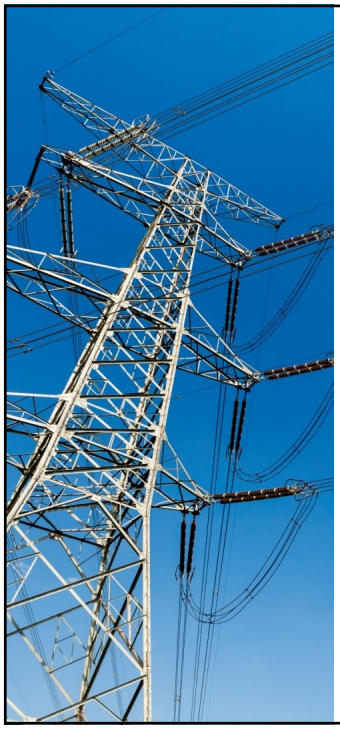

Settings Considerations for Distance Elements in Line Protection Applications

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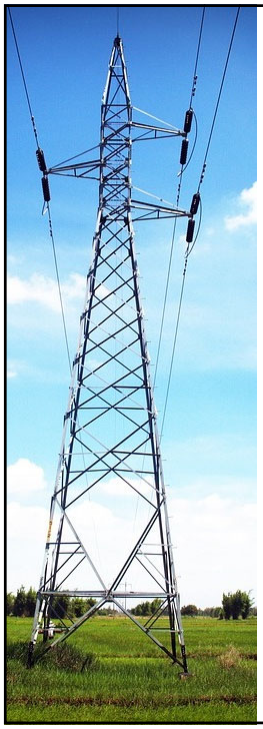

Presentation focus

- Distance element fundamentals
  - IZ−V rediscovered
  - Relay voltage and IZ−V calculations
- Distance elements in weak systems
  - Voltages induced in secondary cables
  - Ground potential rise
  - Mutual coupling
  - CCVT transients
- Distance application recommendations for weak systems

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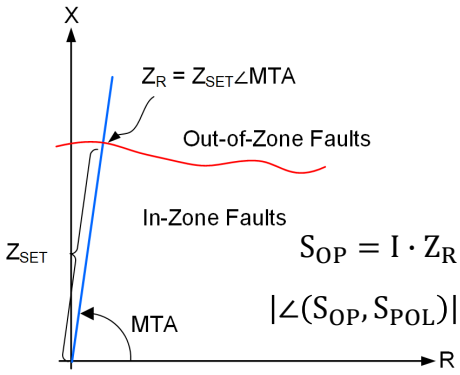
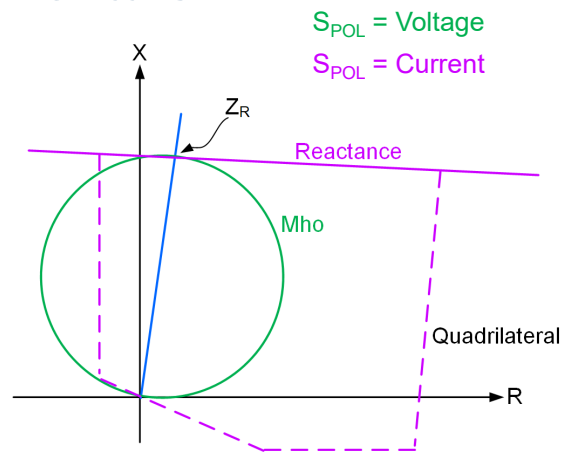
Distance element fundamentals



$$S_{OP} = I \cdot Z_R - V$$

$$|\angle(S_{OP}, S_{POL})| < 90^\circ$$



At the very basic level, a distance element:

- Is a phase comparator
- Responds to IZ−V term

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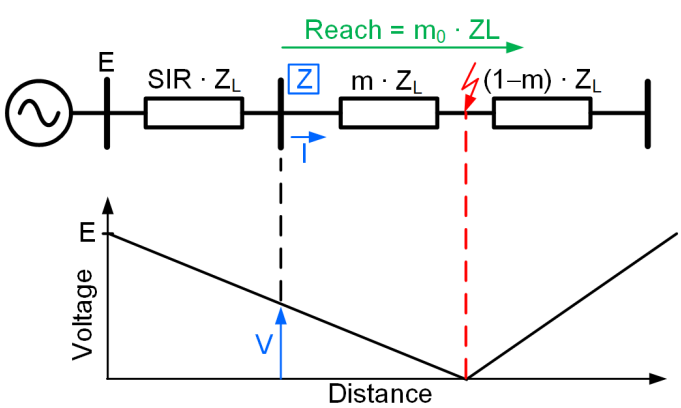
Distance element operating signal and SIR



Current:

$$I = \frac{E}{Z_L \cdot (SIR + m)}$$

Voltage:

$$V = \frac{m \cdot E}{SIR + m}$$

$$V_{PU} = \frac{m}{SIR + m}$$

S_{OP} (IZ−V):

$$S_{OP} = E \cdot \frac{m_0 - m}{SIR + m}$$

$$S_{OP(PU)} = \frac{m_0 - m}{SIR + m}$$

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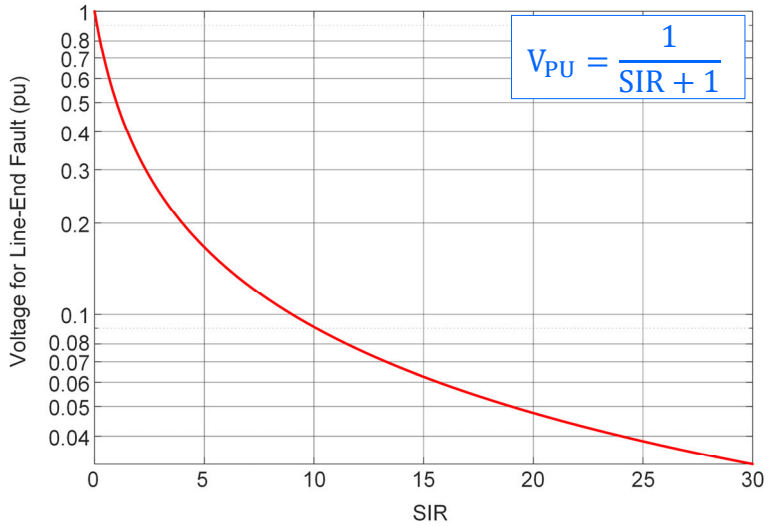
SIR and relay voltage for line-end faults



Low SIR

- Small voltage change (small transients)
- Large fault voltage (good measuring accuracy)

High SIR

- Large voltage change (large transients)
- Small fault voltage (poor measuring accuracy, interfering signals large by comparison)

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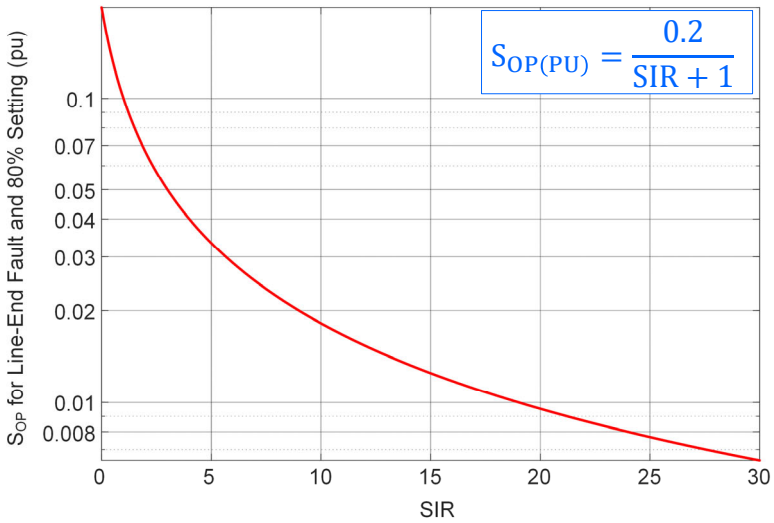
SIR and relay IZ−V for line-end faults



