Transmission Line Setting Calculations – Beyond the Cookbook

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Introduction

- Calculations may have 20+ years of life
- Standardized calculations help you do good work
- You are more effective if you understand background and philosophies

Identify when to look beyond the cookbook

Relay Setting Fundamentals
Defining Performance

- Selectivity
- Speed
- Sensitivity

Relay Setting Fundamentals
Defining Reliability

- Dependability
- Security
- Dependability and security
  - Usually inversely related
  - Better schemes can improve both

NERC Misoperations Report

- 94% of misoperations resulted in false trips
- The rest were failures to trip or slow trips
- Goal is to reduce false trips without increasing failures to trip


Misoperations Report

Prepared by: Protection System Misoperations Task Force

April 1, 2013

See full report at nerc.com

The Art and Science of Line Protection

- We have two “knobs” to adjust
  - Sensitivity (reach, pickup, and so on)
  - Delay
- Every setting affects performance and reliability
  - Set sensitive but not **too** sensitive
  - Set fast but not **too** fast

The Art and Science of Line Protection

- Science – find the limits
  - Dependability
  - Security
- Art – apply margins
  - Use appropriate margins for precision of calculation and element
  - Know which margins can be sacrificed and which should not

Contingencies

- Protection must be reliable for
  - Loss of any single element or component (N − 1)
  - High-probability double contingencies (N − 2)
- Some conditions are alternate normal, not contingencies
- You must identify contingencies appropriate for check at hand

Line Relaying Schemes Are Designed Around Fault Types

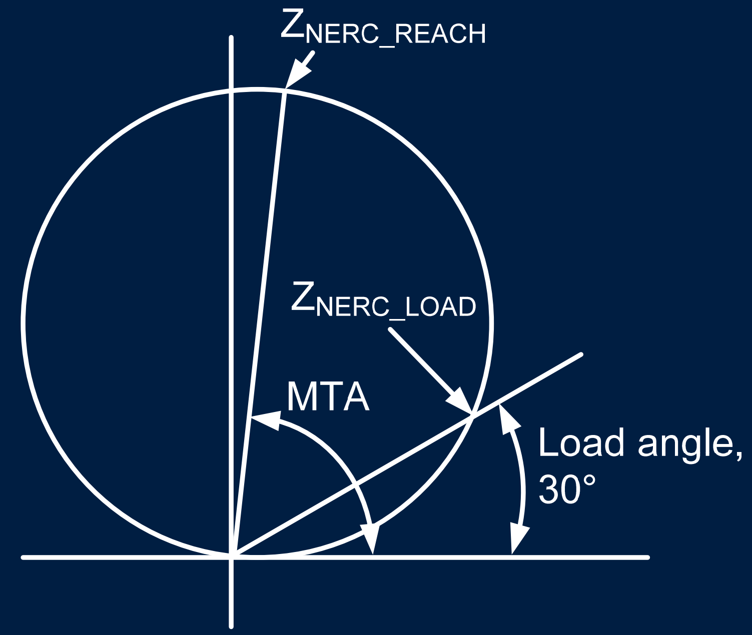
- Phase faults
  - Loadability is a concern
  - System is built for positive-sequence load flow
- Ground faults (most common)
  - Possible high fault resistance
  - Higher Z_0 impedance

Transmission Line Relay Schemes

- Step distance
  - Underreaching elements with no delay
  - Overreaching elements with delay
- Directional pilot schemes
  - Overreaching elements with signaling
  - Signals that either block or permit operation
- Differential

General Calculations

- CTR selection
- Source impedance ratio (SIR)
- Loadability criteria



Phase Distance Zones

- Step Zone 1: typically 80−90%
  Underreaching, instantaneous
- Step Zone 2: typically 120−150%
  Overreaching, end-zone coverage with delay
- Step Zone 3: typically 200%+
  Overreaching, time-delayed remote backup
- Pilot tripping zone
  Common to combine with Zone 2 or Zone 3
- Pilot blocking zone
  Must coordinate with remote pilot tripping zone

