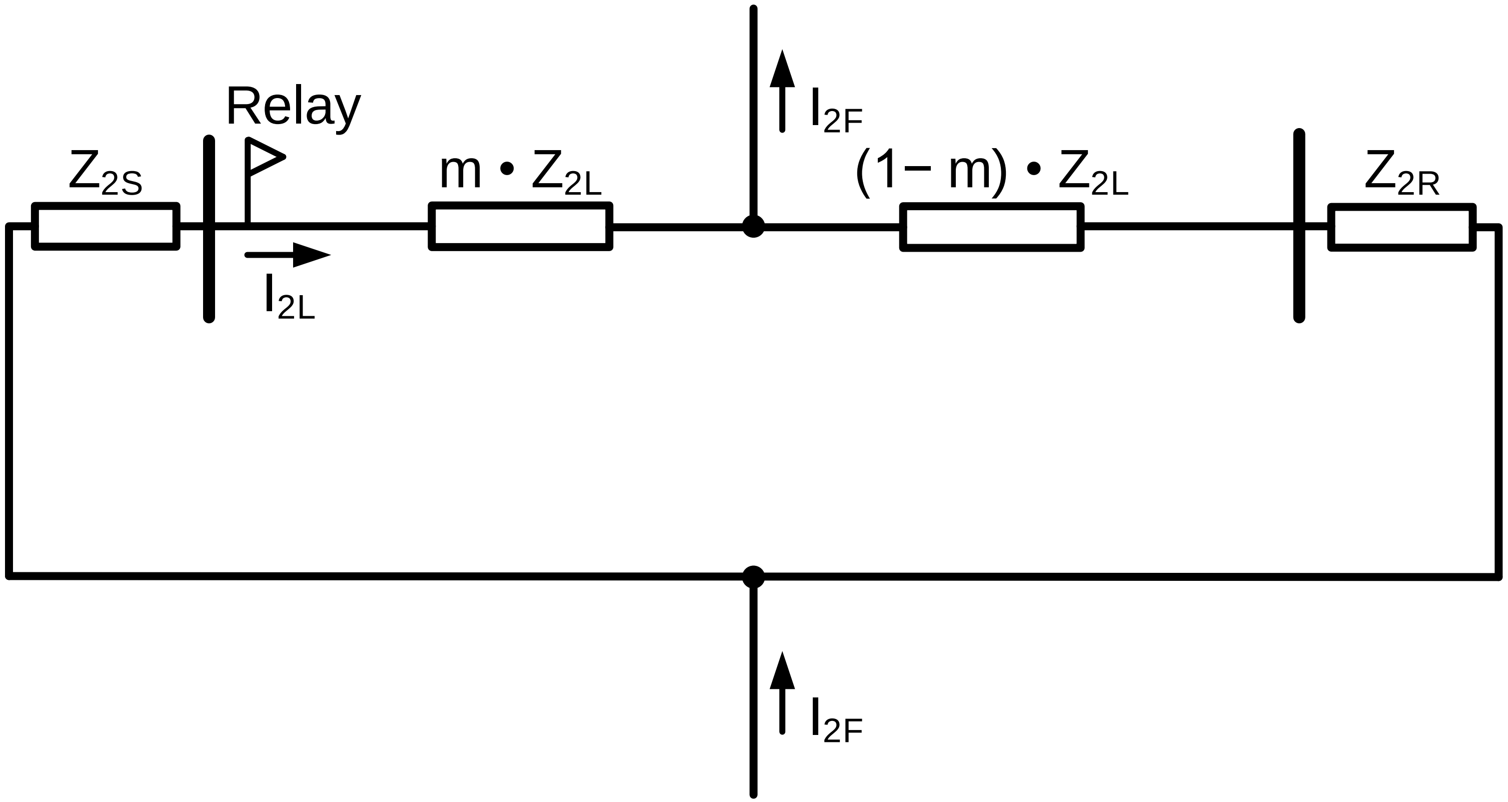
Incoming power flow

Analyzing through power system model

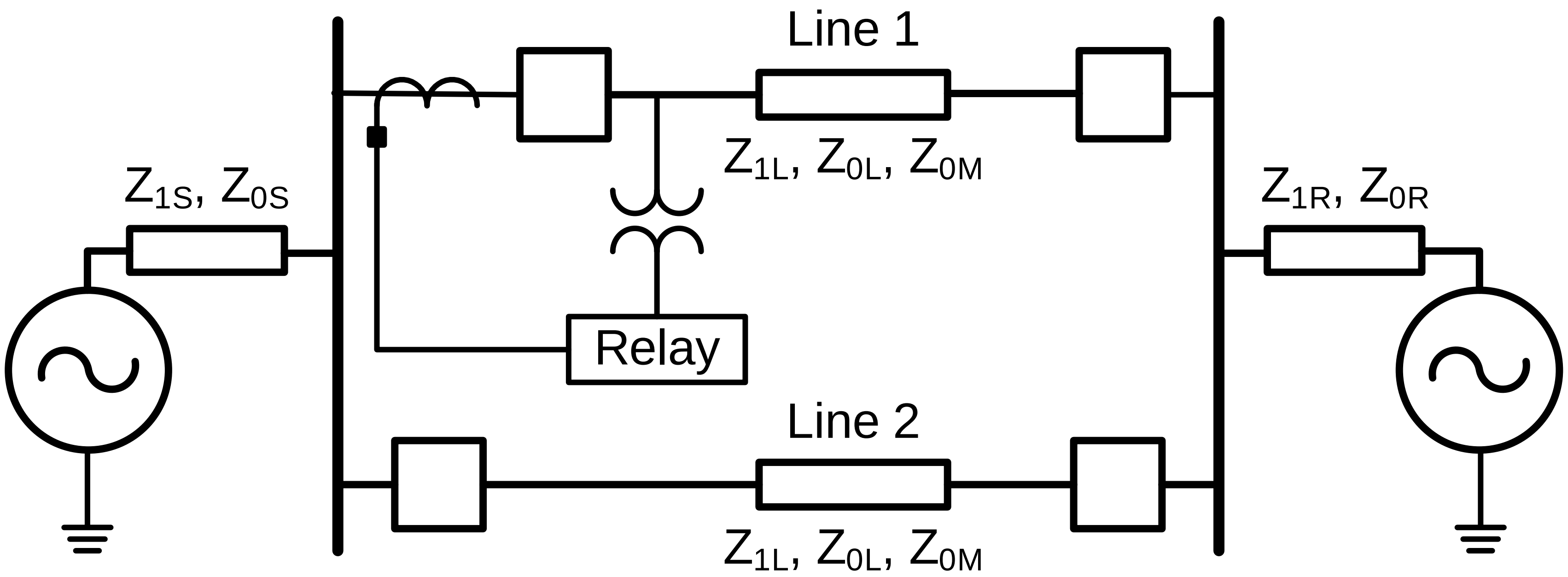


Calculating the negative-sequence nonhomogenous correction angle

$$\theta_{2\_NW\_SL} = \arg\left[\frac{Z_{2S} + Z_{2L} + Z_{2R}}{(1-m)\bullet Z_{2L} + Z_{2R}}\right]$$