- SIR = 5, IZ−V < 4% (CCVT transients can be fivefold higher)
- SIR = 10, IZ−V < 2% (mutually induced voltages can be that high)
- SIR = 20, IZ−V < 1% (for subtransmission lines GPR can be that high)
- SIR = 30, IZ−V < 0.7% (voltages induced in control cables can be that high)

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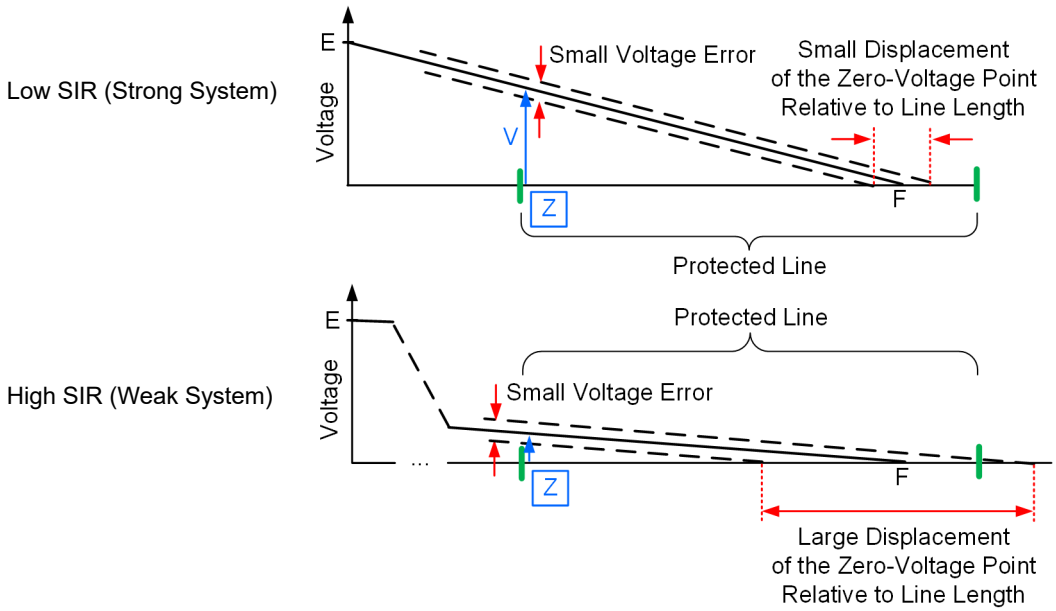
Impact of SIR on distance measurement



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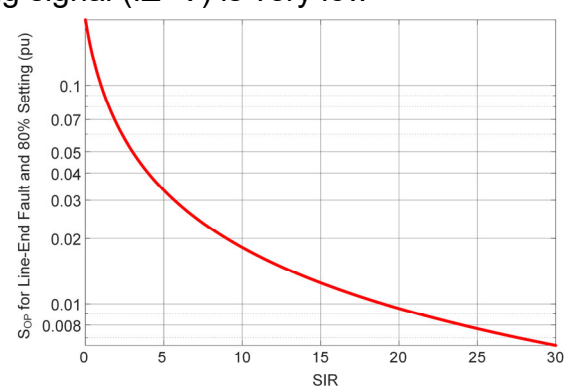
The key role of relay voltage

(1) Voltage error adds directly to the operating signal (IZ−V)

$$S_{OP(PU\ MEAS)} = S_{OP\ (PU\ TRUE)} + V_{PU\ ERR}$$

(2) The operating signal (IZ−V) is very low



(3) Even small voltage errors can invert the polarity of the operating signal

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Zone 1 considerations for high SIR

