Sizing Current Transformers for Line Protection Applications

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Outline

- CT basics
- Effects of CT saturation on protection elements
- Advances in modern protection designs
- Tools for CT sizing

CT Basics

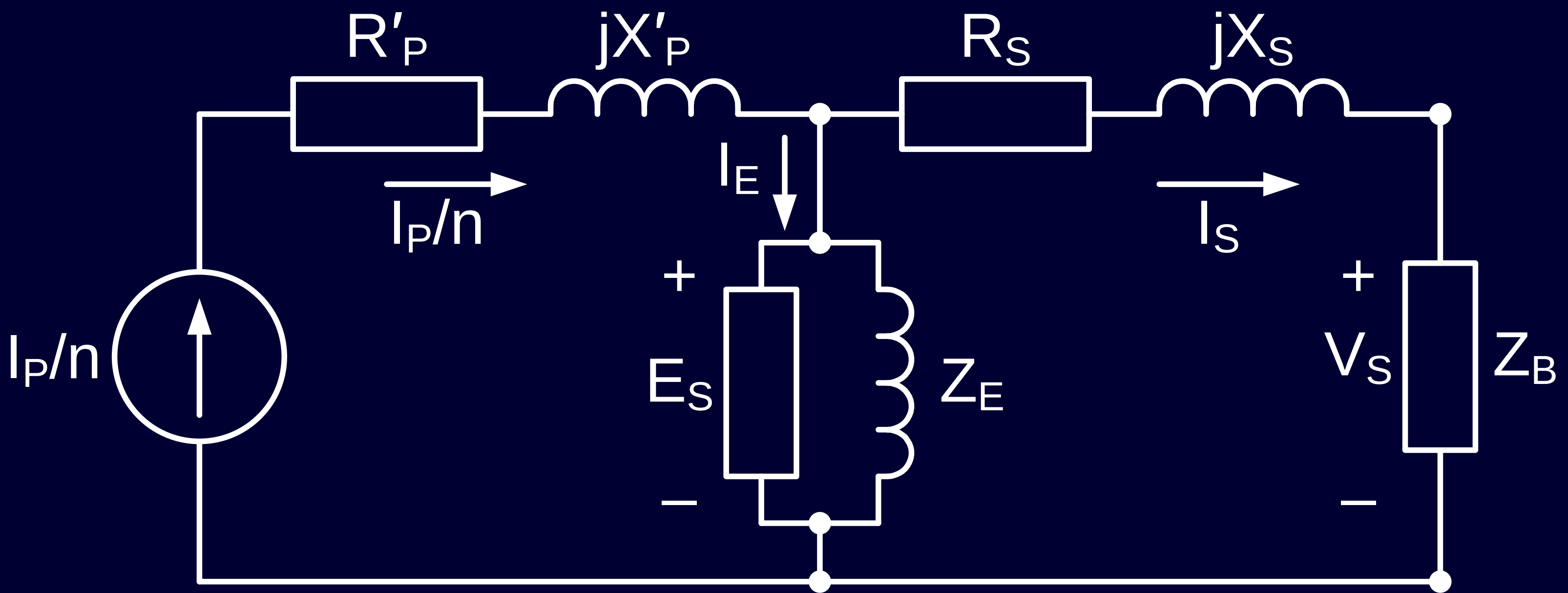
Ideal CT Behavior

$$I_P n_P = I_S n_S$$

$$I_S = \frac{n_P}{n_S} I_P = \frac{I_P}{n_S / n_P} = \frac{I_P}{n}$$

$$I_S(pu) = I_P(pu)$$

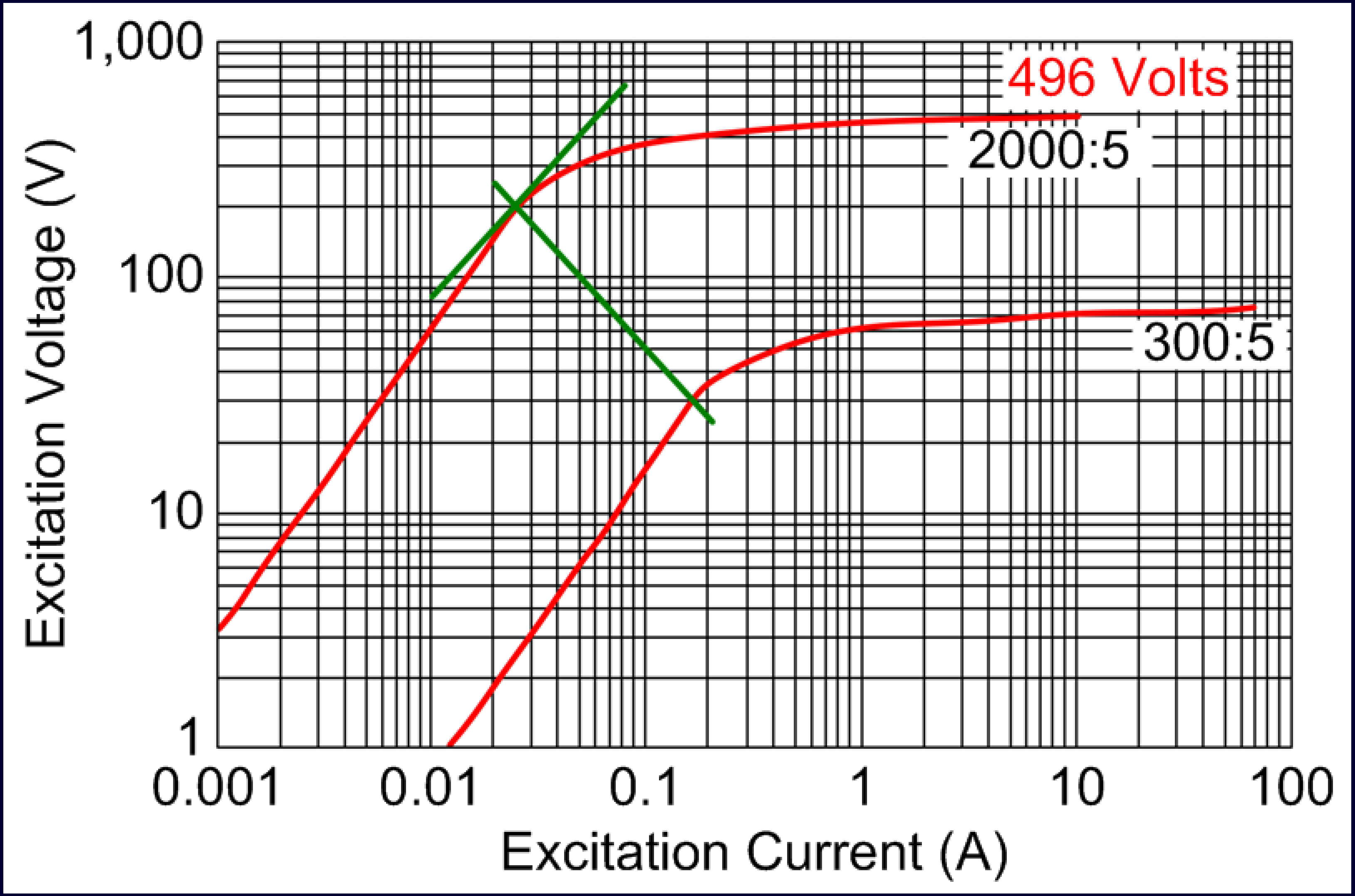
Real CT Behavior



$$I_S = \frac{I_P}{n} - I_E$$

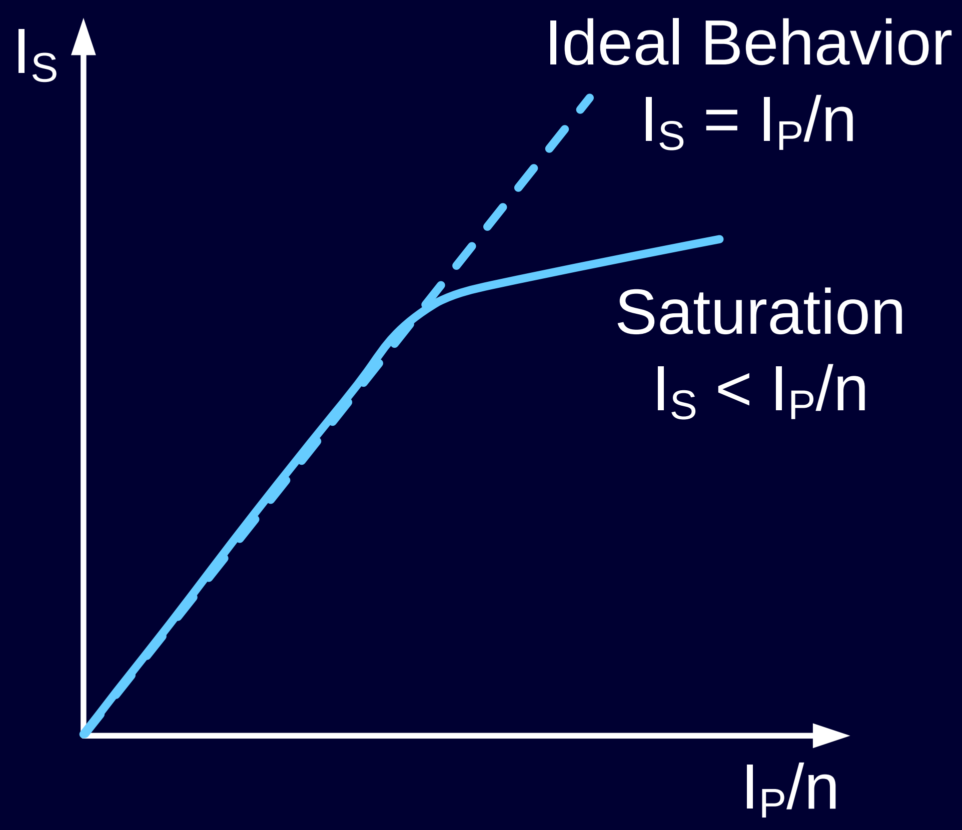
$$V_S = I_S Z_B = E_S - I_S(R_S + jX_S)$$