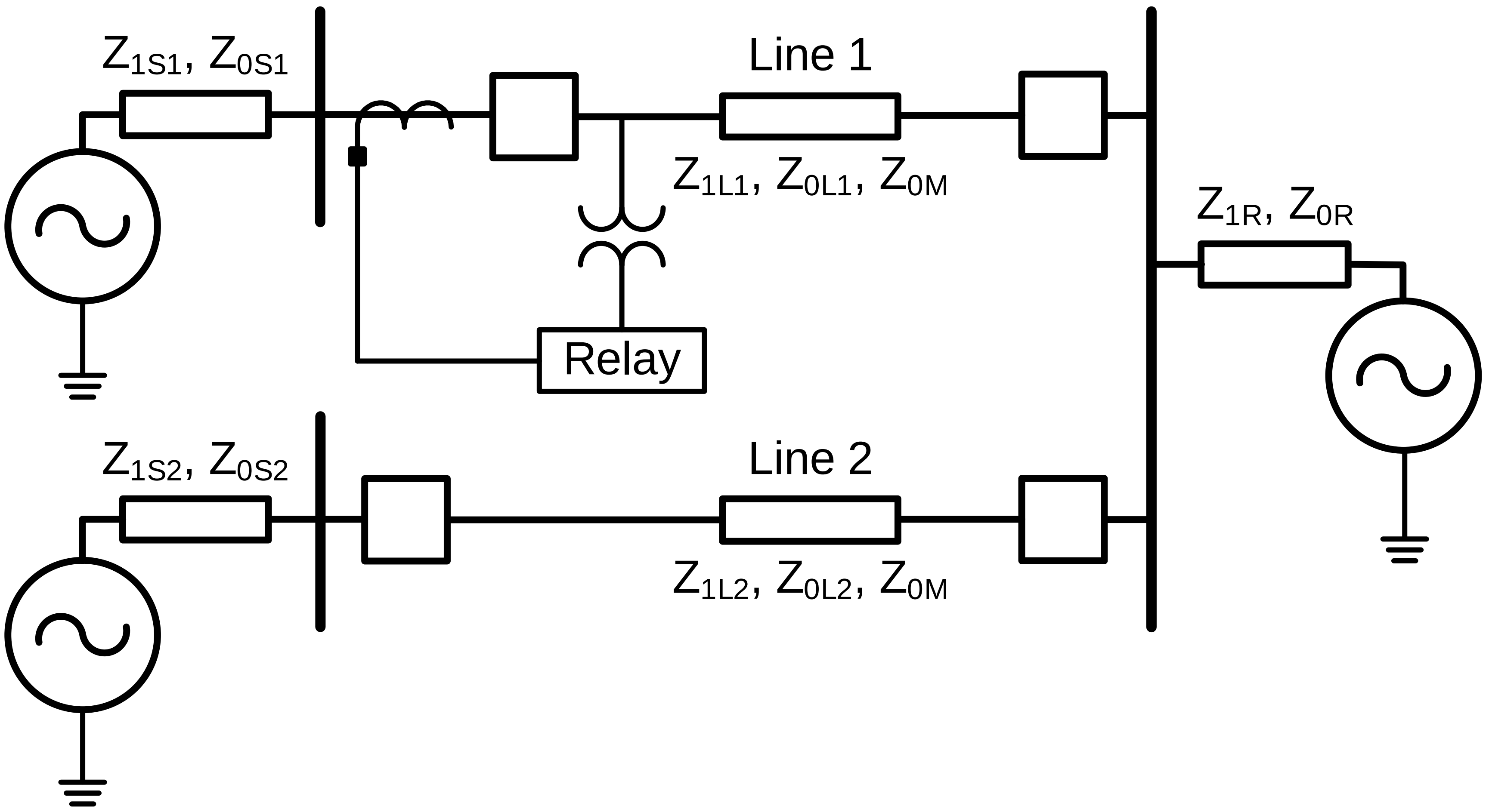


Calculating the negative-sequence nonhomogenous correction angle



$$\theta_{2\_NW\_PL} = -\arg\left[\frac{(1-m)\bullet(Z_{2S}+Z_{2L}+Z_{R})+Z_{2R}}{2\bullet\left(Z_{2S}+\frac{Z_{2L}}{2}+Z_{2R}\right)}\right]$$

