Distance Relays 101

30th Annual
Hands-On Relay School
March 2013

Jon F. Daume
BPA (Retired)
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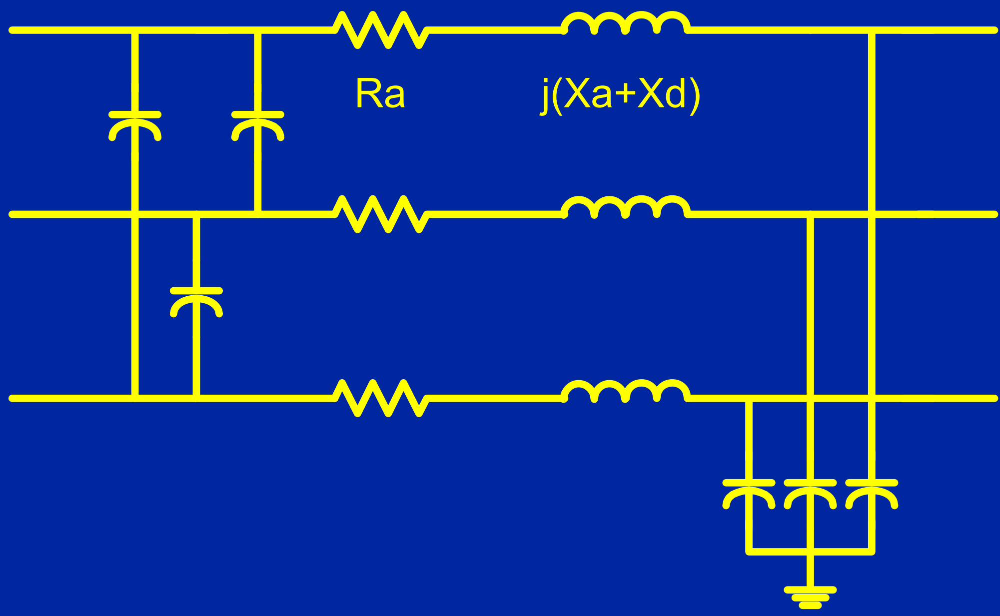
Distance Relays

- Common protective relay for non radial transmission lines
- Fast and consistent trip times
  - Instantaneous trip for faults within zone 1
  - Operating speed little affected by changes in source impedance
- Detect multiphase faults
- Ground distance relays detect ground faults
- Directional capability

Transmission Line Impedance

- Z ohms/mile = $R_a + j(X_a + X_d)$
- R_a, X_a function of conductor type, length
- X_d function of conductor spacing, length
- $X_a + X_d \gg R_a$ at higher voltages