Typical Excitation Characteristic for Multiratio CT

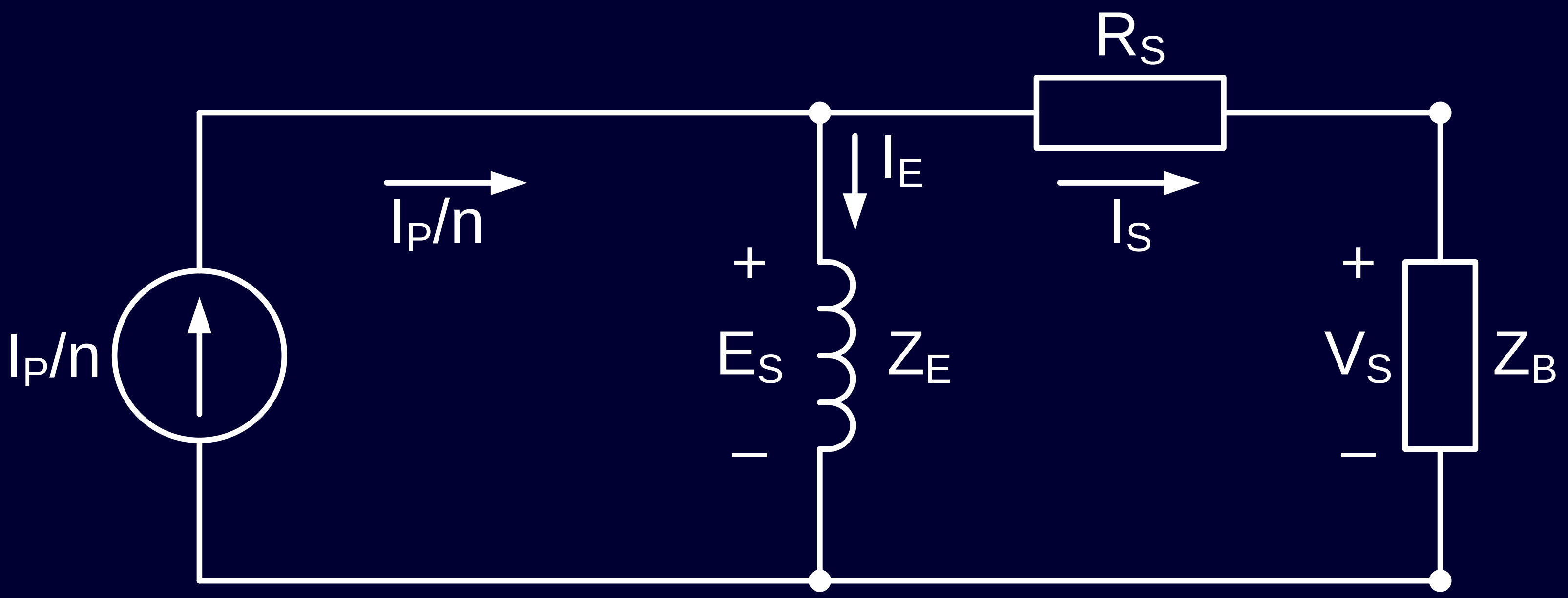


CT Errors

$$\text{Ratio error (\%)} = \frac{I_E}{I_S} \bullet 100$$



Class C and Class K CT Equivalent Circuit



$$V_{STD} = 20\ I_{S\ RATED}\ Z_{B\ STD}$$

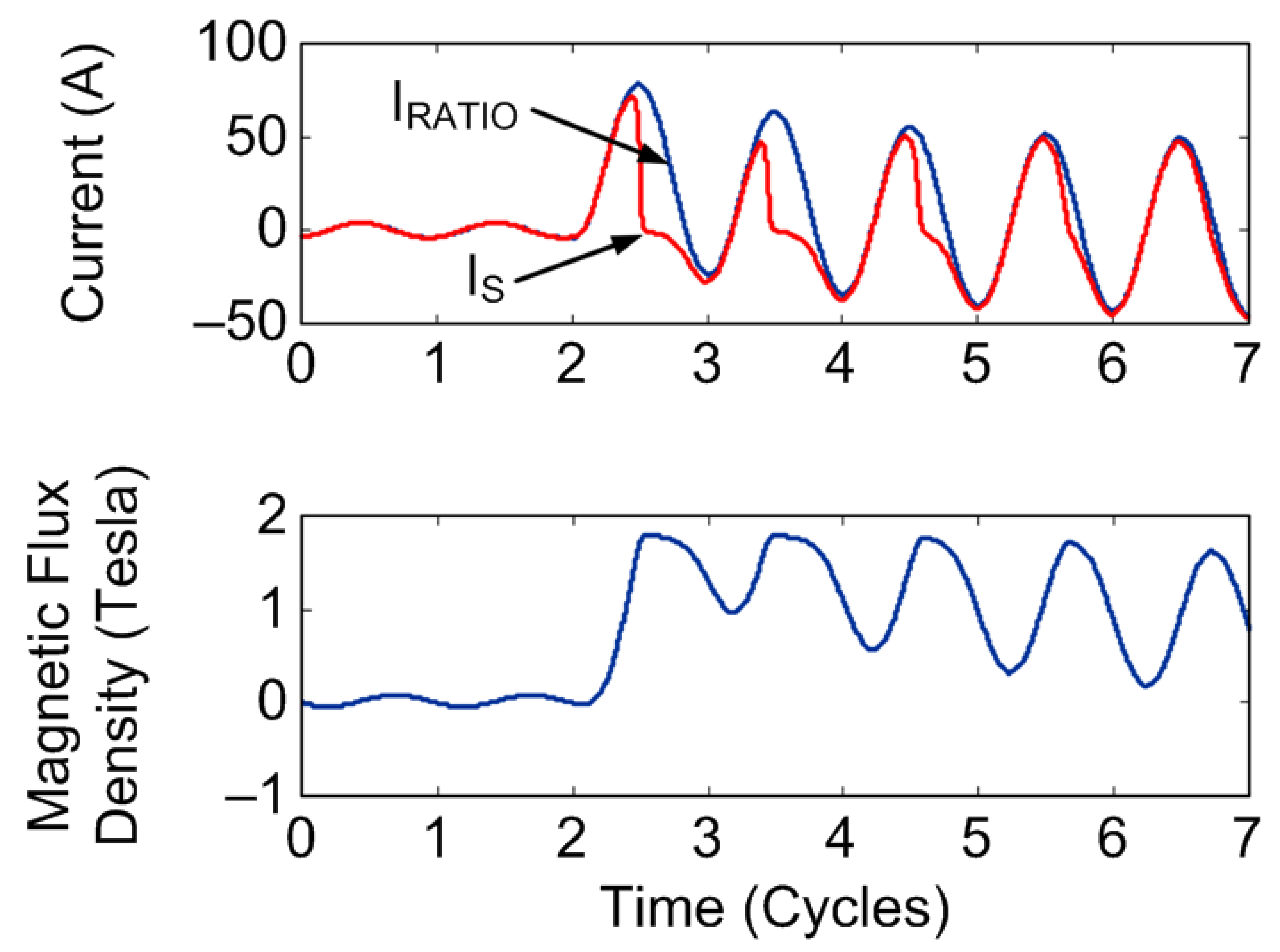
Avoiding CT Saturation for Symmetrical Currents

$$V_S \leq V_{STD}$$

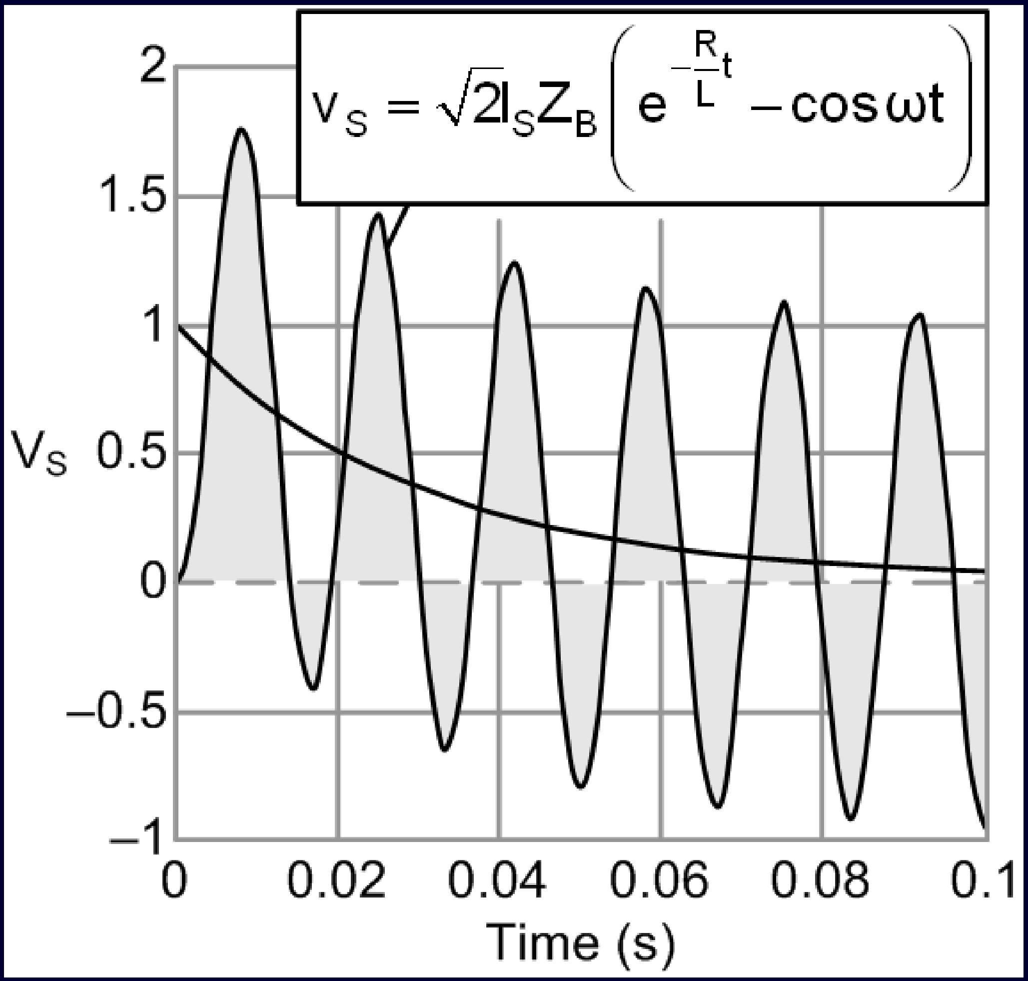
$$\frac{I_S}{I_{S\ RATED}} \bullet \frac{Z_B}{Z_{B\ STD}} \leq 20$$