Calculating the negative-sequence nonhomogenous correction angle



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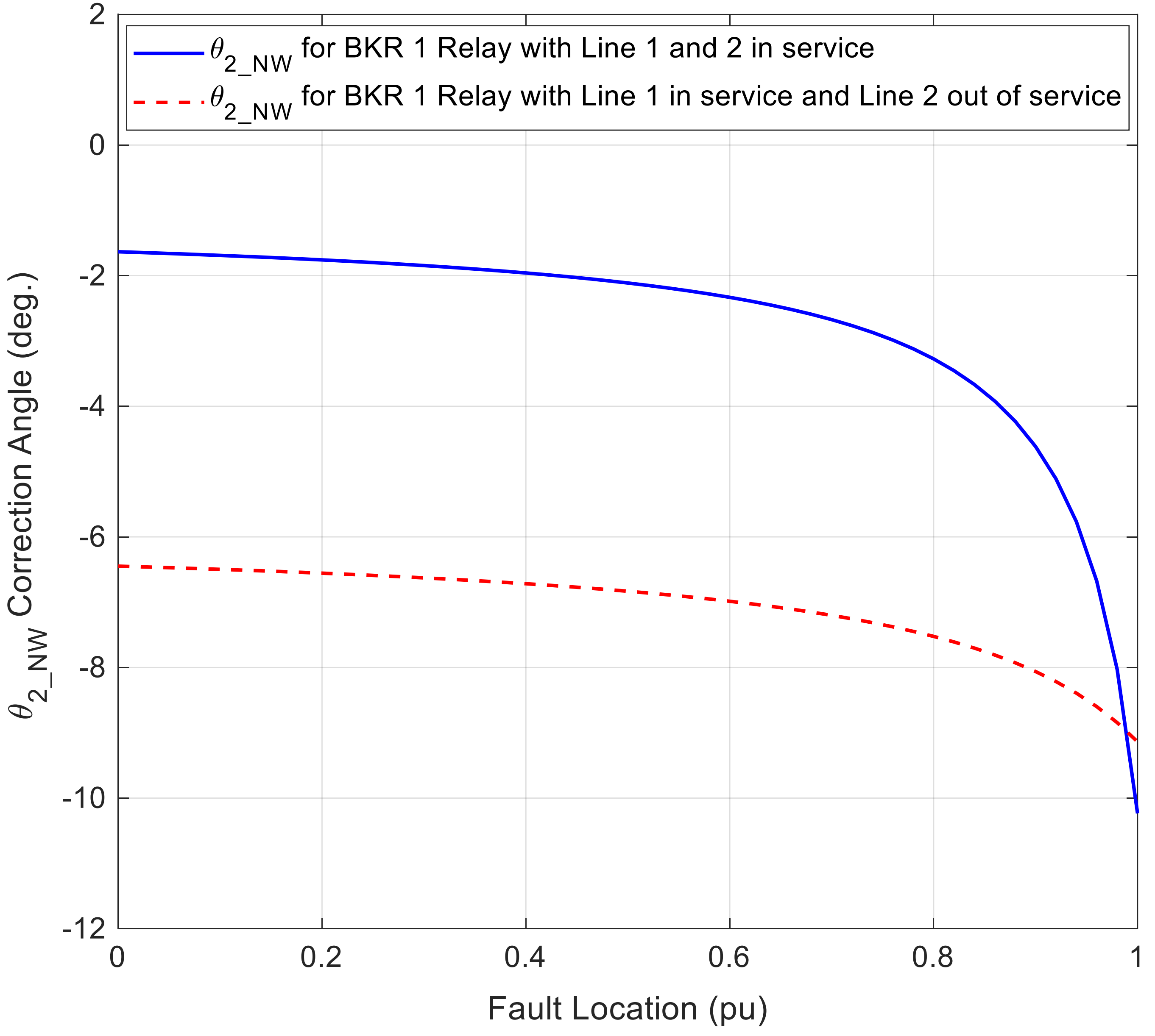
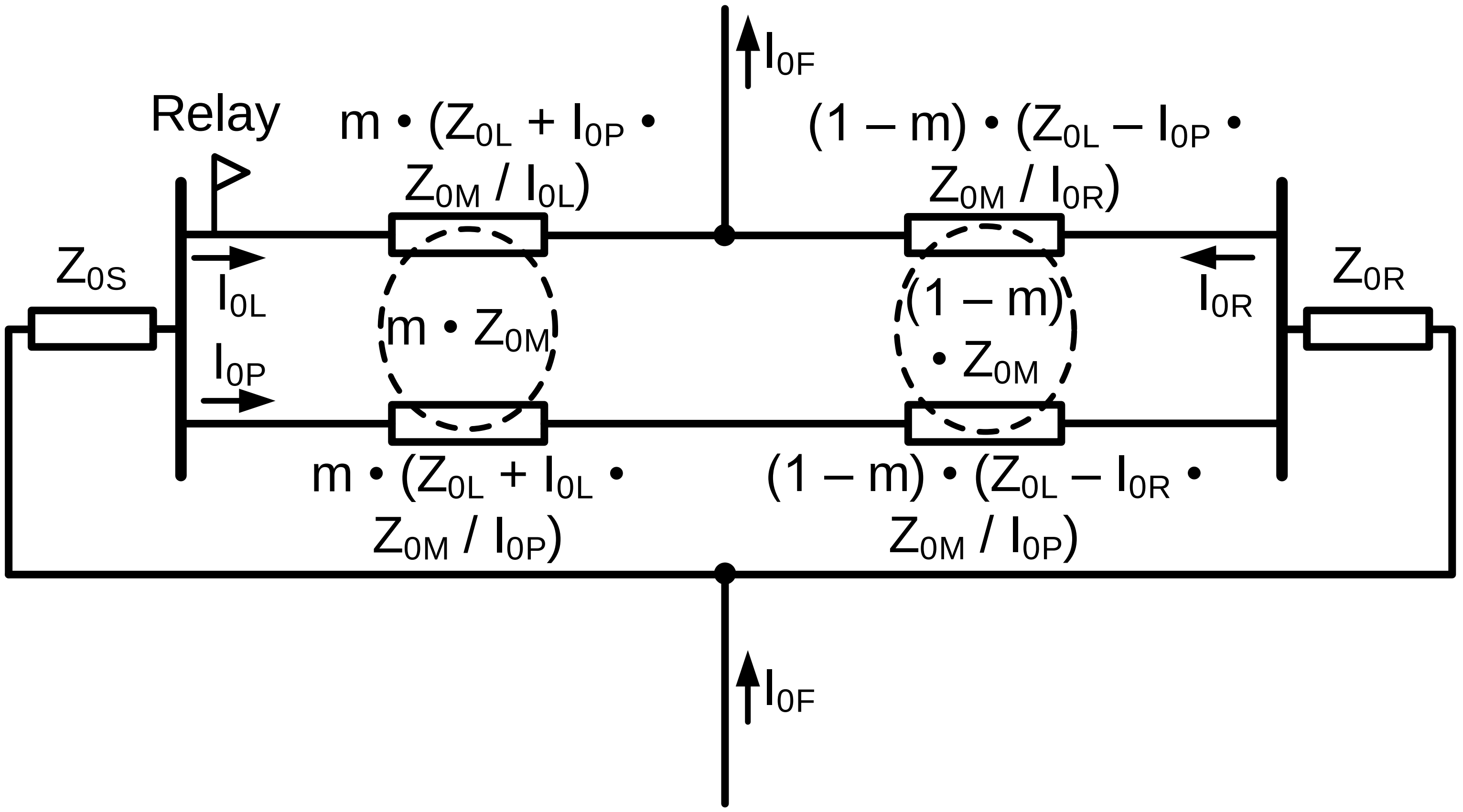
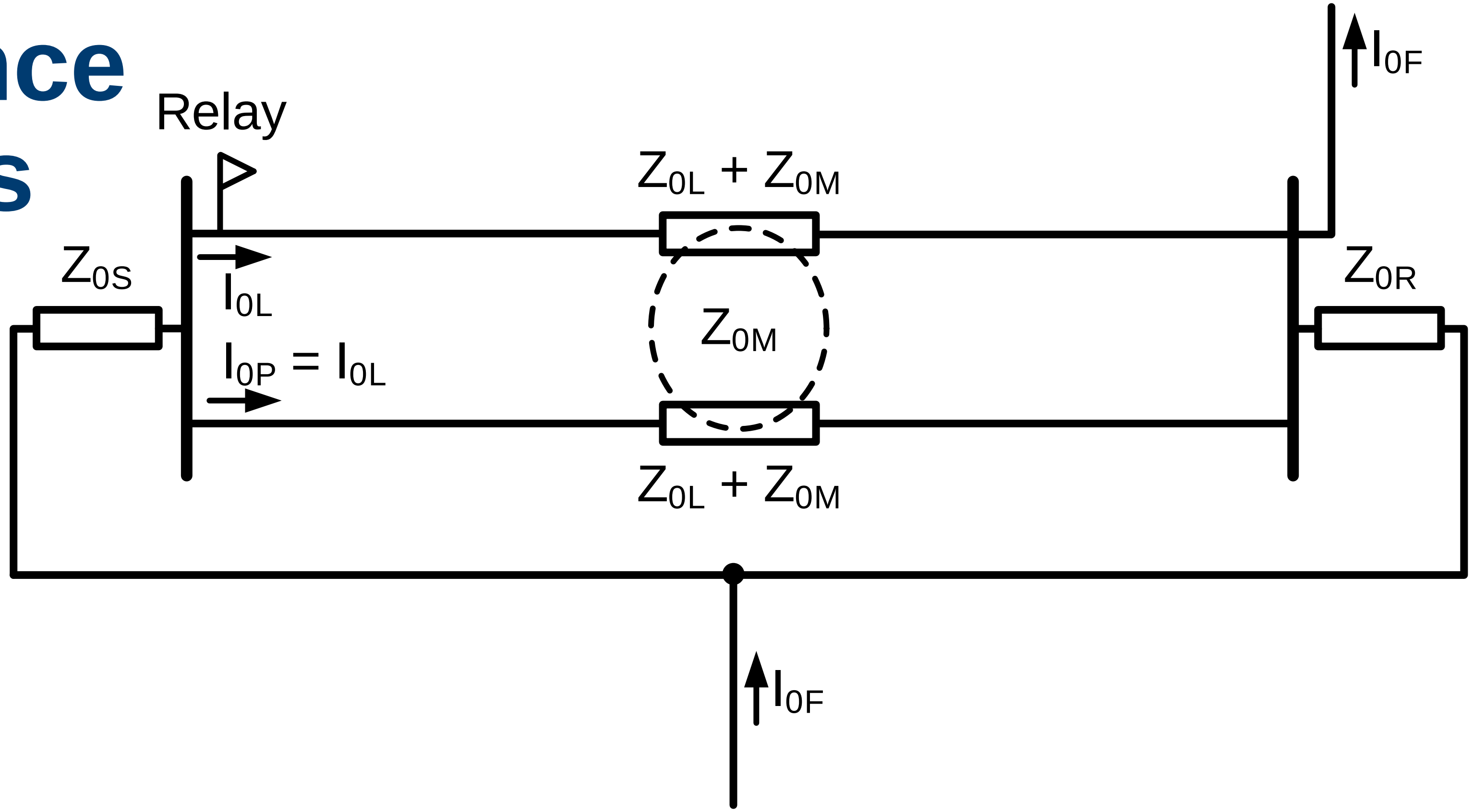


Calculating the zero-sequence nonhomogenous correction angle



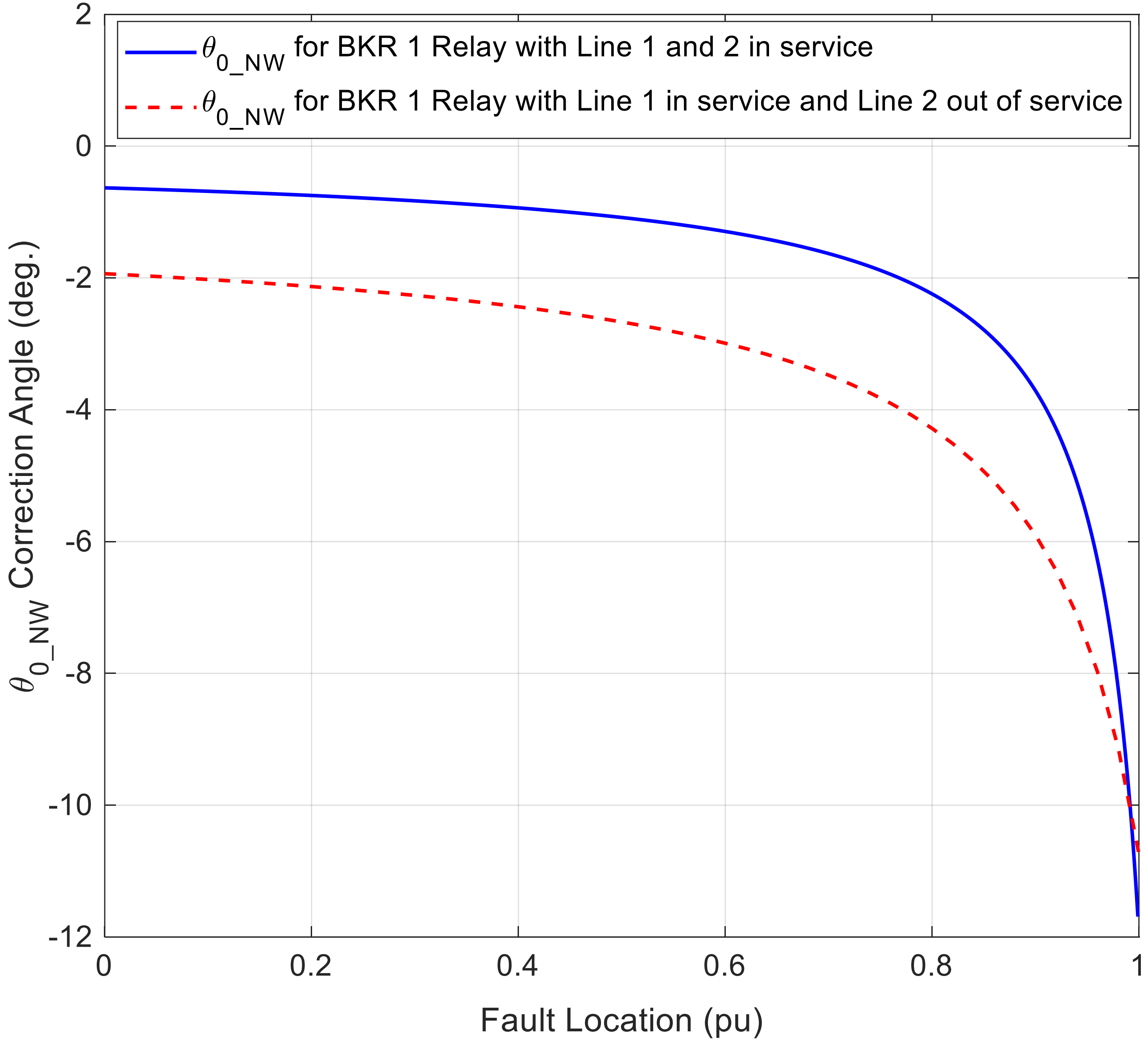
Calculating the negative-sequence nonhomogenous correction angle