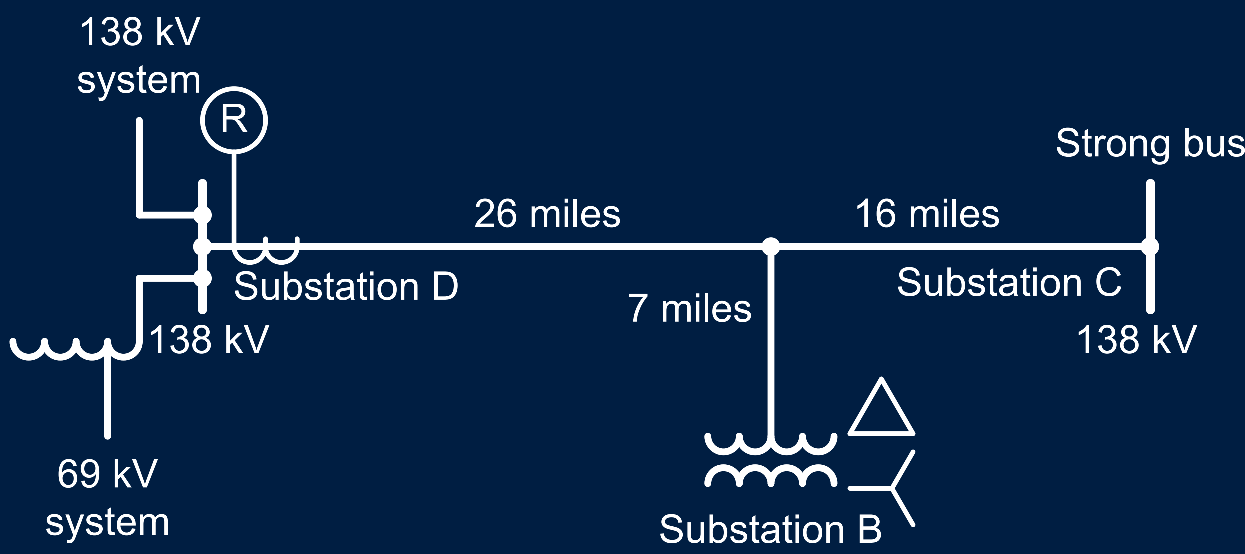
Phase Distance Zones
Why Do We Need Margin?

- Lines are typically not physically balanced
- Short lines have more error for an out-of-zone fault
- Underreaching elements must never overreach
- Overreaching elements must never underreach

When Do We Disregard Cookbook Margins?

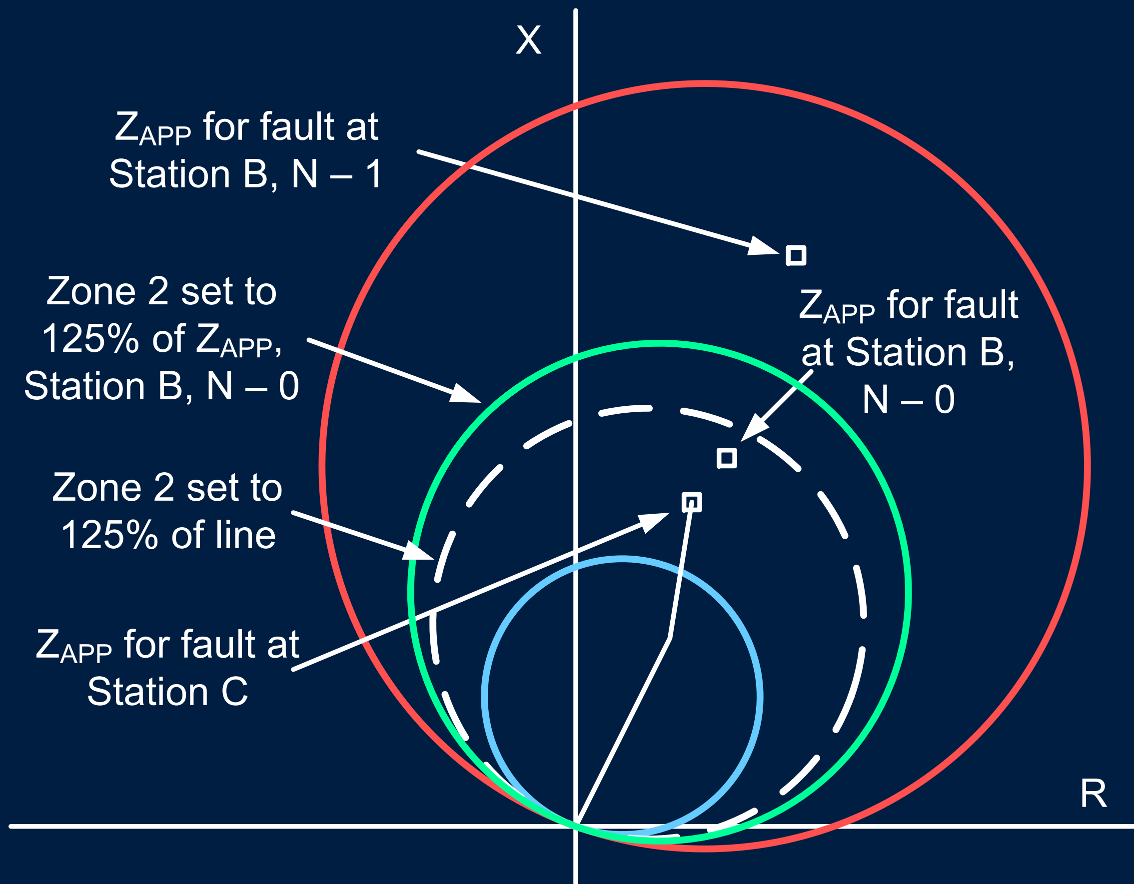
- Step Zone 1
  - Short lines
  - Radial lines
- Step Zone 2
  - Lines with tapped branches
  - Long / short line arrangements
- Step Zone 3
  - Branch beyond a remote shared breaker
  - Short lines