$$I_f\ Z_b \leq 20$$

CT Transient Operation



Avoiding CT Saturation for Offset Currents

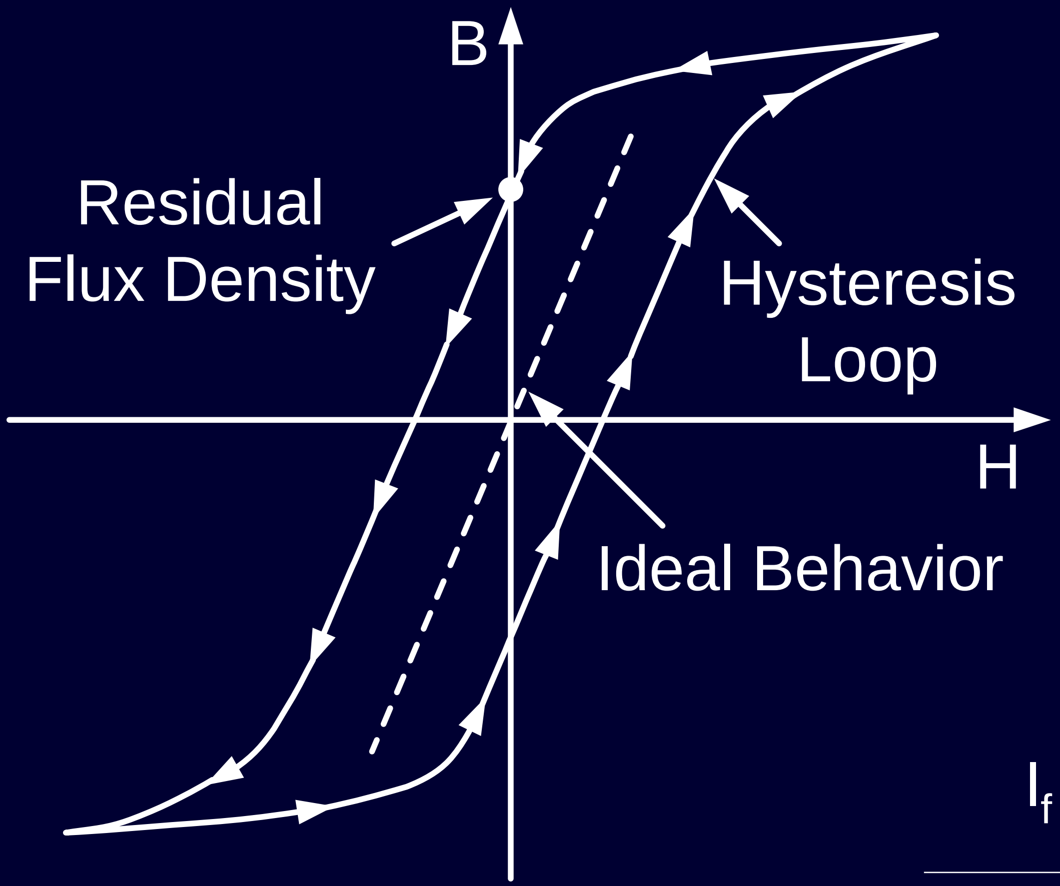


$$V_S = n\omega BA = I_S Z_B \left(1 + \frac{X}{R}\right)$$

$$\frac{I_S}{I_{S\ RATED}} \bullet \frac{Z_B}{Z_{B\ STD}} \left(\frac{X}{R} + 1\right) \leq 20$$

$$I_f \ Z_b \left(\frac{X}{R} + 1\right) \leq 20$$

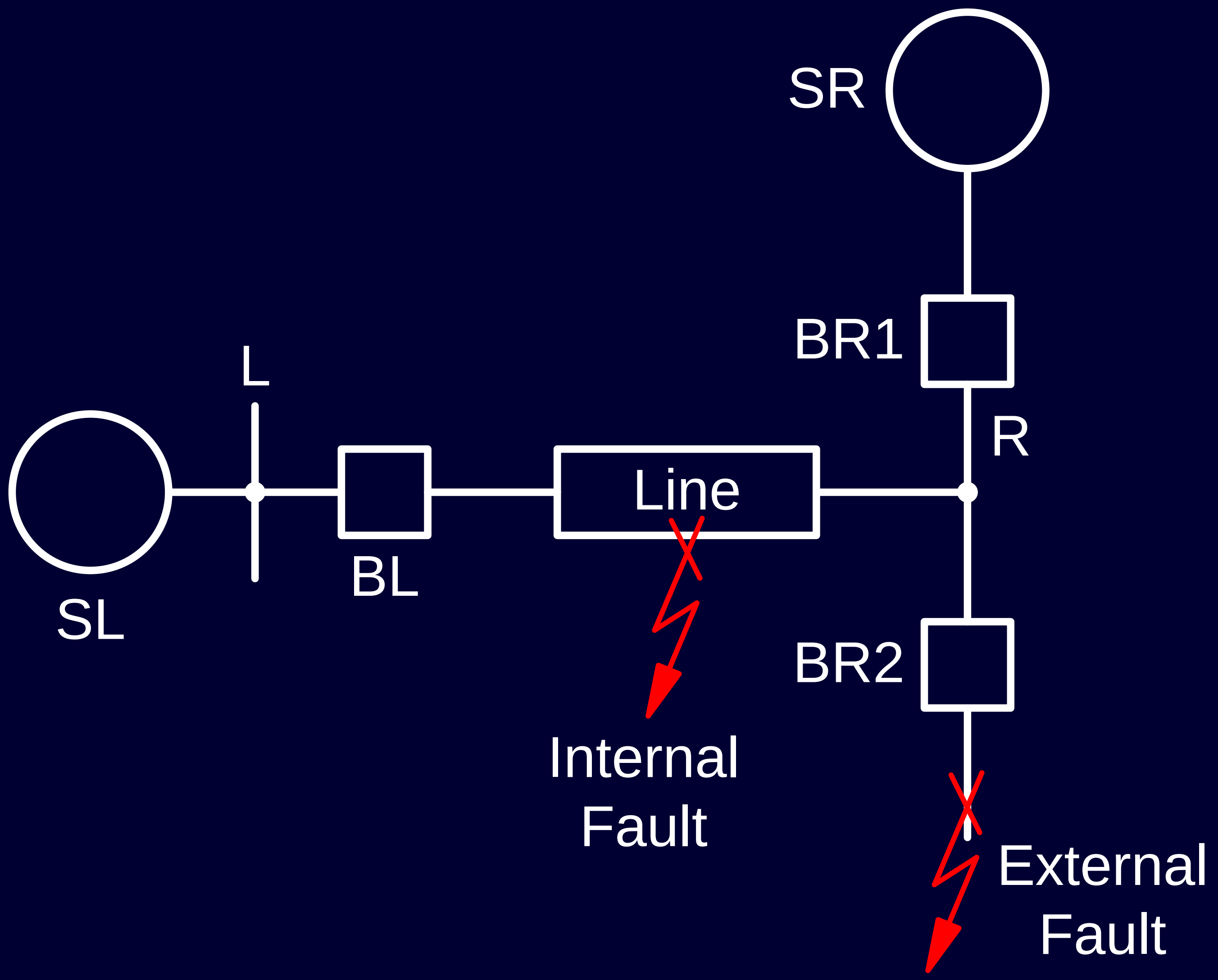
Effect of Remanence on CT Performance



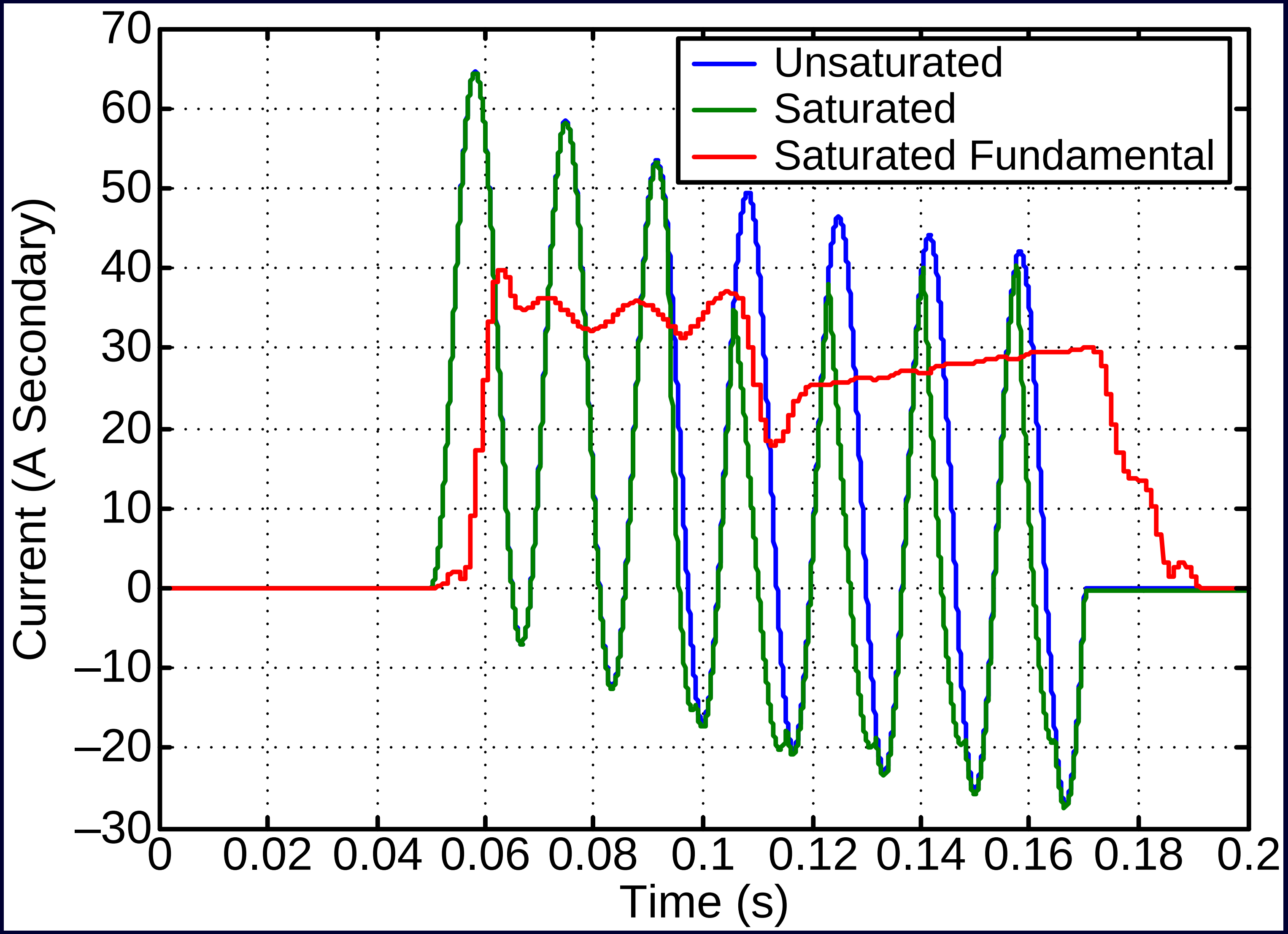
$$\frac{I_f \; Z_b \left(\frac{X}{R} + 1 \right)}{1 - \text{remanence (pu)}} \leq 20$$