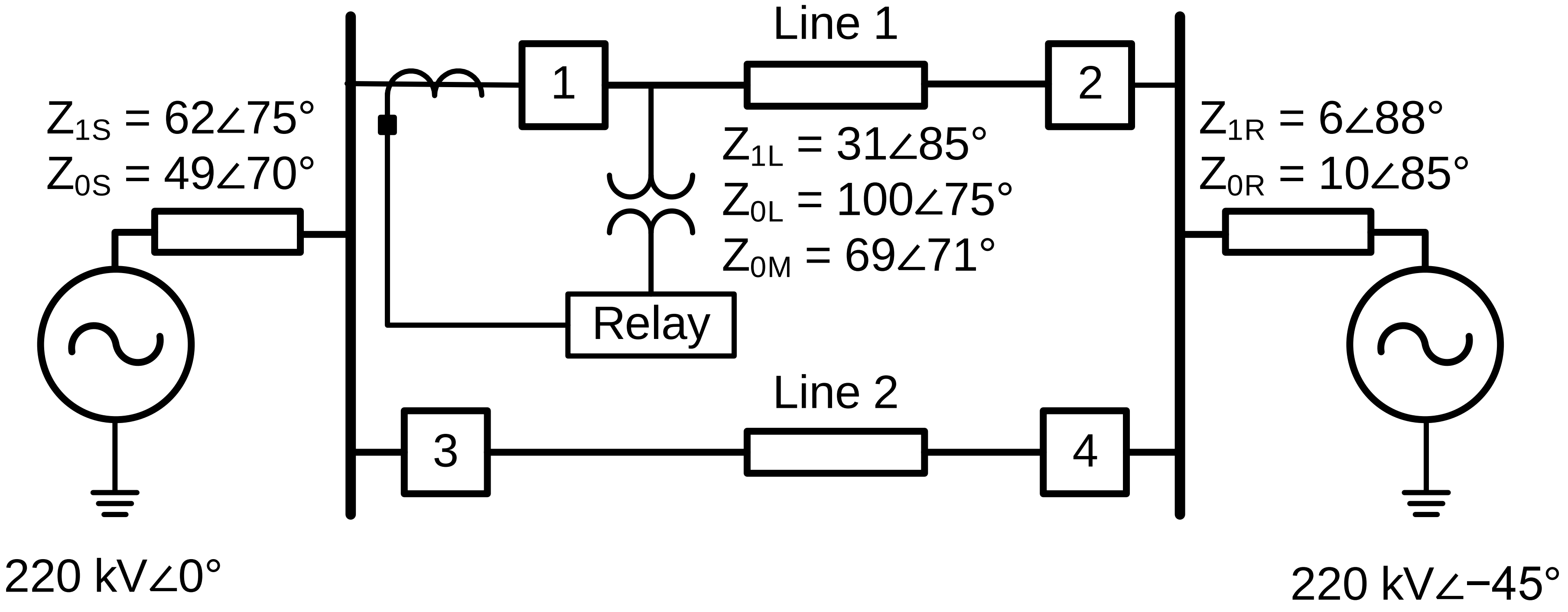
$$\theta_{0\_NW\_PL}\Big|_{m=1} = \arg\left(\frac{n \bullet \left(Z_{0S} + \frac{Z_{0L}}{n} + Z_{0R}\right) + \sum_{k=2}^{n} Z_{0M_{1,k}}}{Z_{0R}}\right)$$

$$\theta_{0\_NW\_PL'}\Big|_{m=1} = \arg\left(\frac{Z_{0S} + Z_{0L} + Z_{0R} + \sum_{k=2}^{n}\left(\frac{I_{0P_k}}{I_{0L}}\right) Z_{0M_{1,k}}}{Z_{0R}}\right)$$