Tapped Branch Example



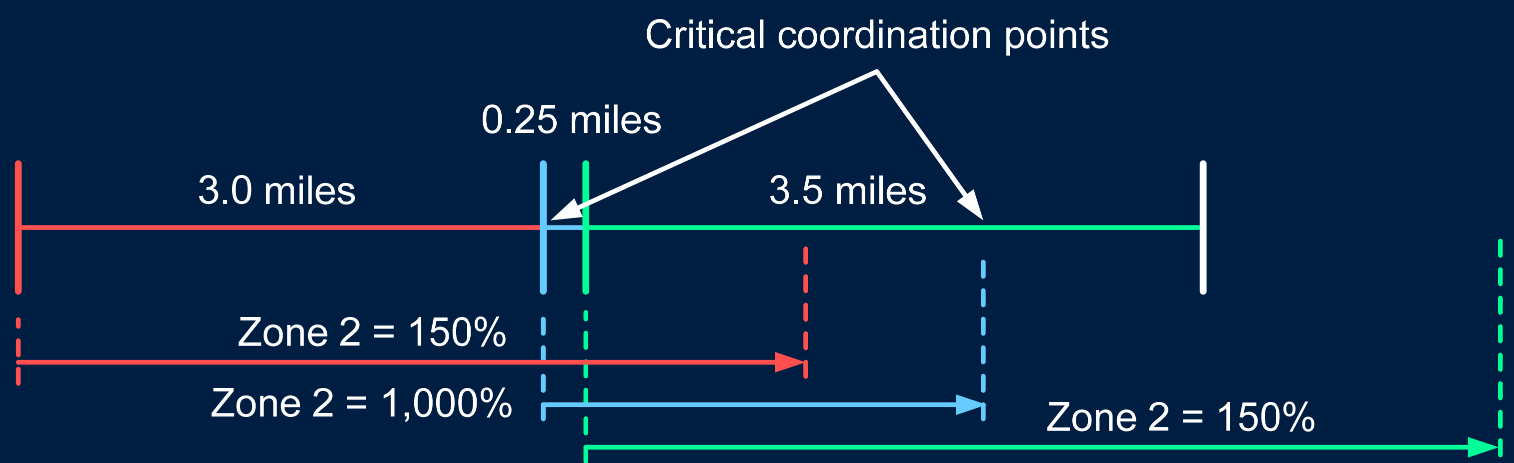
- Check Z_{APP} at each tap bus
- Check system normal and N − 1 from each terminal

Tapped Branch Example
Z_{APP} at Station D



Long / Short Line Example

- Cookbook reach on short lines could cause excessive coordination delays
- You must increase reach on short line to assist coordination



Phase Distance Pilot Tripping Zone

- Number of relay elements is limited
- Step Zone 2 or Step Zone 3 can be reused as pilot tripping zone
- Independent distance element can be used for more freedom in setting reach

Phase Distance Pilot Blocking Zone

- Pilot blocking zone must be more sensitive to reverse faults than remote relay pilot tripping zone
- Coordination is just as important for hybrid POTT as DCB
- You must coordinate current supervision pickup if CTRs are different

