Settings Considerations for Distance Elements in Line Protection Applications

Bogdan Kasztanny
Schweitzer Engineering Laboratories, Inc.

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
Distance element fundamentals

At the very basic level, a distance element:
- Is a phase comparator
- Responds to IZ−V term

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):
\[ S_{OP} = E \cdot \frac{m_0 - m}{SIR + m} \]
\[ S_{OP(PU)} = \frac{m_0 - m}{SIR + m} \]
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)

\[ V_{PU} = \frac{1}{SIR + 1} \]

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)
Impact of SIR on distance measurement

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
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

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
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

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
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

CCVT transients

- Low Voltage
  - Transients Are High By Comparison
- Large Voltage Change
  - Large Transients
CCVT transients and electromechanical relays

Electromechanical relay slows down when
- Fault is close to the reach point
- SIR increases

CCVT transients and μP-based relays

A secure μP-based Z1 slows down when
- Fault is close to the reach point
- SIR increases
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

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
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

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
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

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
Backup slides for discussion

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)
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