Calculating the zero-sequence nonhomogenous correction angle

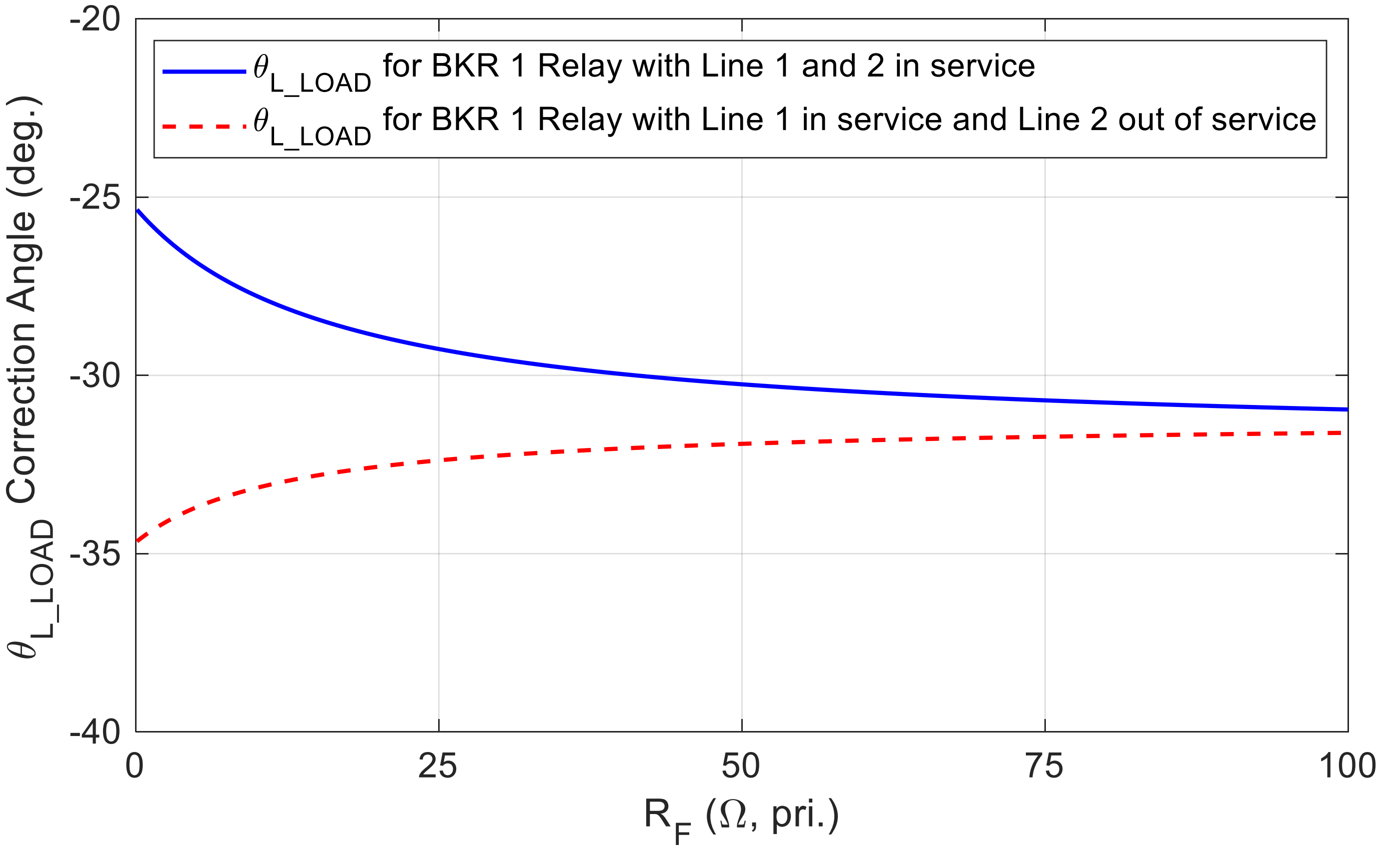


Calculating the loop correction angle

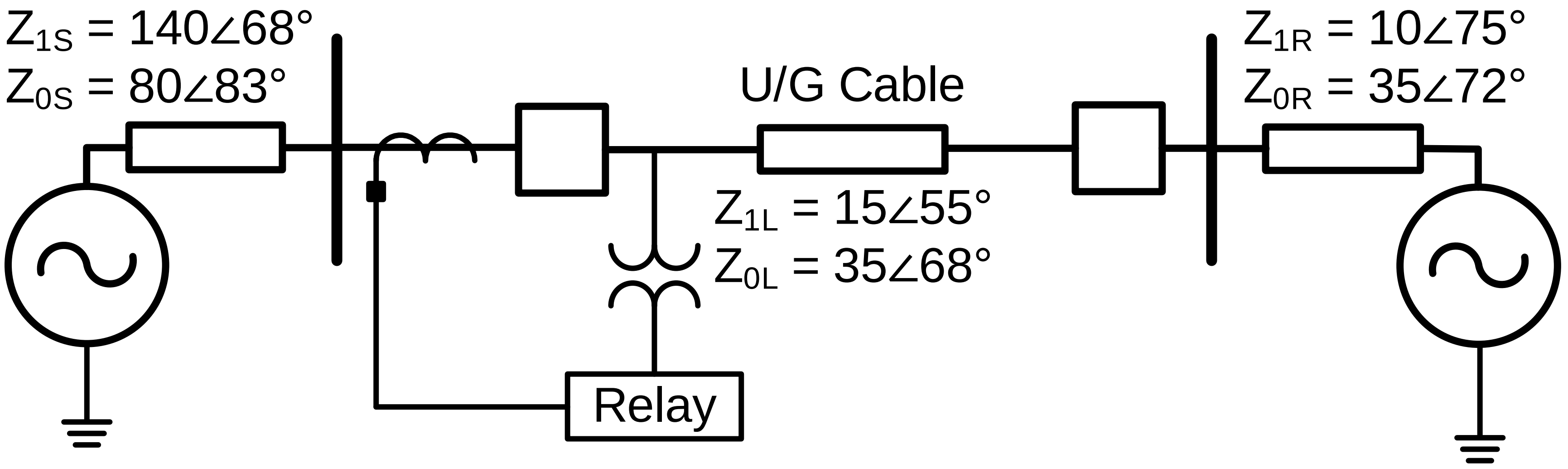


$$\theta_{L\_LOAD}\Big|_{m=1} = \min\left[\arg\left(\frac{I_F}{I_L}\right) \quad \forall \quad 1 \le R_F < 100\right]$$

Calculating the loop correction angle



Calculating the nonhomogenous correction angle for lines with low-impedance angle



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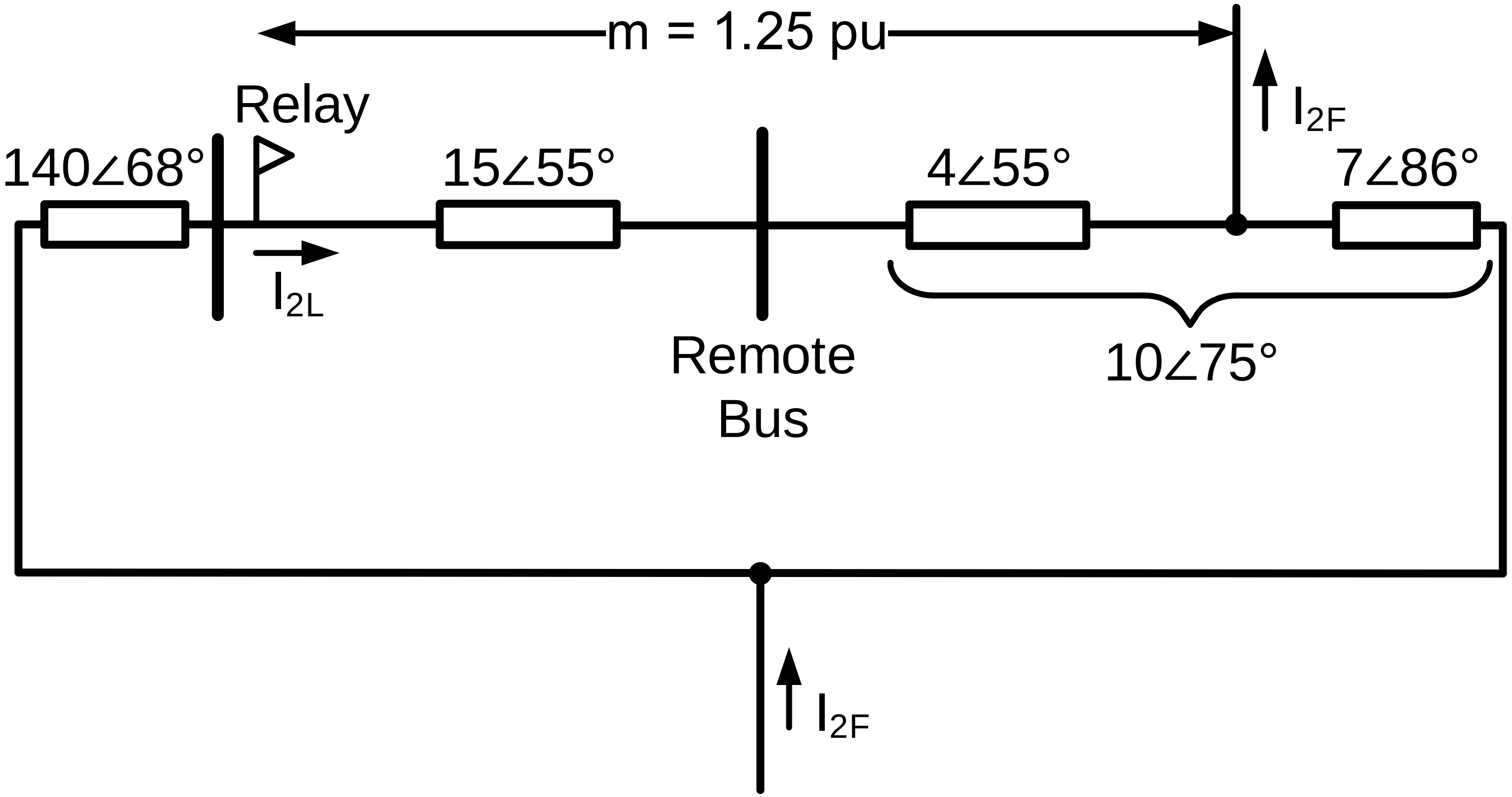
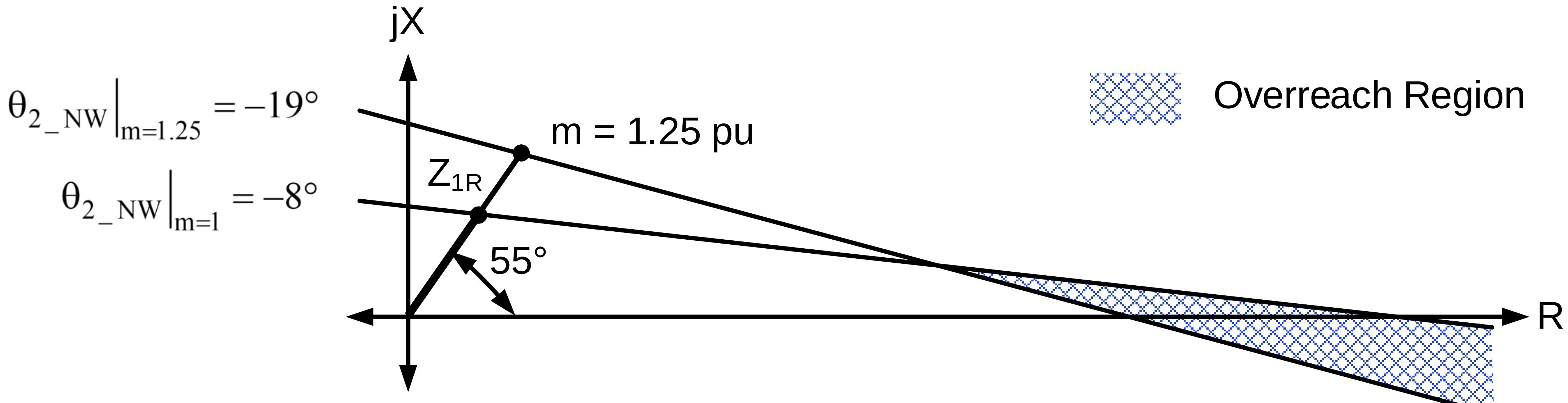


$$\theta_{2\_NW}\Big|_{m=1} = -8°$$

$$\theta_{2\_NW}\Big|_{m=1.25} = -19°$$

Calculating the nonhomogenous correction angle for lines with low-impedance angle