Ground Distance Zones

- Step Zone 1: typically 50−80%
  Underreaching, instantaneous
- Step Zone 2: typically 125−150%
  Overreaching, end-zone coverage with delay
- Step Zone 3: N/A
  Backup functions rely on 67G TOC
- Pilot tripping zone: typically 200%+
  Reach same as phase pilot tripping zone
- Pilot blocking zone
  Must coordinate with remote pilot tripping

Ground Distance Zones

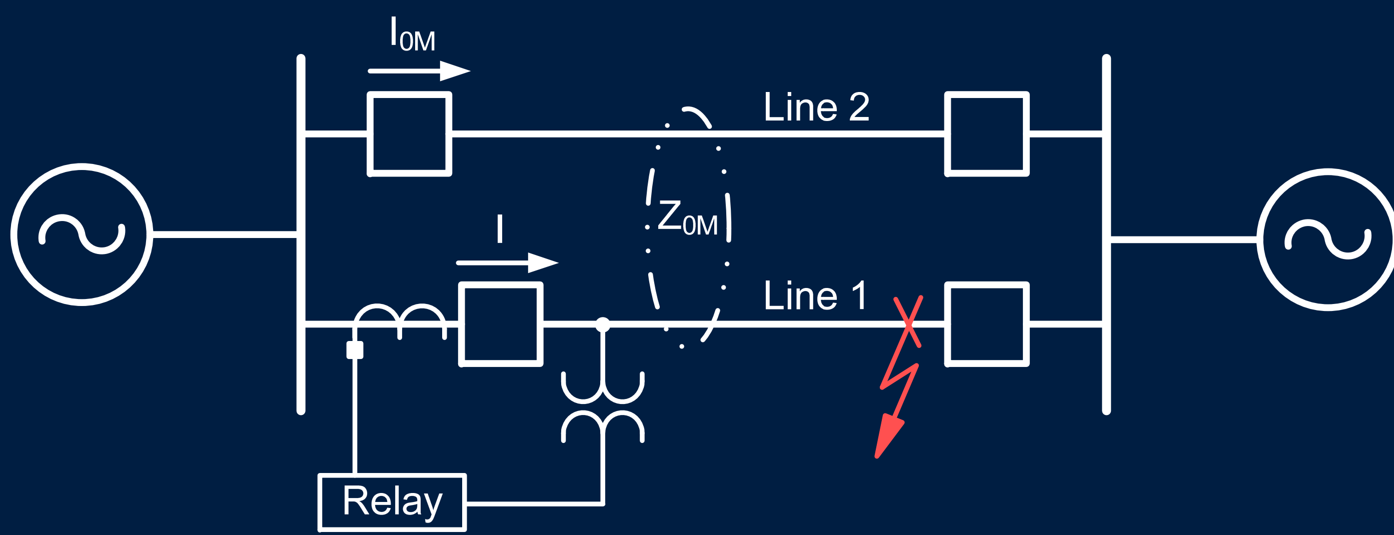
Why Do We Need More Margin Than Phase?

- Zero-sequence impedance is known with less precision
- Can be difficult to find worst-case mutual coupling effect
- Fault resistance can cause overreach

When Do We Disregard Cookbook Margins?

- Same as for phase distance
  Recheck using ground faults because 3I0 will have different distribution than phase current
- When line is mutually coupled

Mutual Coupling Affects Reach



$$Z_{APP} = \frac{V_a}{I_a + k_0 I_r} = mZ_{1L} + mZ_{0M}\frac{I_{0M}}{(I_a + k_0 I_r)}$$