Effects of CT Saturation on Protection Elements

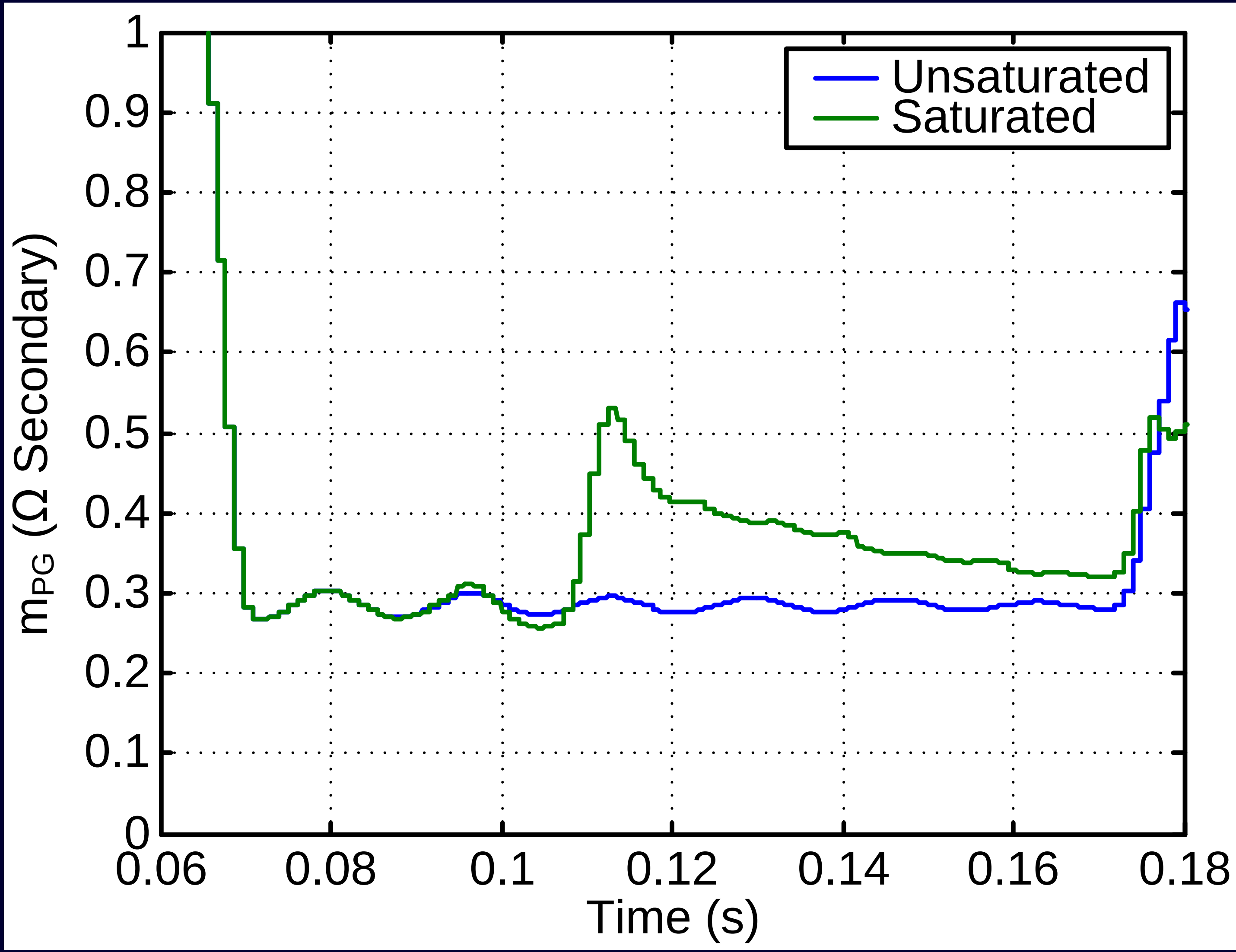
Example Power System



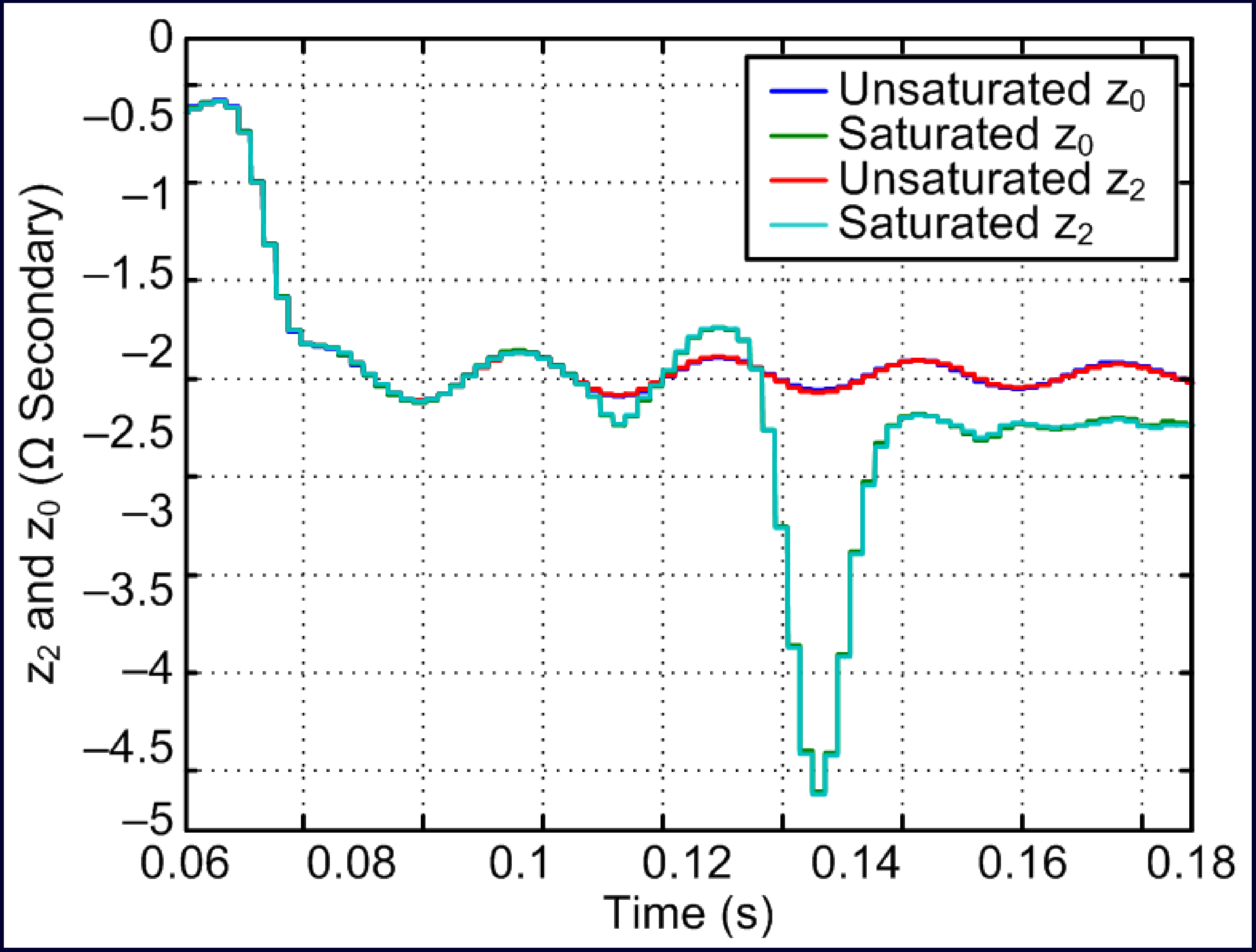
CT Saturation Affects Overcurrent Element Measurements