VT and CT steady-state error affects polarizing current angle

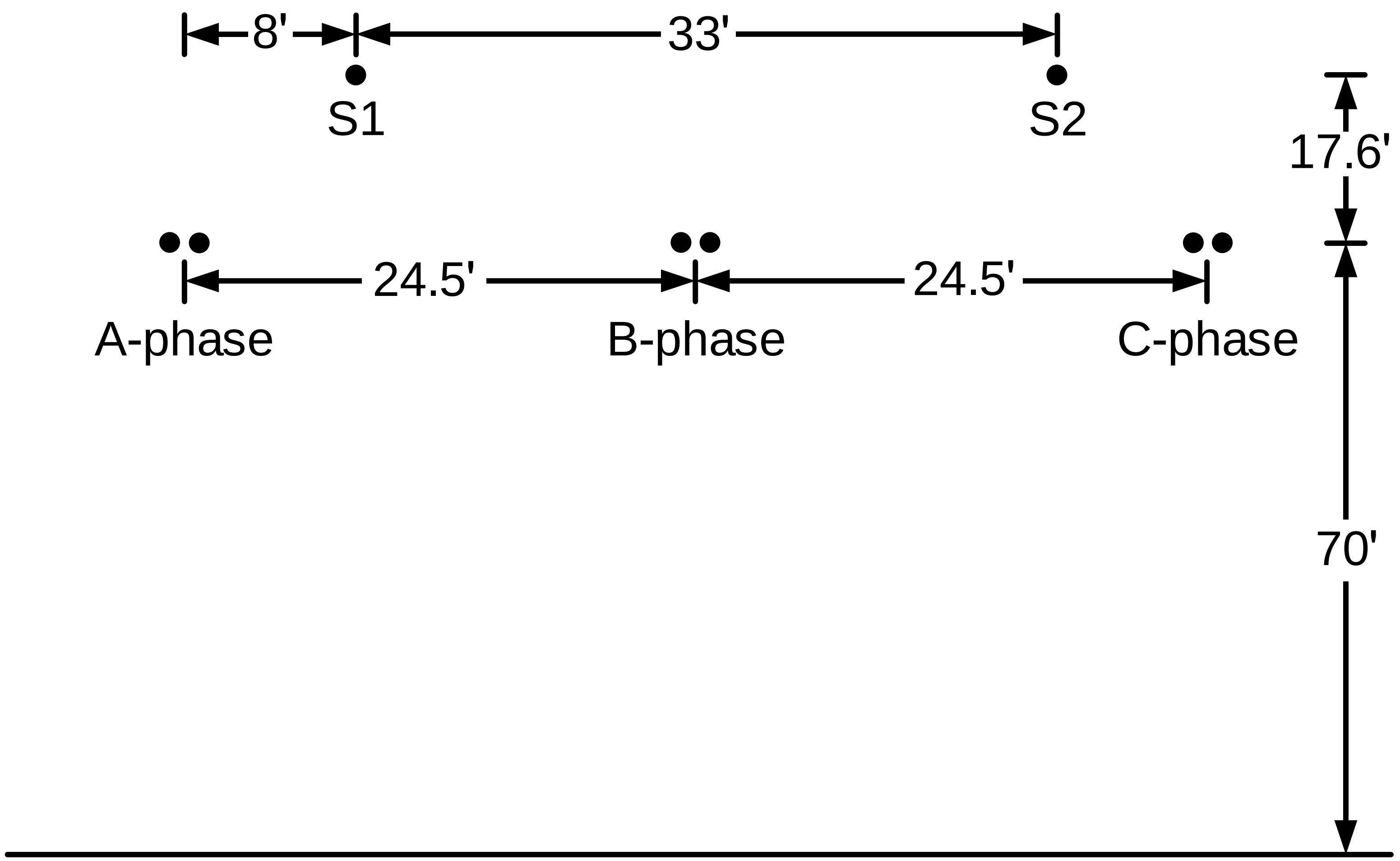
$$\Psi_{m\_IT\_ANG} \approx \cot\left(\theta_V - \theta_{I_F}\right) \bullet \left(\theta_{V\_ERR} - \theta_{I_{POL\_ERR}}\right)$$

	Ideal Phasors	Phasors With Angle Errors	θ_{IPOL_ERR}
Phase Currents	$I_A = 720\angle{-49}°$	$I_A' = 720\angle{-47}°$	–
	$I_B = 574\angle{-112}°$	$I_B' = 574\angle{-110}°$	–
	$I_C = 590\angle 126°$	$I_C' = 590\angle 124°$	–
Corresponding Polarizing Quantities	$3 \bullet I_2 = 642\angle{-101}°$	$3 \bullet I_2' = 632\angle{-103}°$	−2°
	$3 \bullet I_0 = 605\angle{-99}°$	$3 \bullet I_0' = 578\angle{-94}°$	5°
	$I_L = 1006\angle{-73}°$	$I_L' = 1004\angle{-69}°$	4°

Line charging current affects polarizing current angle

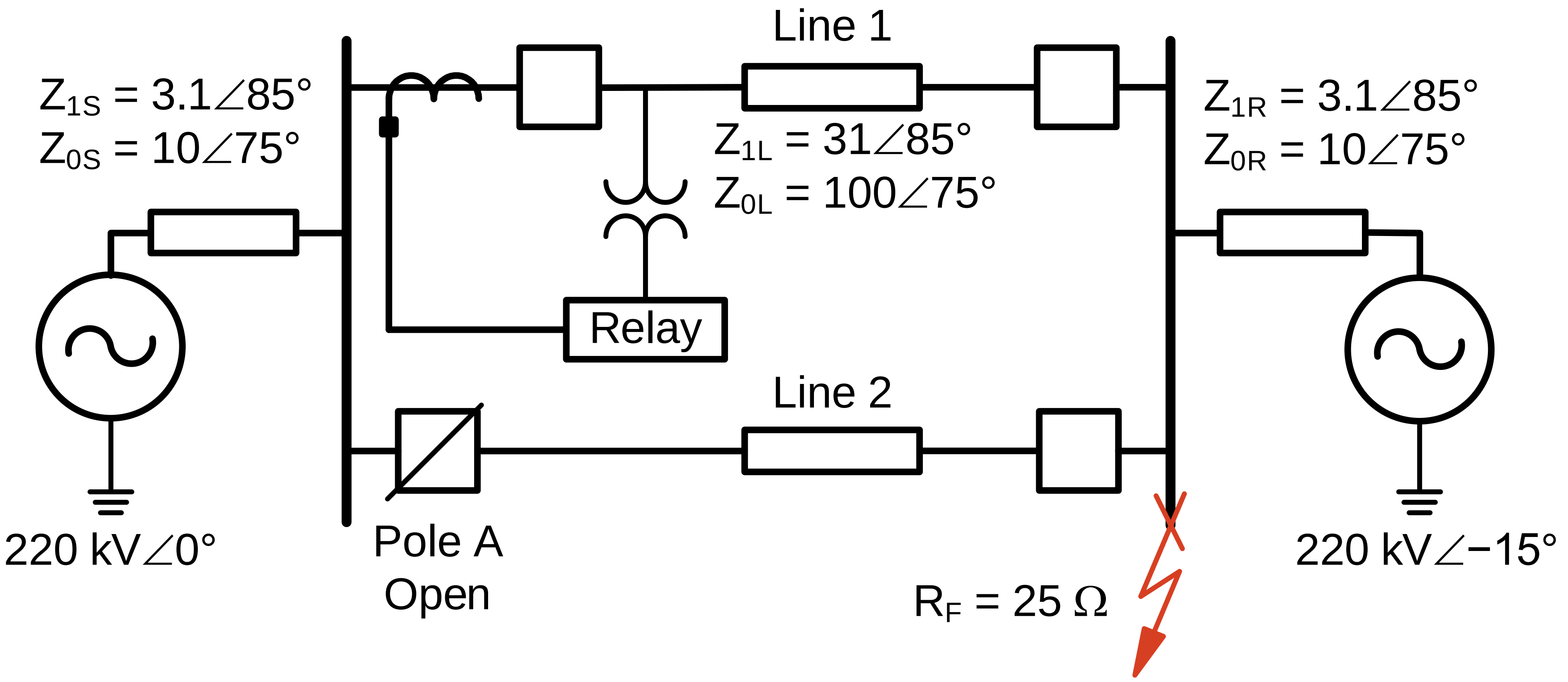
Polarizing Quantity Angle With Respect to Total Fault Current Angle	With Line Capacitance (1)	Without Line Capacitance (2)	(1) − (2)
$\angle 3 \cdot I_2 - \angle I_F$	8.6°	9.1°	−0.5°
$\angle 3 \cdot I_0 - \angle I_F$	10.4°	10.8°	−0.4°
$\angle I_L - \angle I_F$	36.8°	35.8°	1°