- General considerations apply, such as:
  - Steady-state VT, CT, and relay errors
  - Line impedance data errors

  but the impact is magnified when SIR is high
- Additional considerations include:
  - Stray voltages induced in secondary cables
  - Ground potential rise
  - Mutual coupling with lines that carry large currents
  - Resistive faults and accuracy of polarizing
  - CCVT transients

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Voltages induced in secondary cables

- SIR = 25, line-end fault, Z1 set to 80%:
  IZ−V < 0.8%, 0.8% of 66.4 V sec is only 530 mV
- 530 mV induced in the secondary cables can cause Z1 to overreach
- Induced voltage is zero-sequence, phase distance elements are not affected
- Apply best practices (shielding, grounding, using high VT tap, avoiding parallel cable trench runs)
- Do not use Z1 ground distance elements if you cannot deliver a true voltage signal to the relay

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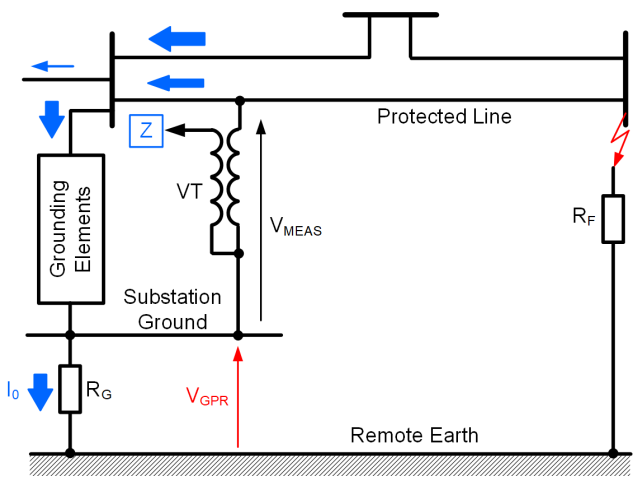
Ground potential rise



- SIR = 25, line-end fault, Z1 set to 80%: IZ−V < 0.8%
- 115 kV system, GPR of 500 V is 0.75% of nominal
- Line I_0 and voltage drop across R_F and R_G are not proportional
- Z1 ground distance elements do not work well on short lines

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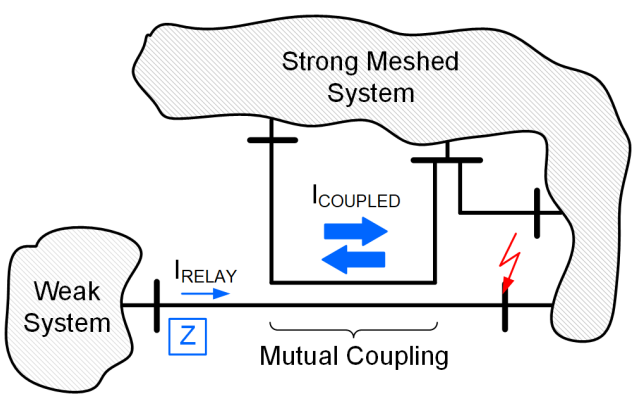
Mutual coupling



- Lines are not fully transposed considering segments of coupling
- Zero-sequence, but also positive- and negative-sequence currents couple
- Coupled line can carry arbitrarily high current
- In weak systems, an induced voltage of a fraction of a percent can affect distance elements

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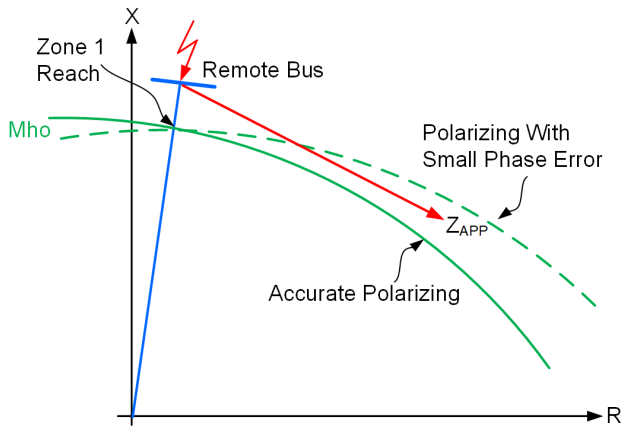
Resistive faults