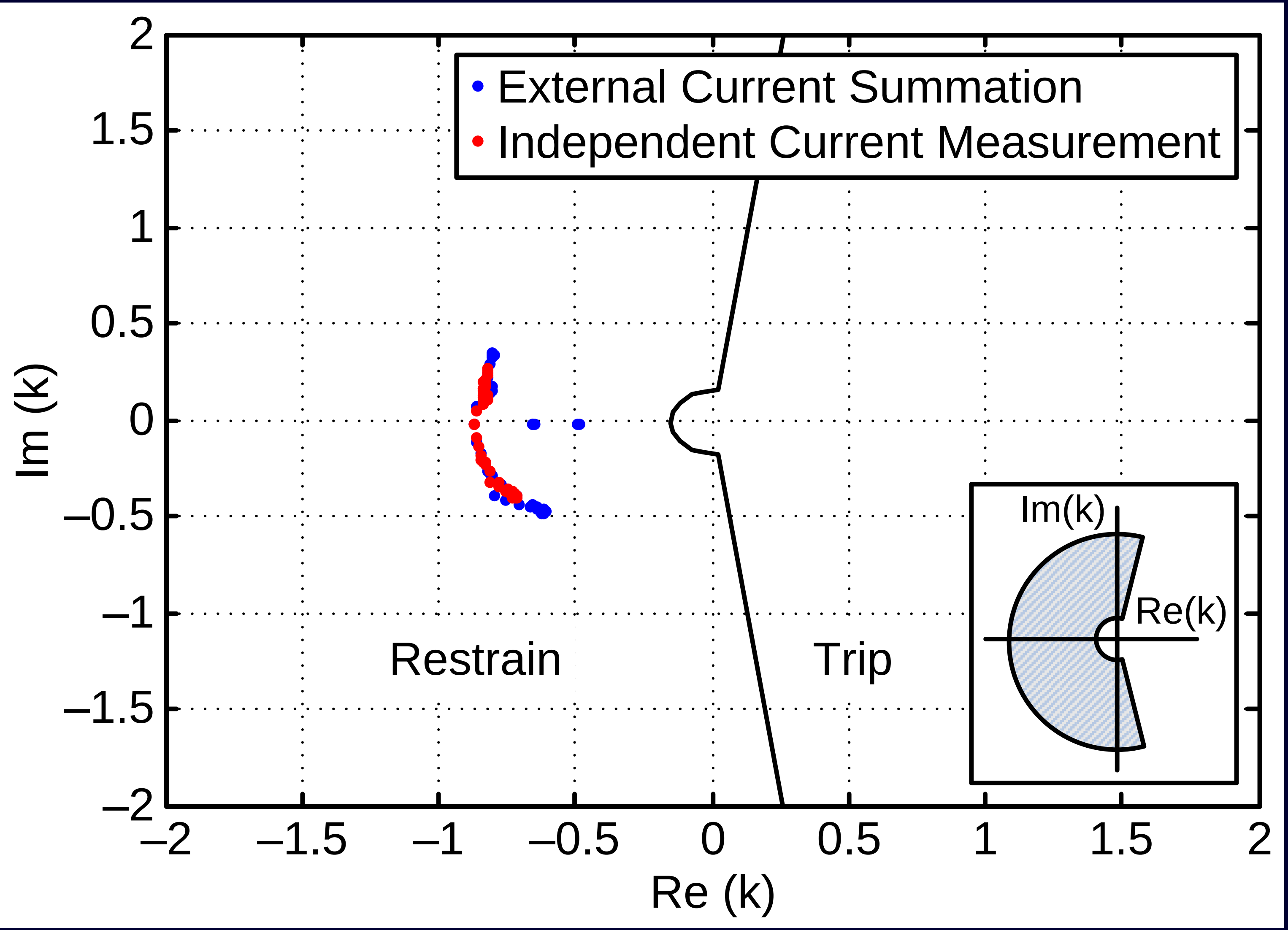
CT Saturation Causes Distance Element Underreach



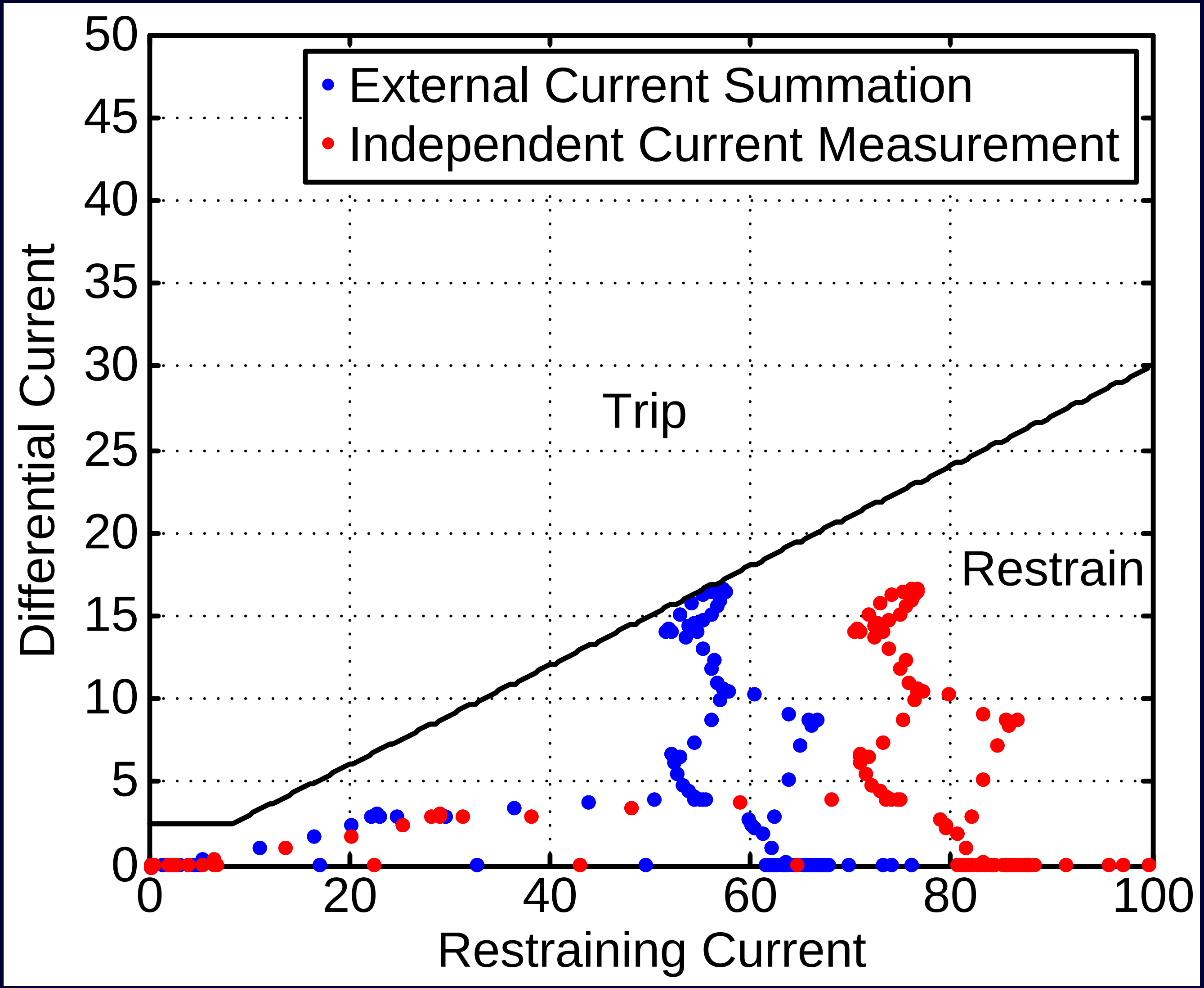
Directional Element Response for Internal Fault



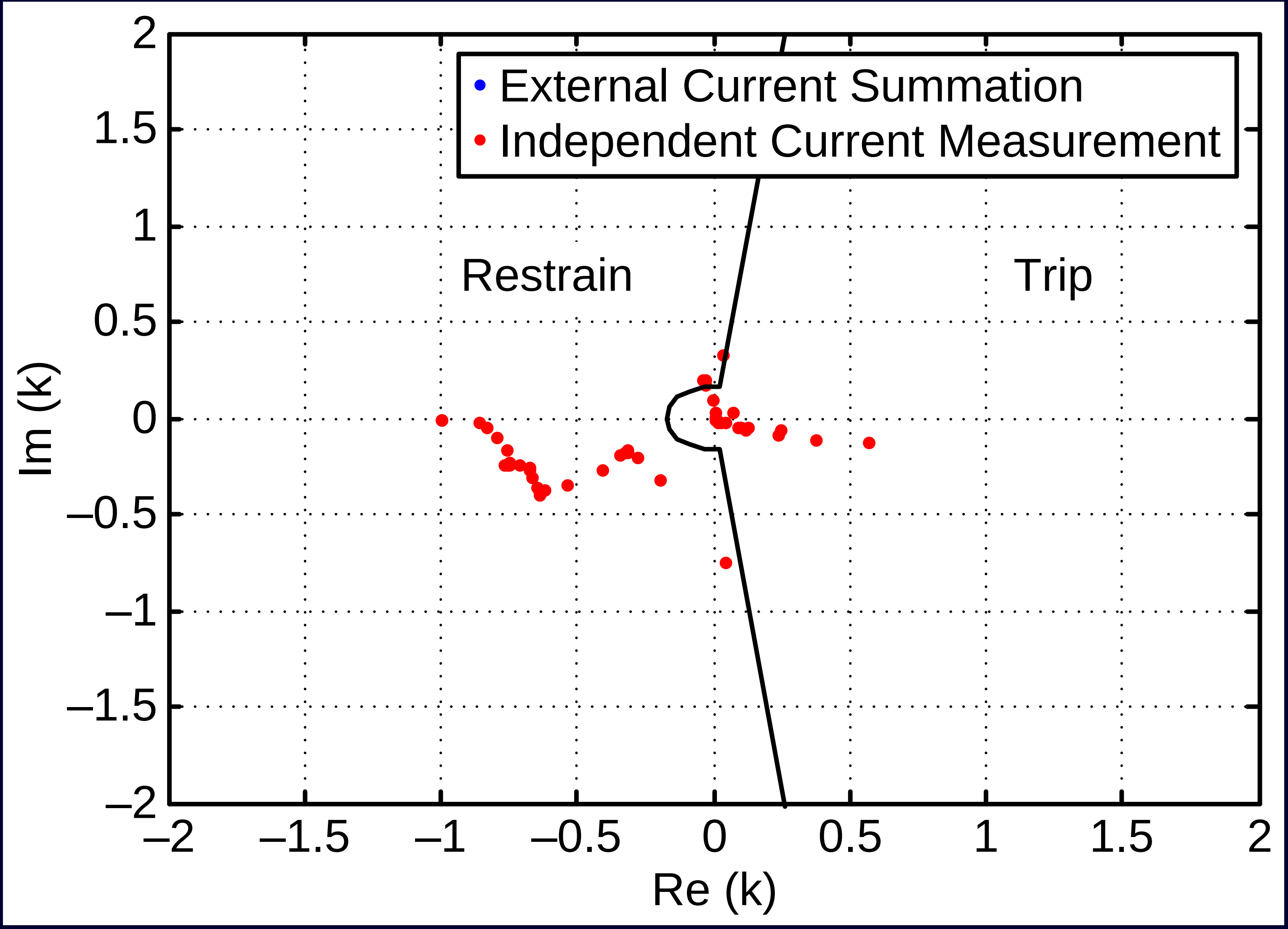
Alpha Plane Phase Plot for External Fault