Mutual Coupling Affects Reach

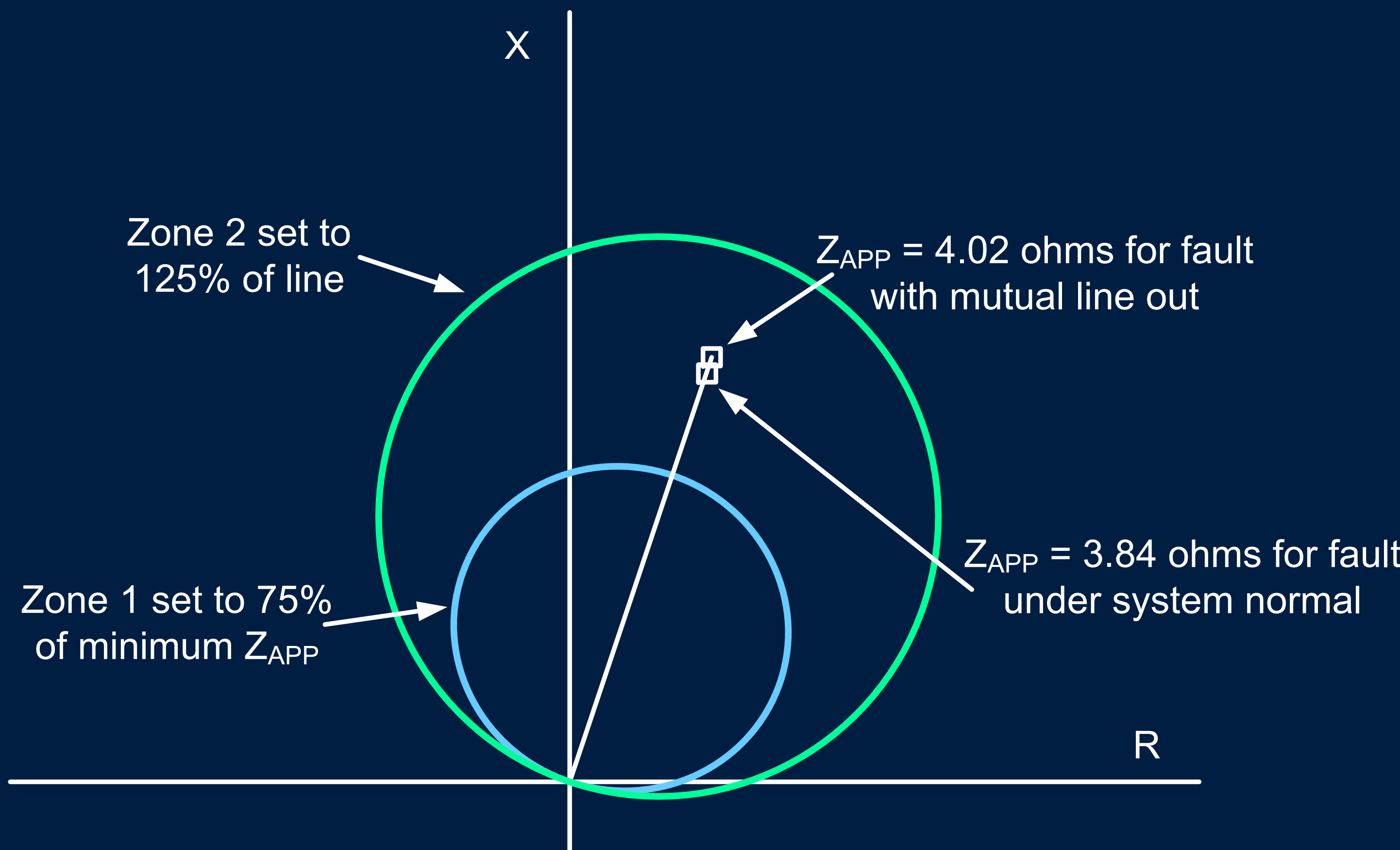
- Z_{APP} depends on current through mutually coupled line
- Z_{APP} is reduced when mutually coupled line is out of service and grounded at both ends