- Phase angle error in IZ−V signal can be analyzed as a phase angle error in the polarizing signal
- Polarizing errors can lead to Z1 security issues during resistive faults
- Both mho and quadrilateral elements can be affected

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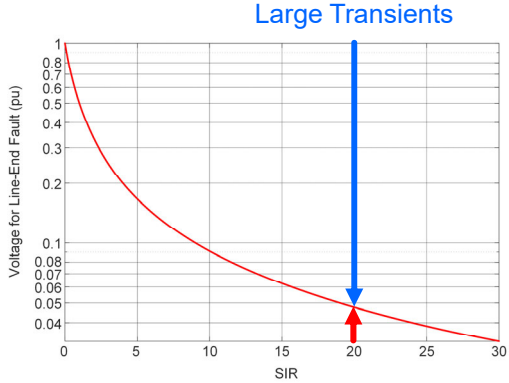
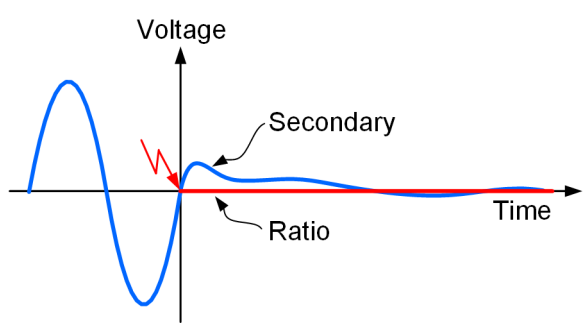
CCVT transients

Large Voltage Change
=
Large Transients



Low Voltage
=
Transients Are High By Comparison



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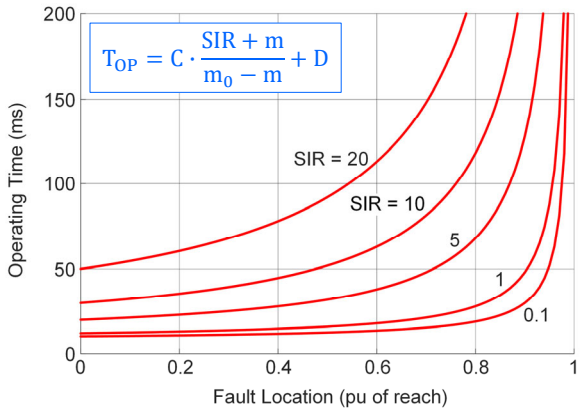
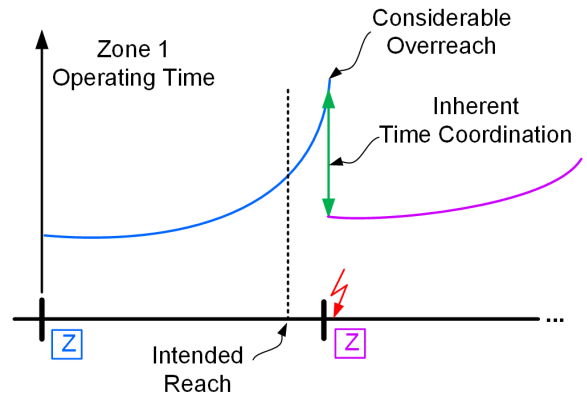
CCVT transients and electromechanical relays