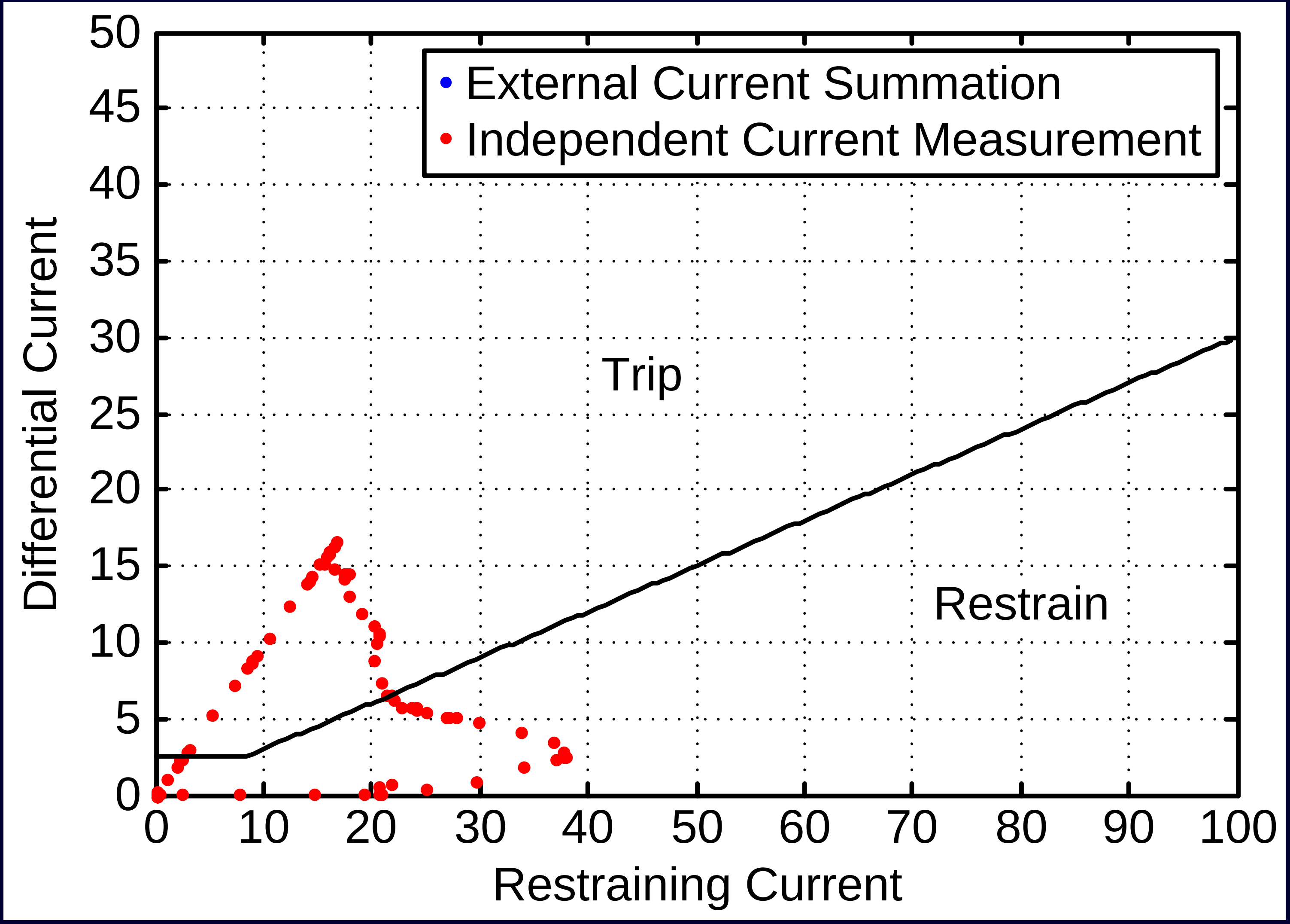
Percentage Differential Phase Plot for External Fault



Zero-Sequence Alpha Plane Plot for External Fault



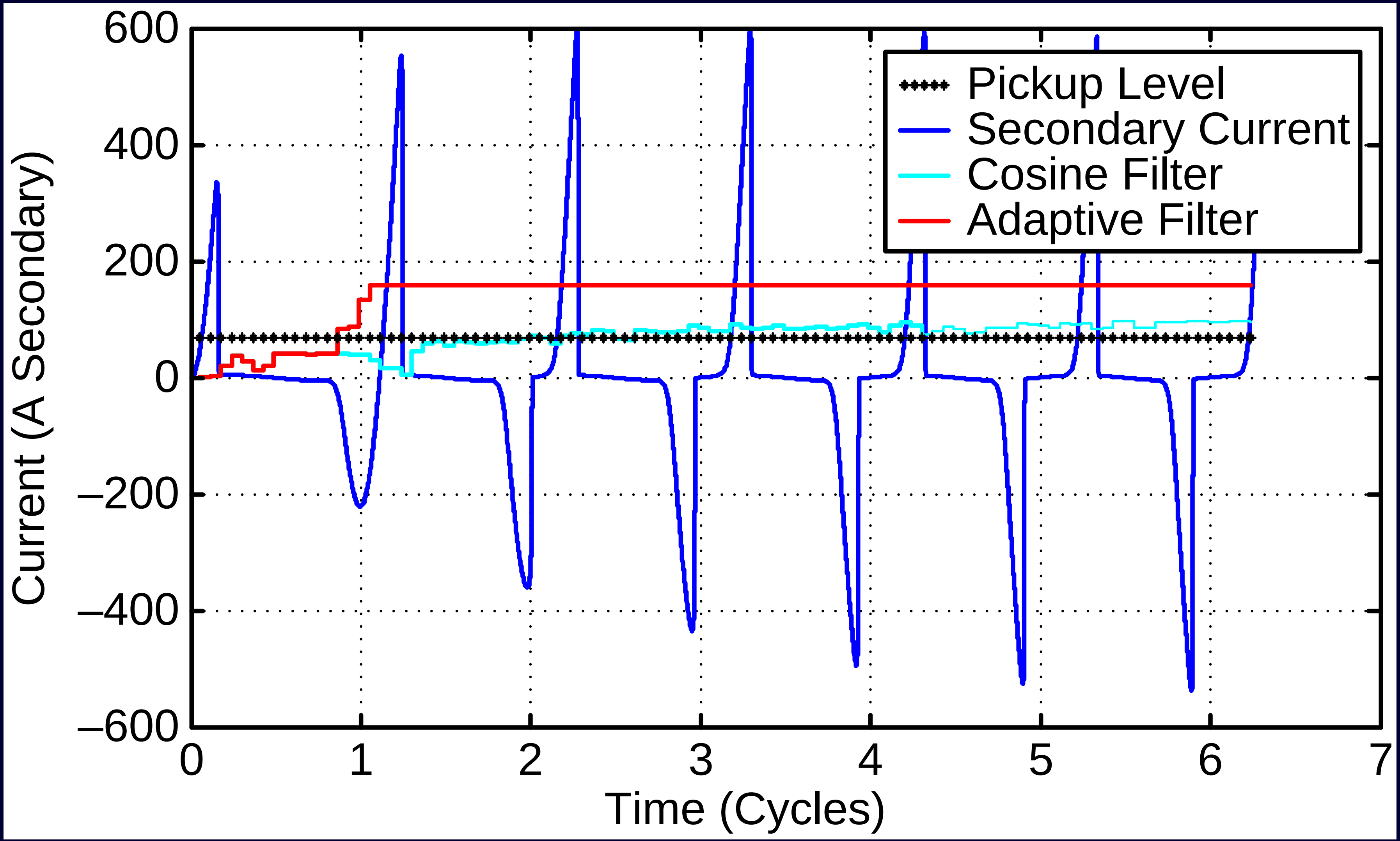
Zero-Sequence Percentage Differential Plot for External Fault