Line Angles vs. Voltage Level

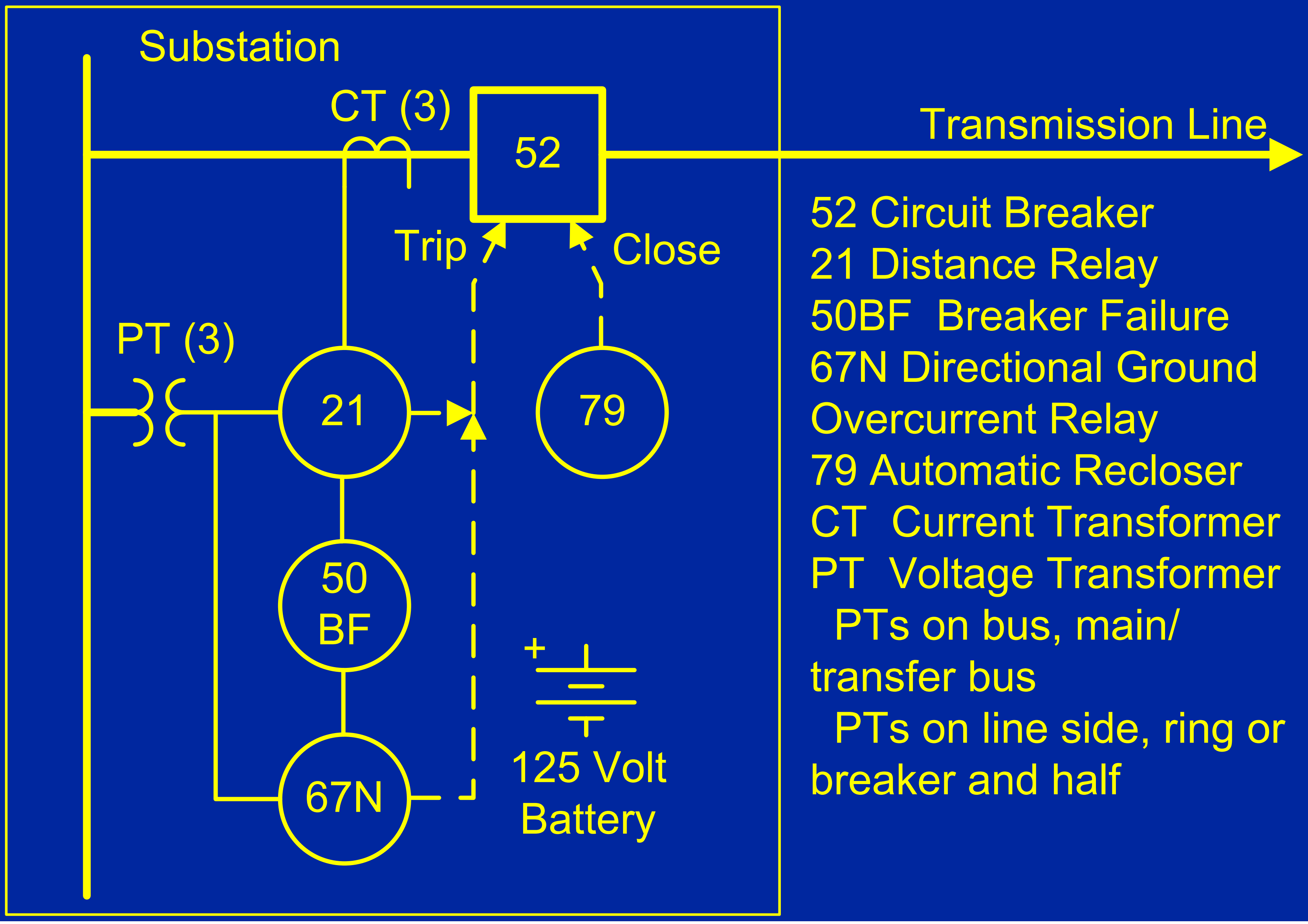
$$Z = \sqrt{[R_a^2 + j(X_a+X_d)^2]}$$

$$\angle\theta\,^\circ = \tan^{-1}(X/R)$$

Voltage Level	Line Angle ($\angle\theta\,^\circ$)
7.2 - 23 kV	20 - 45 degrees
23 - 69 kV	45 - 75 degrees
69 - 230 kV	60 - 80 degrees
230 - 765 kV	75 - 89 degrees

$\angle\theta\,^\circ$ generally used to set relay maximum torque angle (MTA)

Typical Line Protection



52 Circuit Breaker
21 Distance Relay
50BF Breaker Failure
67N Directional Ground
Overcurrent Relay
79 Automatic Recloser
CT Current Transformer
PT Voltage Transformer
  PTs on bus, main/
transfer bus
  PTs on line side, ring or
breaker and half