Electromechanical relay slows down when

- Fault is close to the reach point
- SIR increases

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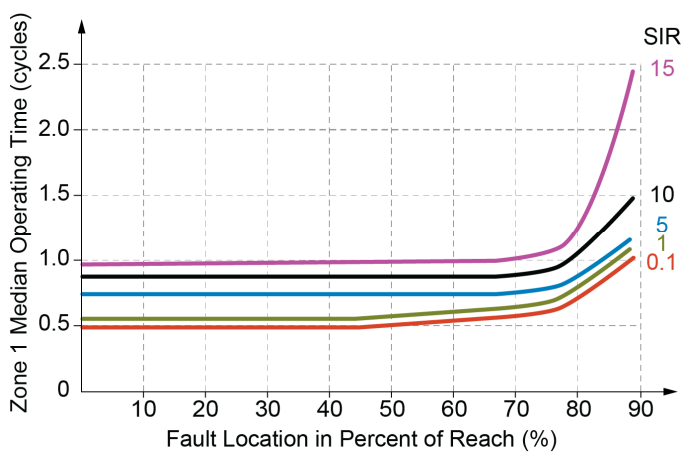
CCVT transients and μP-based relays



A secure μP-based Z1 slows down when

- Fault is close to the reach point
- SIR increases

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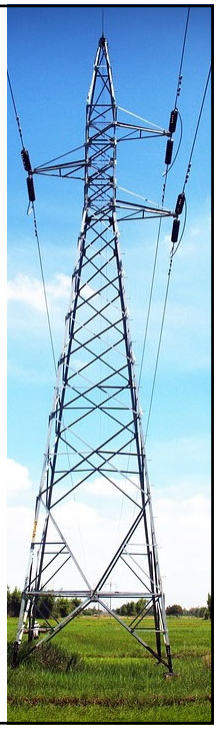
Zone 1 recommendations for high SIR

- All general issues apply but have disproportionately high adverse impact
- Be prepared to address uncertainty and to contact equipment manufacturers to obtain data
- Phase and ground elements may have very different operating conditions
- Mutual coupling plays considerable role; impact extends to phase distance elements
- Use short-circuit program to maximize data use



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Zone 1 recommendations for high SIR

- When in doubt (GPR, mutual coupling, etc.) use pilot schemes or 87L schemes
- Use Z1 extension logic (permit unintentional overreach, but disable while reclosing)
- If SIR is highly variable, use overcurrent supervision to allow Z1 elements to operate when system is sufficiently strong
- Limit the resistive reach and apply downward reactance tilt when using quadrilateral elements

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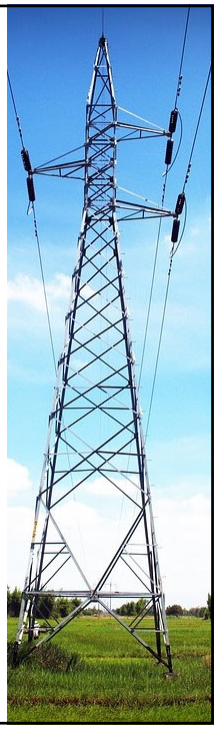
Zone 1 recommendations for high SIR

- When upgrading relays
  - Remember to fully load CCVTs
  - Use highest VT tap, if possible
  - Inspect secondary cables and rectify issues, if any
  - Understand Z1 transient overreach specification
  - Do not necessarily trust old settings
- In new installations
  - Prefer magnetic VTs over CCVTs
  - Order CCVTs with low and quickly damped transients
  - Use shielded voltage cables



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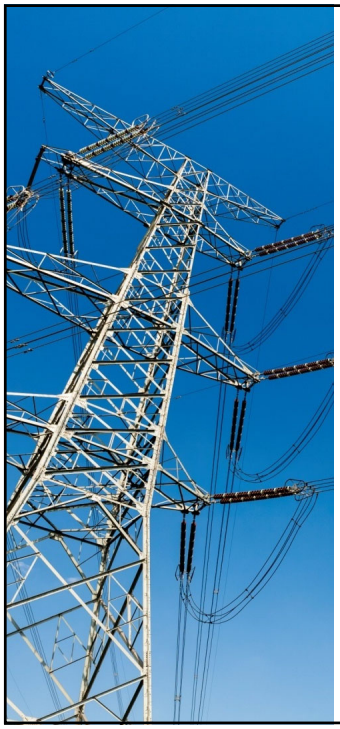