Line transposition affects polarizing current angle



Fault	Angle Error, in Degrees, for		
	I_{2_UT}	I_{0_UT}	I_{L_UT}
AG (outgoing power)	1.1	−0.1	0.5
BG (outgoing power)	2.3	−0.8	0.1
CG (outgoing power)	−3.5	0	−0.6
AG (incoming power)	2.3	−0.5	0.2
BG (incoming power)	−2.3	−0.2	−0.2
CG (incoming power)	−0.5	−0.5	0.0

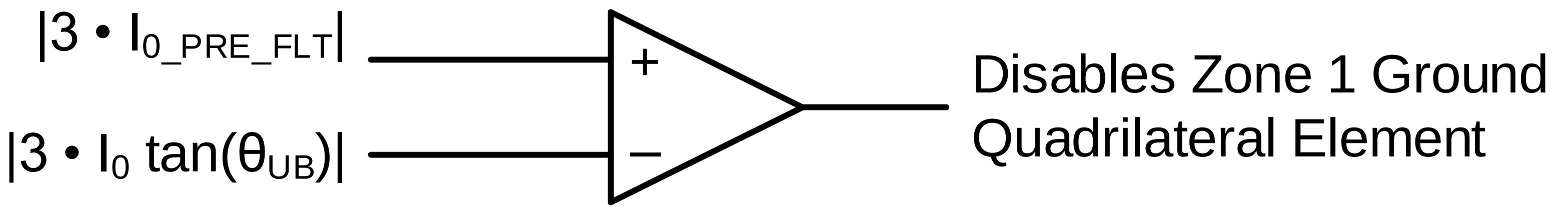
Unbalance operating condition affects polarizing current angle



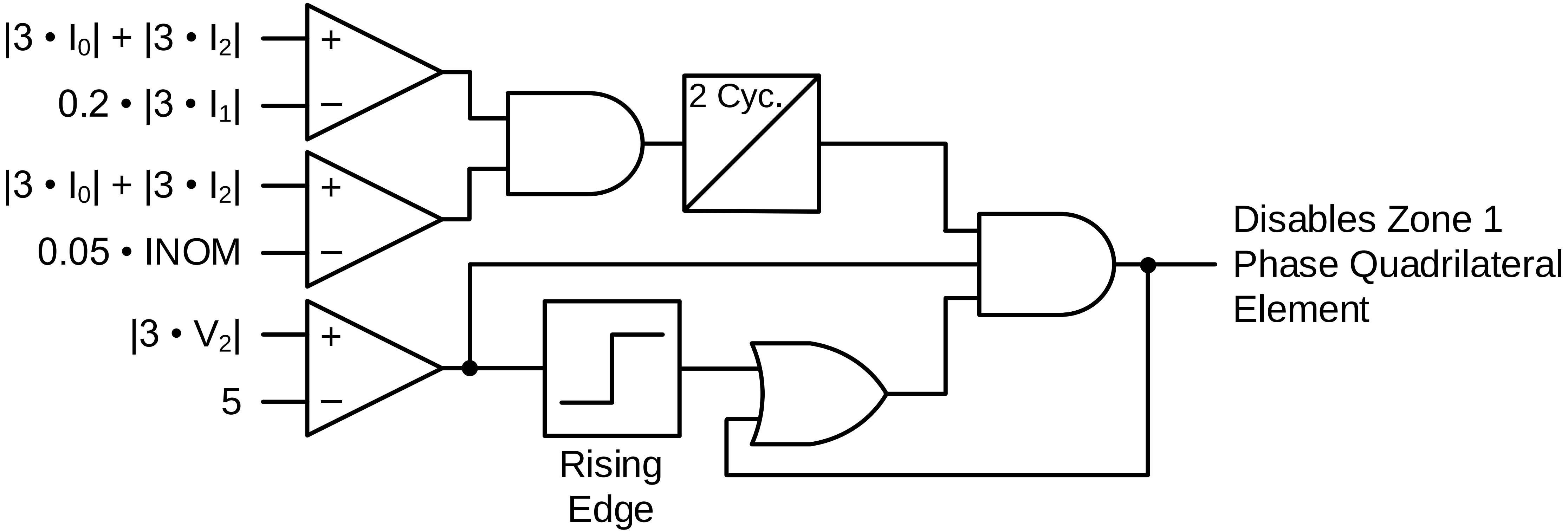
Unbalance operating condition affects polarizing current angle

Phasor	Magnitude (A Primary)	Angle (Deg.)	Overreach (pu) in the Corresponding Reactance Element
$3 \cdot I_{0\_UB}$	69	35	–
$3 \cdot I_{2\_UB}$	223	25	–
I_{L_UB}	821	26	–
$3 \cdot I_{2\_FLT}$	888	7	0.23
$3 \cdot I_{0\_FLT}$	615	5	0.17
I_{L_FLT} (with −7° tilt)	1793	3	0.10
I_{FLT}	4507	0	–

Unbalance operating condition affects polarizing current angle



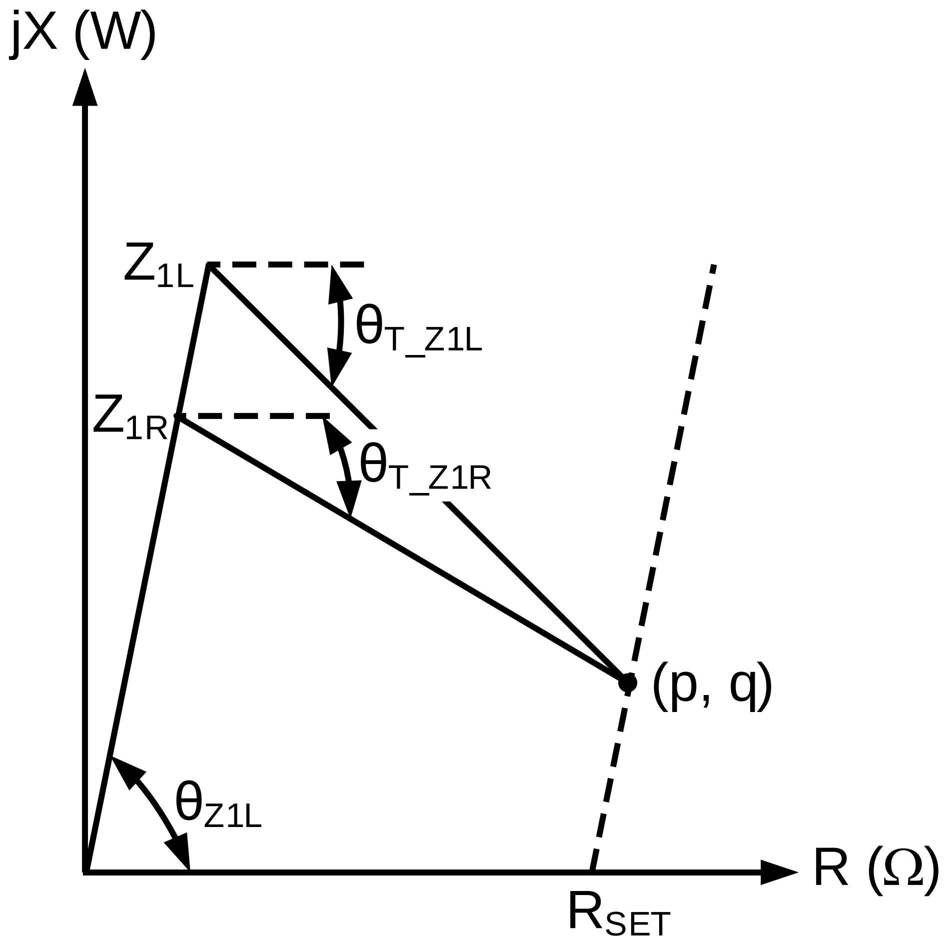
Unbalance operating condition affects polarizing current angle