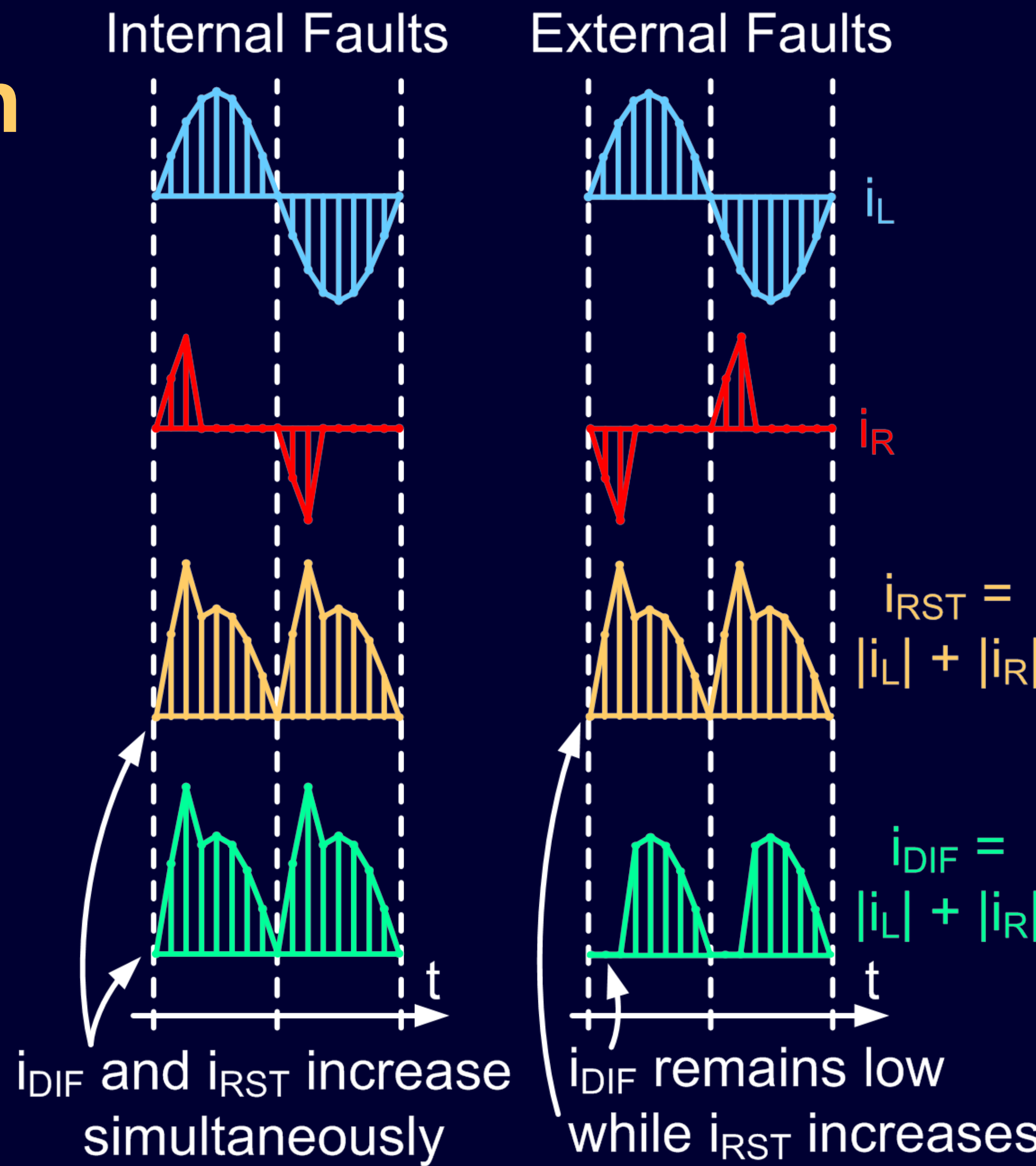
Advances in Modern Protection Designs

- High-speed distance elements
- Cosine-peak adaptive filter for overcurrent elements
- External fault detection for differential elements

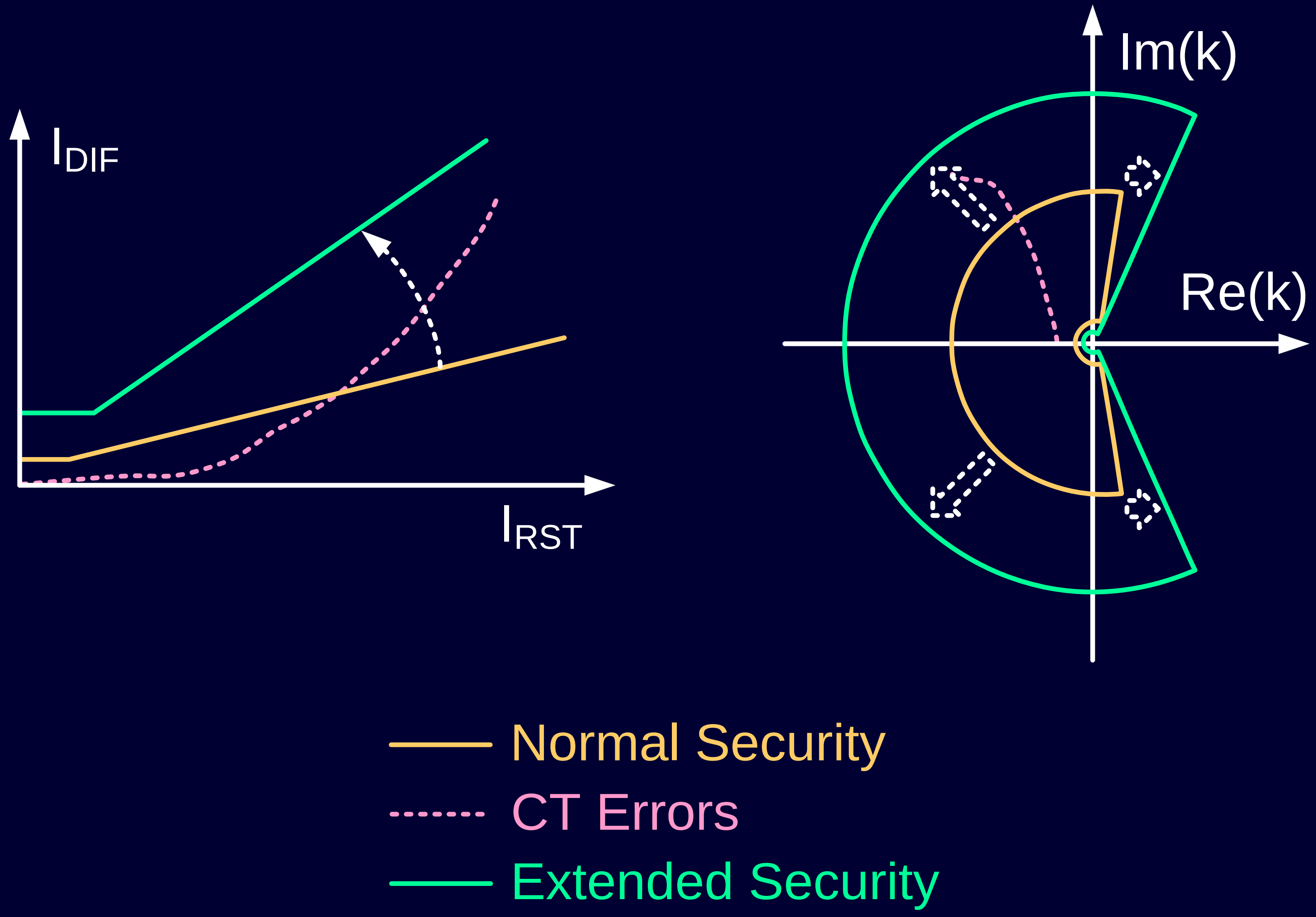
Adaptive Filter Performance



External Fault Detection Principle



Adaptive Differential Characteristics



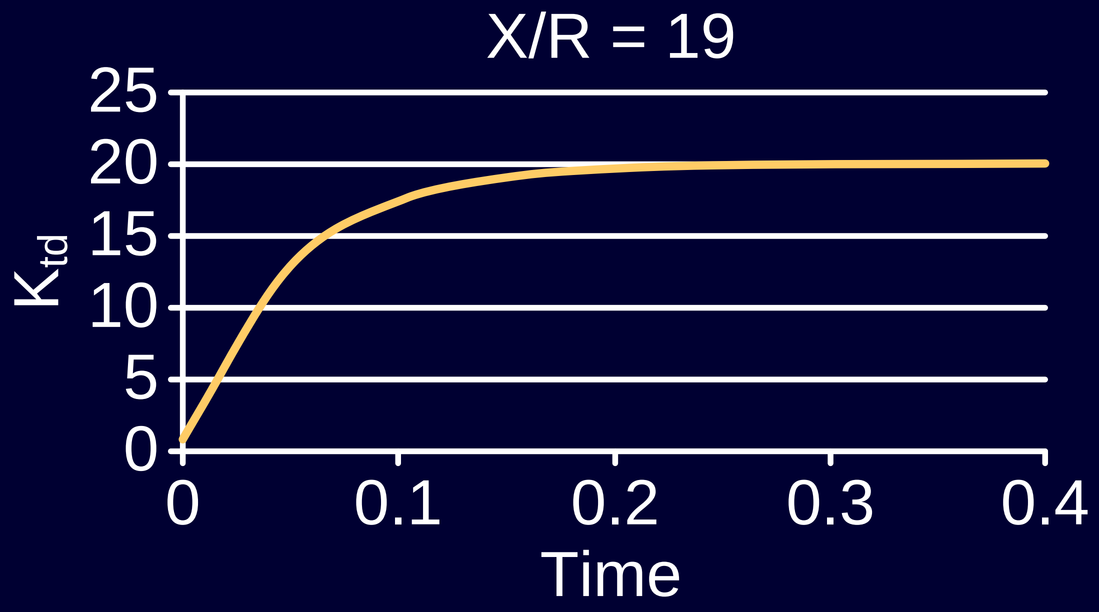
Tools for CT Sizing

Checks for Saturation-Free Operation

- Example: C400, 2000/5 CT with 1 Ω burden and 30% remanence
  - $Z_b = 1\ \Omega$
  - $Z_{B\ STD} = 4\ \Omega$
- Maximum asymmetrical fault current for X/R = 12: $I_{f\ max} = 6.15\ (1 – 0.3) = 4.3$ pu = 8.6 kA

IEC Guidelines

$$E_{al} = K_{ssc} K_{td} \left(R_{ct} + R_b \right) I_{sn} \qquad K_{td} = \frac{\omega T_P T_S}{T_P - T_S} \left(e^{-t/T_P} - e^{-t/T_S} \right) + 1$$