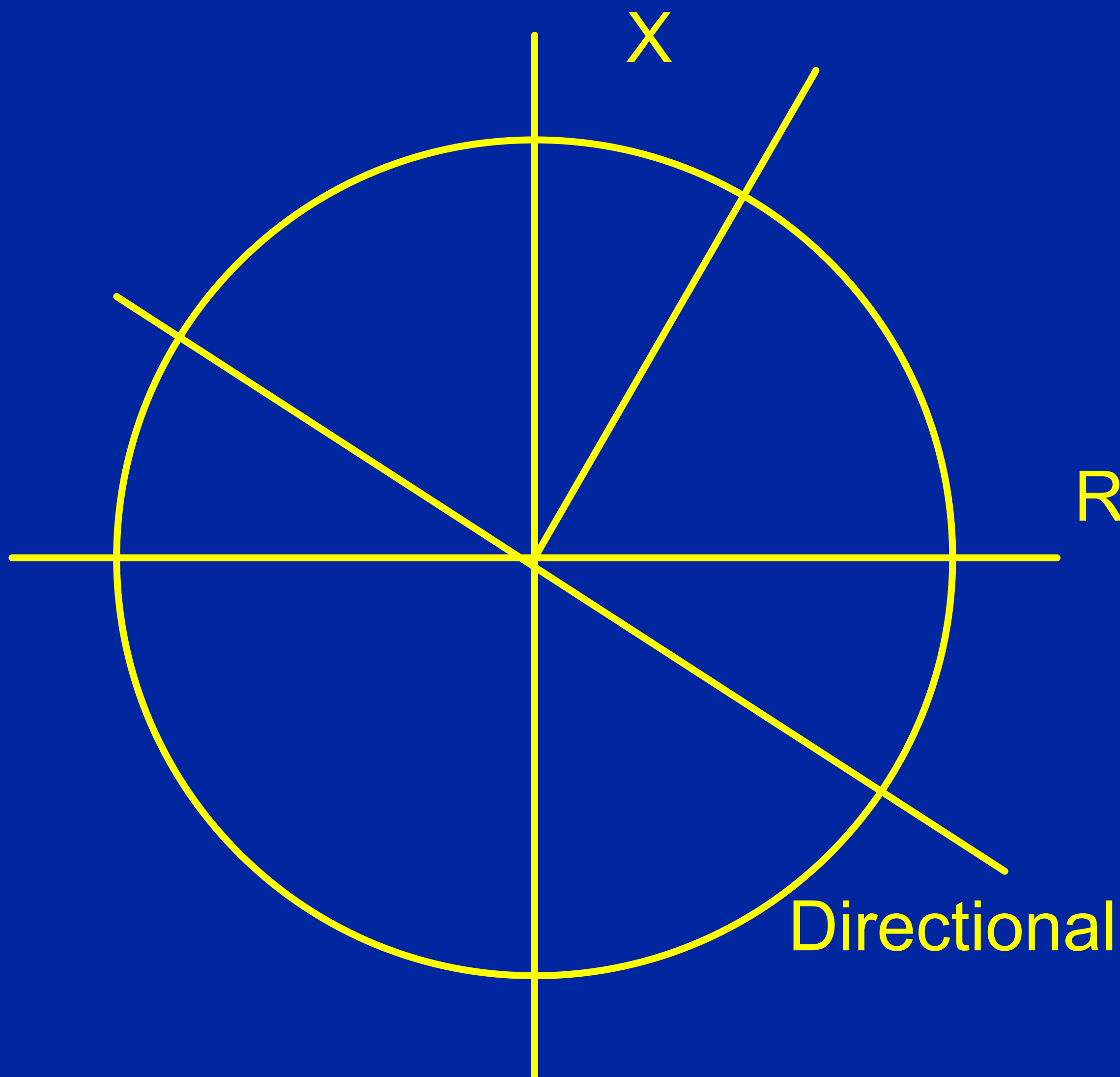
Instrument Transformers

- $Z_{secondary} = Z_{primary}$ x CTR / VTR
- The PT location determines the point from which impedance is measured
- The CT location determines the fault direction
- Very important consideration for
  - Transformer terminated lines
    - If PTs and CTs on different sides of transformer, must consider transformer turns ratio
  - Series capacitors

Original Distance Relay

- True impedance characteristic
  - Circular characteristic concentric to RX axis
- Required separate directional element
- Balance beam construction
  - Similar to teeter totter
  - Voltage coil offered restraint
  - Current coil offered operation
- Westinghouse HZ
  - Later variation allowed for an offset circle