Compensating for factors affecting polarizing current angle

Factors Affecting Polarizing Current Angle	Tilt Angle Compensation for Reactance Elements Polarized With		
	Negative-Sequence Current	**Zero-Sequence Current**	**Loop Current**
Network nonhomogeneity	−10°	−12°	NA
Load	NA	NA	−34°
VT and CT (steady-state angle errors)	−7°	−7°	−7°
Line charging current	−0°	−0°	−1°
Untransposed line	−2°	−1°	0°
Unbalanced operating conditions	0°	0°	0°
Total Tilt	**−19°**	**−20°**	**−42°**

Determining the best tilt angle corresponding to R_{SET}



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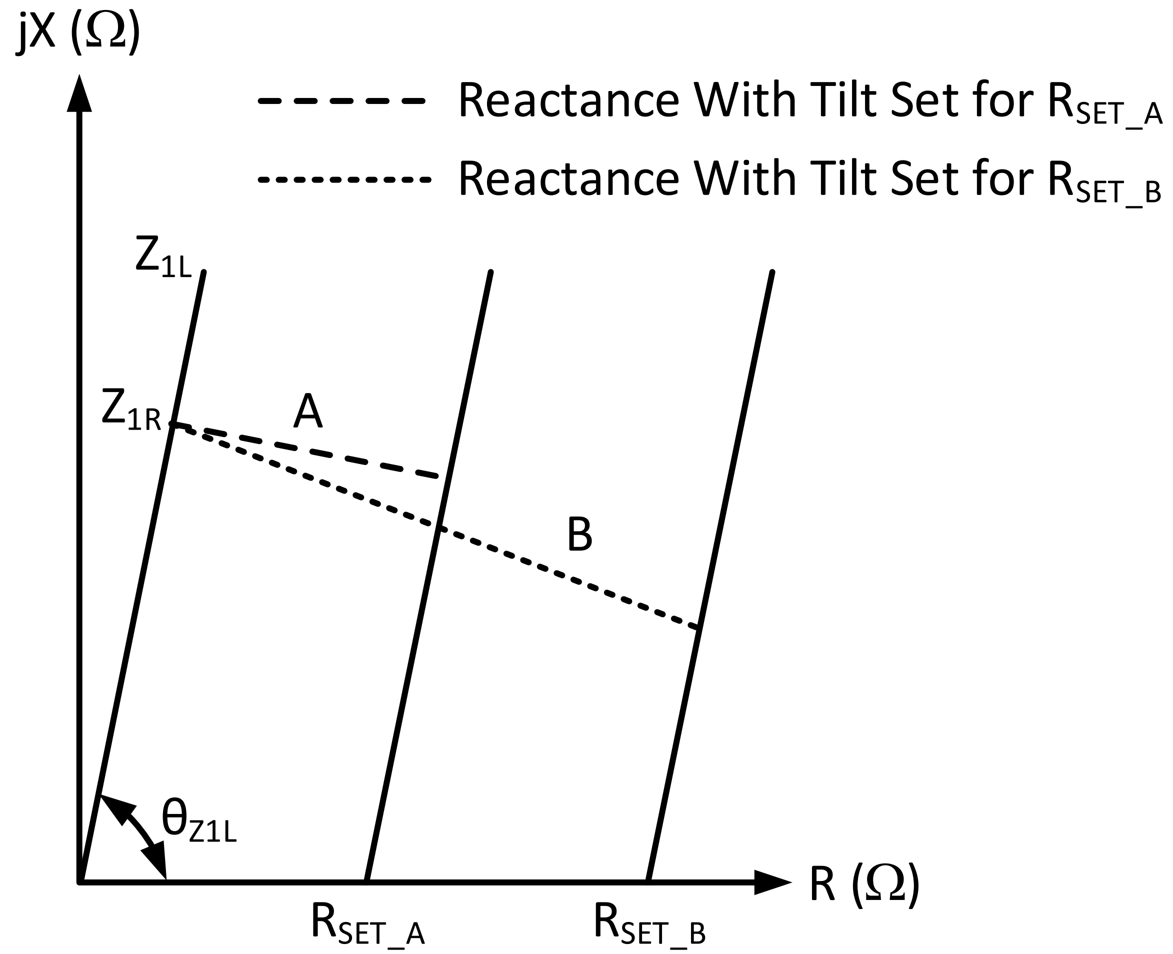

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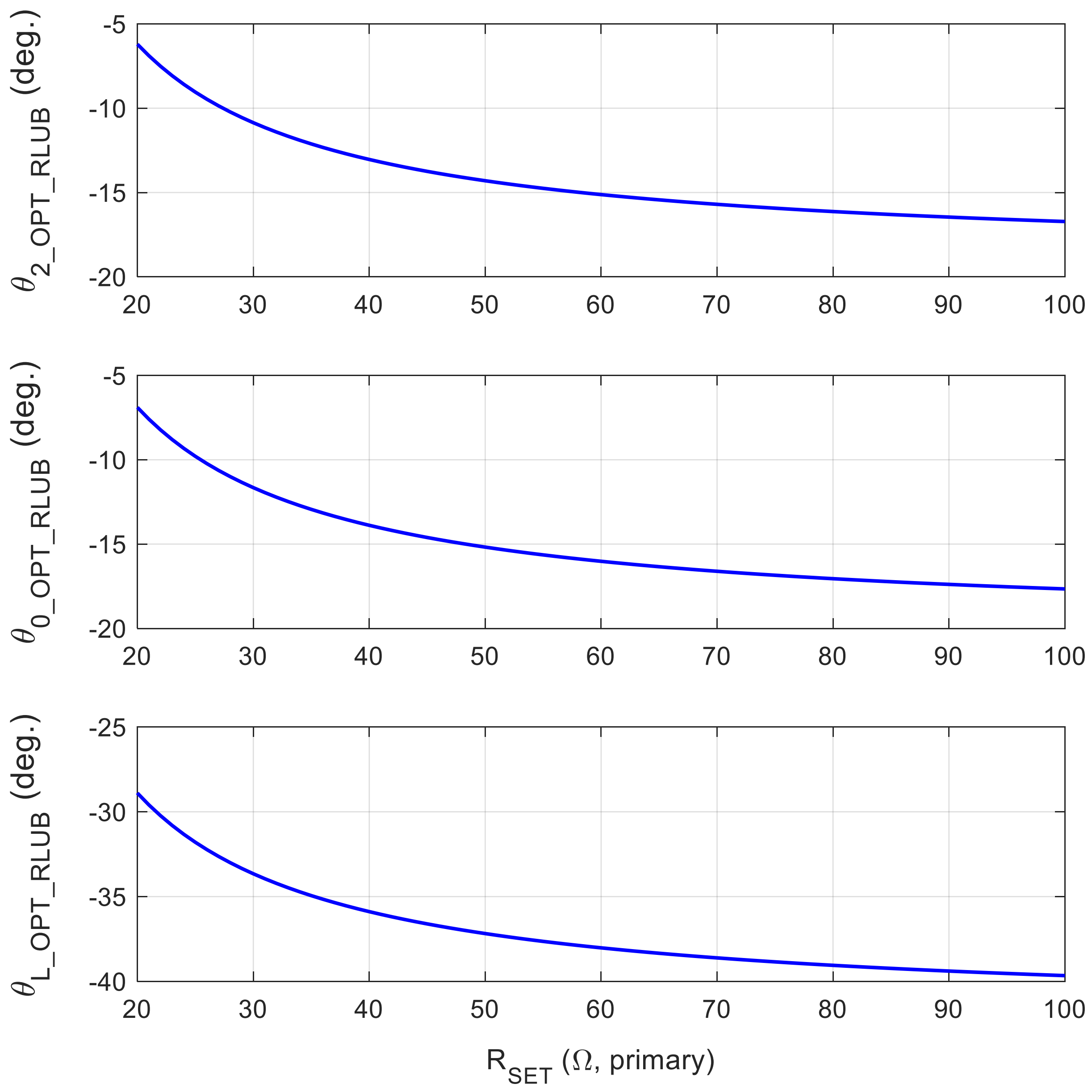

Conclusions

- Factors that have significant effect on polarizing current angle
  - Nonhomogeneous network correction angle
  - VT and CT steady-state angle errors
  - Unbalance operating conditions
- Determining best tilt angle and corresponding R_{SET}

Questions?