Mutual Coupling, Ground Distance

Check Conditions for Remote Bus Fault

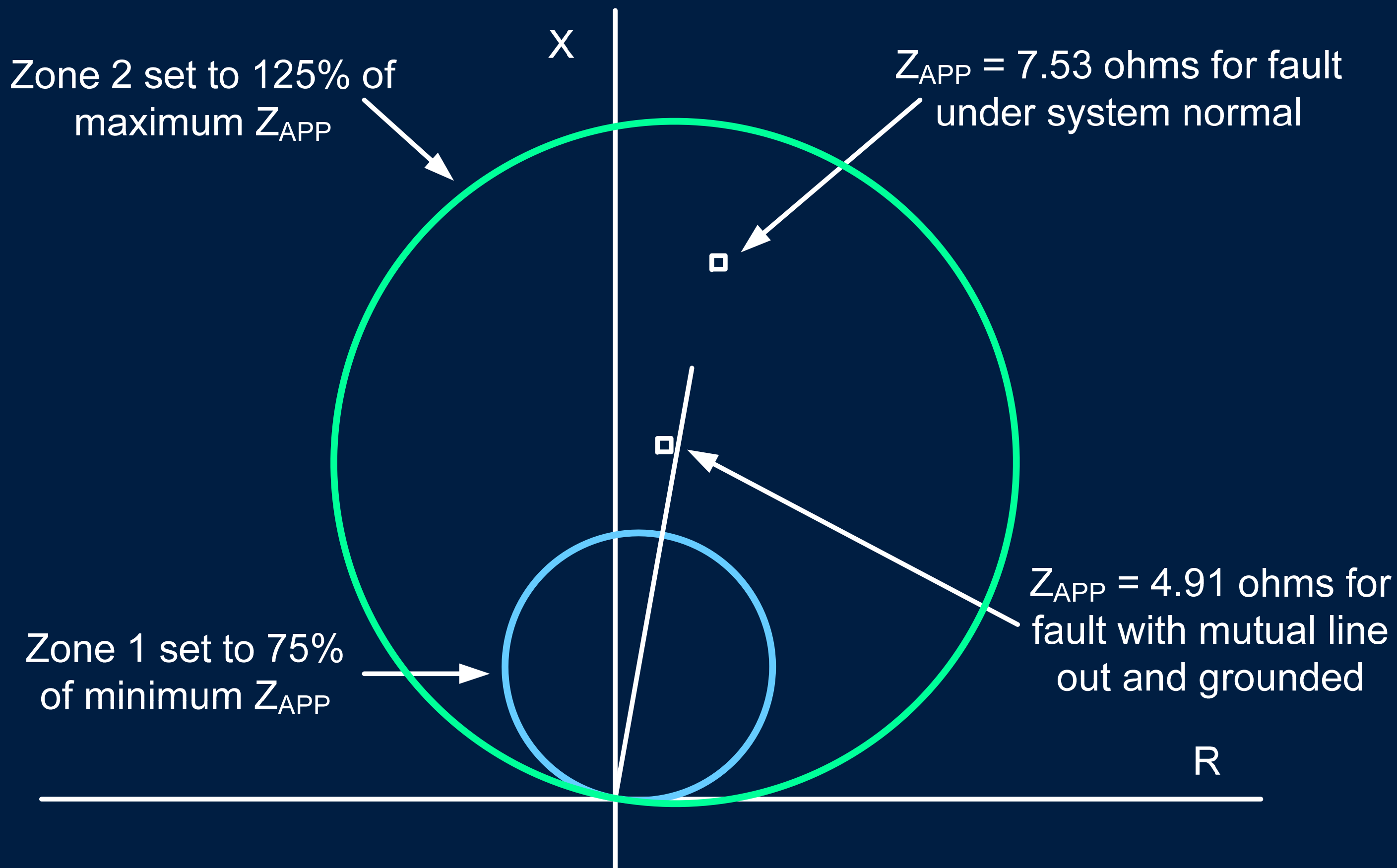
- Z_{APP} under normal conditions
- Z_{APP} when mutually coupled line is out
- Z_{APP} when mutually coupled line is out and grounded

Mutual Coupling
Coupling Between 138 and 69 kV



Mutual Coupling

Parallel Line



Ground Overcurrent

- Most uncertainty in zero-sequence network
- Higher zero-sequence line impedance
- High fault resistance possible
- Speed dichotomy
  - Little impact on stability and power quality
  - High impact on public safety

Ground Overcurrent Elements

- Instantaneous overcurrent
  - Security: 150% of maximum external fault current (N − 2)
  - Dependability: 150% pickup for close-in fault
- Inverse-time overcurrent
  - Security: above 10% winter emergency
  - Dependability: 200–300% pickup for minimum internal fault
- Automated coordination for time dial

Pilot Ground Overcurrent

- Pilot blocking element − set it low but above 10% winter emergency
- Pilot tripping element
  - Security: 200% margin with remote pilot blocking
  - Dependability: 200% pickup for minimum internal fault
- Margin adjustment if lower pickup is needed

Impedance-Based Directional Element

- Element measures source impedance to fault
- For reverse faults, impedance is in front of relay
  - Measured value is at least the line impedance
  - Boundary between forward and reverse is half line impedance

Do Not Use Automatic Settings When…

- There is low or no line impedance
- Pilot tripping or pilot blocking pickups are below default current thresholds
- A pilot scheme is used and CTRs are different at each terminal
- You are protecting series-compensated or three-terminal lines

Selecting Impedance-Based Directional Elements

$$Z_2 = \frac{\mathrm{Re}\left[V_2 (I_2 \bullet 1\angle Z1ANG)^* \right]}{\left| I_2 \right|^2}$$

- Z_2 with Z_0 fallback is suitable for most applications
- Z_2 only for mutually coupled lines

Summary

- Determine if cookbook settings can be applied to protected line
- Calculate appropriate security and dependability limits
- Record using thorough documentation

Questions?