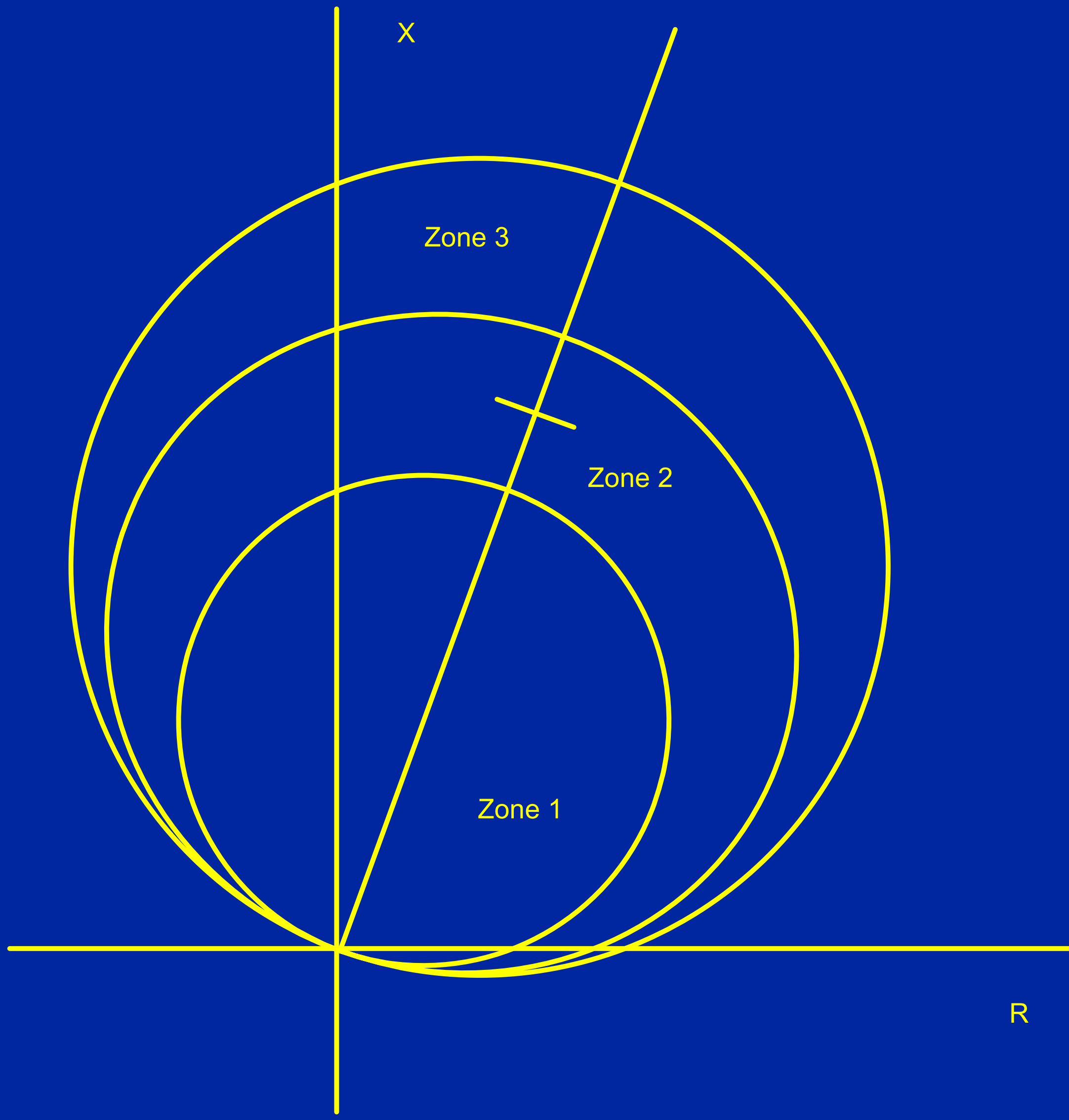
Impedance Characteristic



mho Characteristic

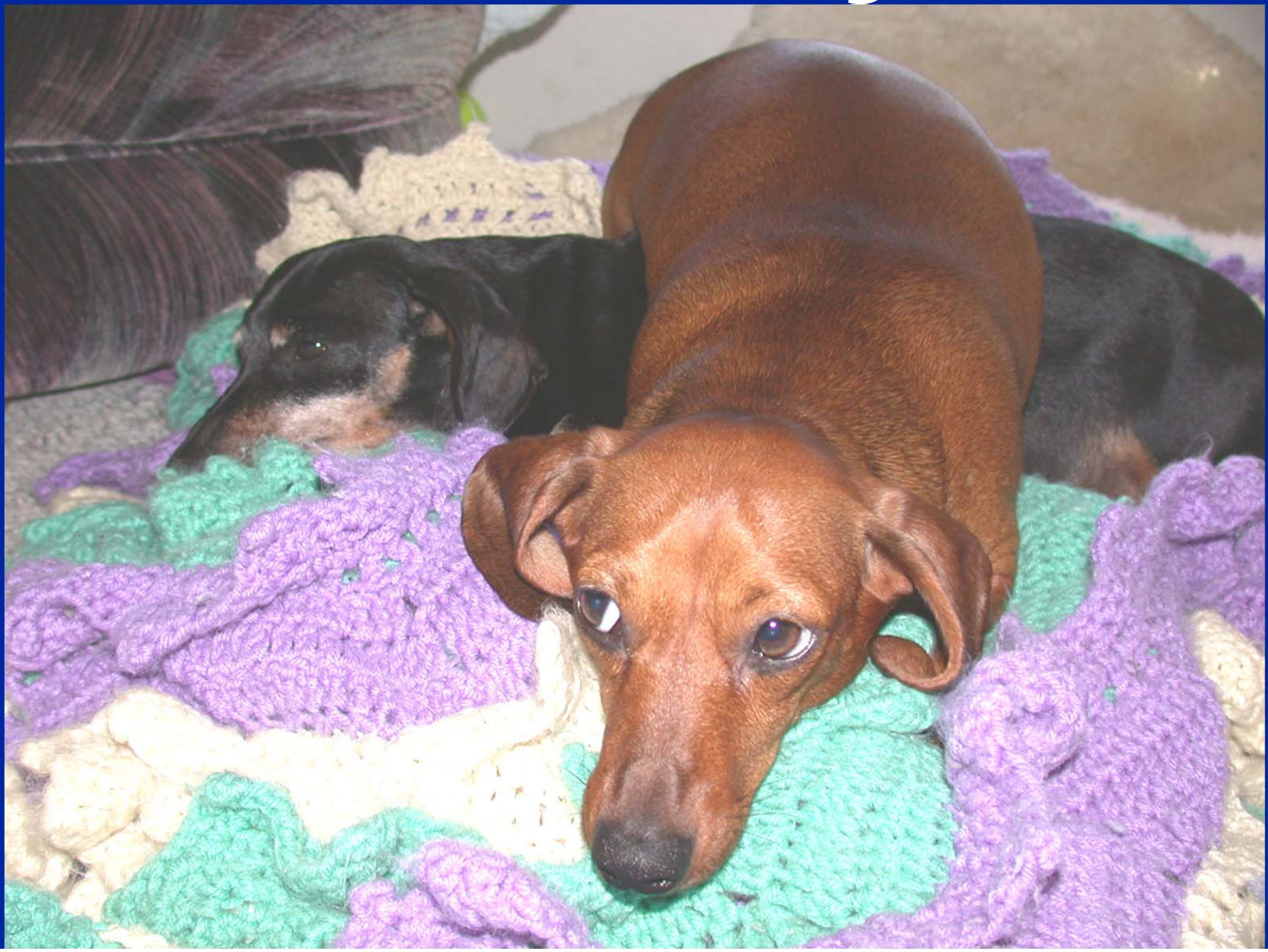
- Most common distance element in use
- Circular characteristic
  - Passes through RX origin
  - No extra directional element required
- Maximum torque angle, MTA, usually set at line angle, $\angle\theta$ °
  - MTA is diameter of circle
- Different techniques used to provide full fault detection depending on relay type
  - Relay may also provide some or full protection for ground faults