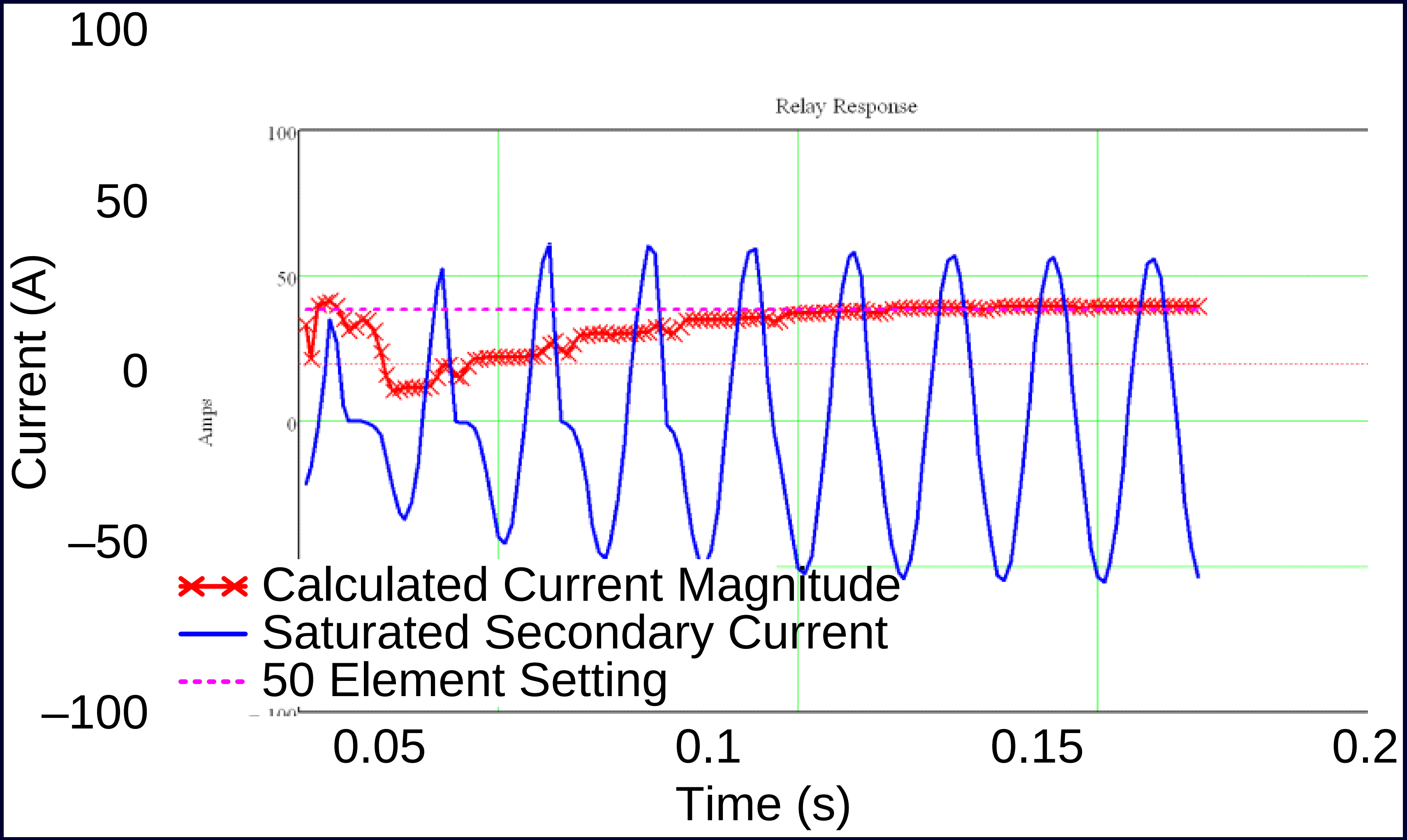
Faster operating time results in lower transient dimensioning factor

Manufacturer Guidance

$$R_{bmax} = \frac{kV_S}{I_f\left(\frac{X}{R}+1\right)}$$

Relay	*k*	Criteria
Distance	6	No dropout of Zone 2 with reach of 125%
Differential	7.5	Secure operation during external faults

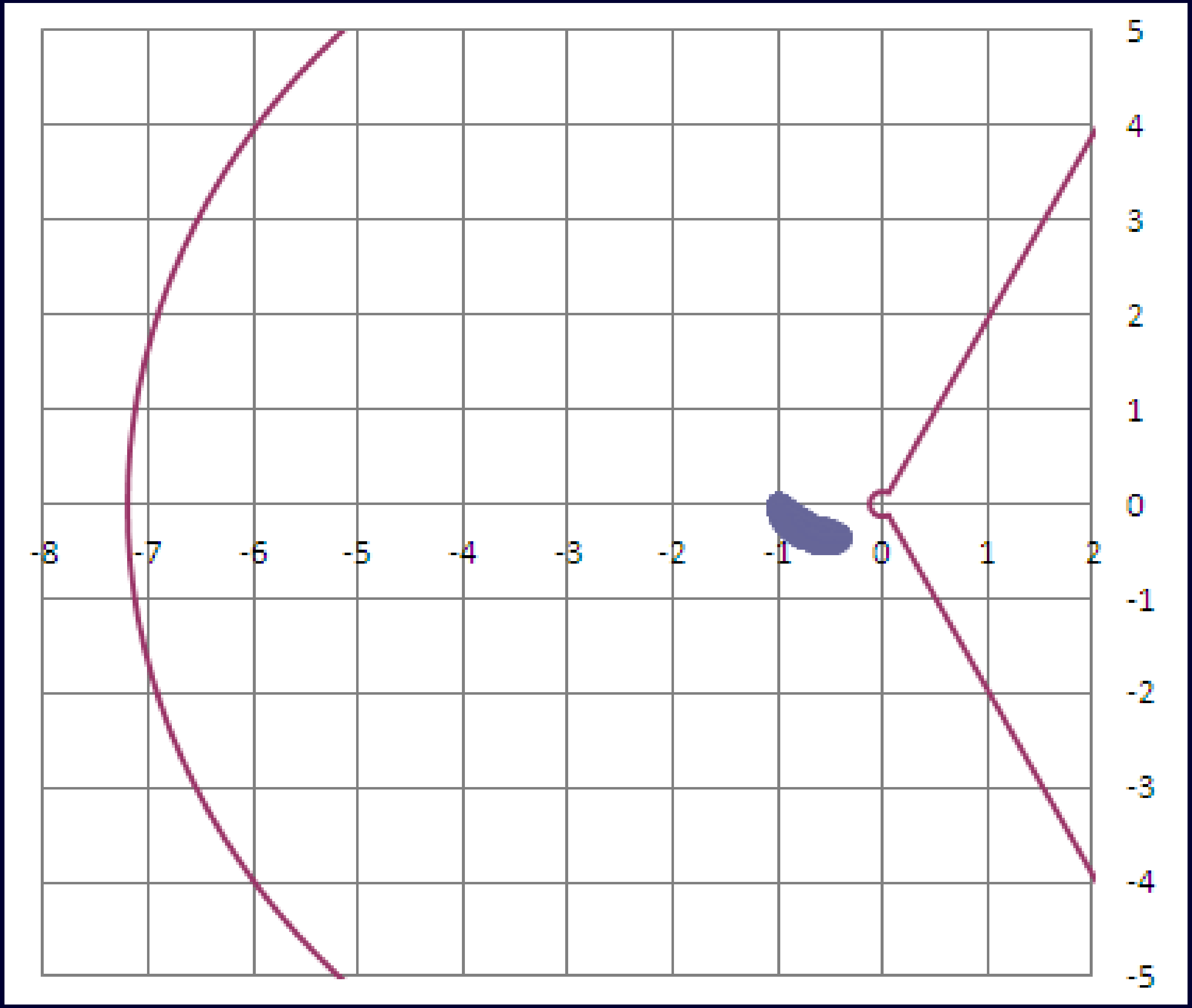
CT Modeling – Mathcad®



Evaluate impact on settings and speed

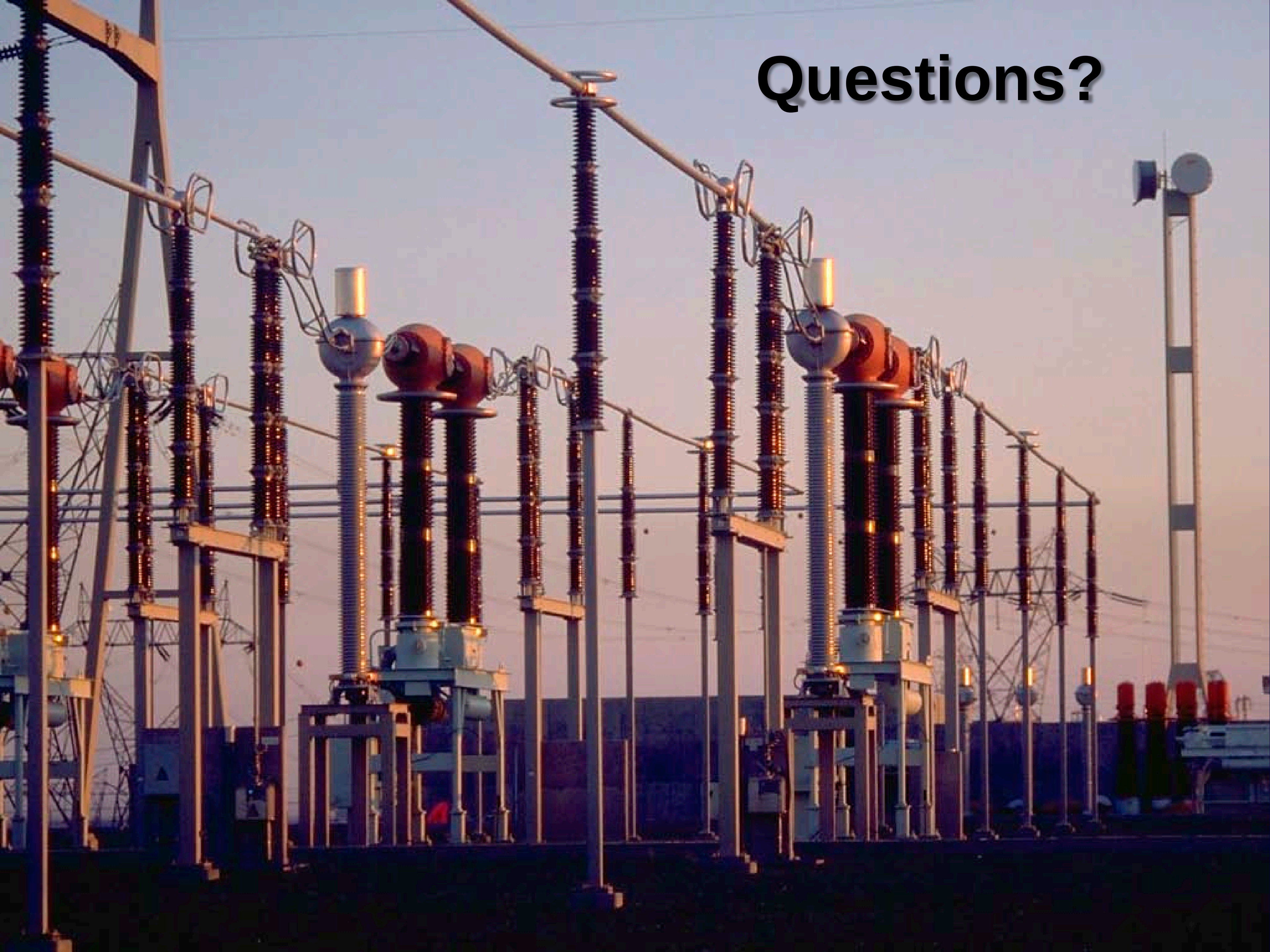
CT Modeling – PSRC Spreadsheet

Relay Model Linked to Spreadsheet



Conclusion

- CT saturation is sometimes unavoidable
- CT saturation affects relay security, speed, and sensitivity
- Modern relays include algorithms to deal with CT saturation
- Manufacturers provide guidelines that simplify CT selection
- Tools are available to protection engineers


Questions?