Summary

- Use the IZ–V term to analyze the impact of interfering signals on distance elements
- Use a short-circuit program to obtain apparent impedance values when setting distance elements
- Do not exceed a safe ratio between the resistive and reactive reach when using quadrilateral elements

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Summary

- Do not focus exclusively on CCVT transients and Zone 1 design when the system is weak
- Remember to consider steady-state errors in distance element application to weak systems and follow recommendations from the paper
- In weak systems, not only the underreaching but also the overreaching and blocking distance applications can face issues

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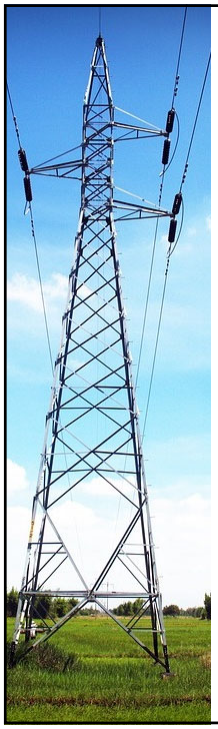

Summary

- Engineering based on hard data can be impossible in distance element applications to weak systems
- Be prepared to estimate data or ask equipment manufacturers for data in applications to weak systems
- Limit the use of and lower the expectations for distance elements in weak systems

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Backup slides for discussion

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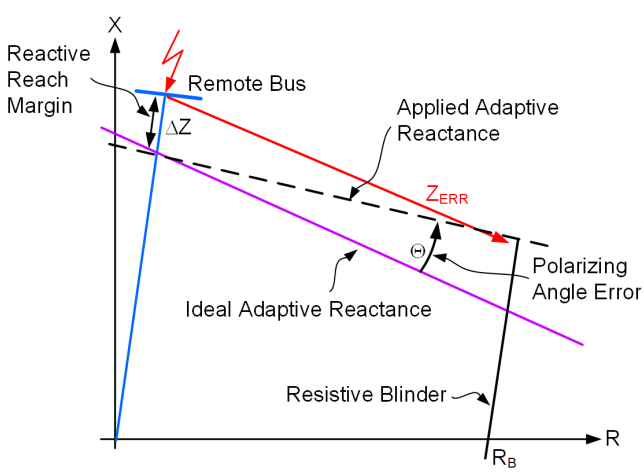
Quadrilateral elements



- Quadrilateral elements are susceptible to polarizing errors
- Reactive and resistive reach must be coordinated:

$$\frac{\Delta Z}{R_B} > \Theta \cdot \frac{\pi}{180}$$

- Large resistive reach is difficult to achieve for short lines (high SIRs)

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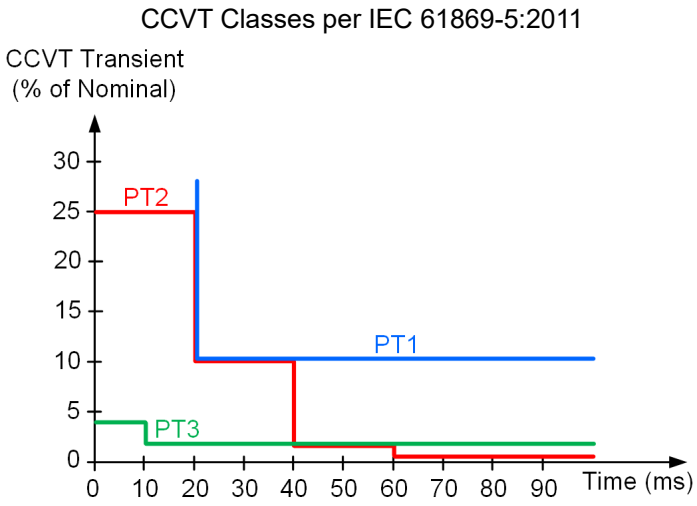
CCVT transients



- CCVT transient can be tenfold higher than the Z1 operating signal for as long as 1–2 cycles
- CCVT transients can impact Z1 security, Z2 dependability, and speed in general

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