3 Zone mho Characteristic

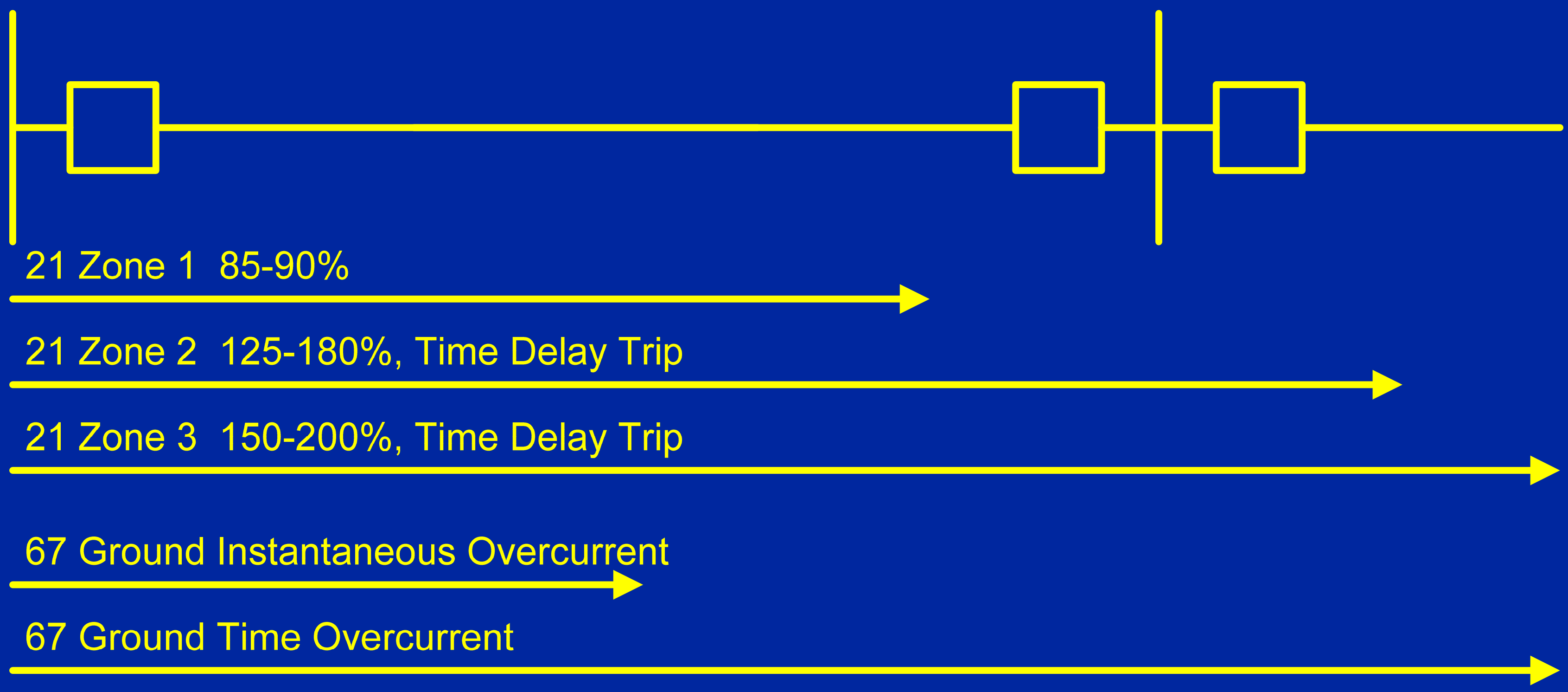


3 Zone Distance Elements Mho Characteristic

Overlapping & Redundant Systems



Typical Reaches



Typical Relay Protection Zones

Coordination Considerations

- Zone 1
  - 80 to 90% of Line impedance
  - Account for possible errors
    - Line impedance calculations
    - CT and PT Errors
    - Relay inaccuracy
  - Instantaneous trip

Coordination Considerations

- Zone 2
  - 125% or more of line impedance
    - Consider strong line out of service
    - Consider lengths of lines at next substation
  - Time Delay Trip
    - > 0.25 seconds (15 cycles)
    - Greater than BFR clearing time at remote bus
    - Must be slower if relay overreaches remote zone 2's.
  - Also consider load encroachment
  - Zone 2 may be used with permissive overreach transfer trip w/o time delay

Coordination Considerations

- Zone 3
  - Greater than zone 2
    - Consider strong line out of service
    - Consider lengths of lines at next substation
  - Time Delay Trip
    - > 1 second
    - Greater than BFR clearing time at remote bus
    - Must be longer if relay overreaches remote zone 3's.
  - Must consider load encroachment

Coordination Considerations

- Zone 3 Special Applications
  - Starter element for zones 1 and 2
  - Provides current reversal logic for permissive transfer trip (reversed)
  - May be reversed to provide breaker failure protection
  - Characteristic may include origin for current only tripping
  - May not be used

Problems for Distance Relays

- Fault in front of relay
- Apparent Impedance
- Load encroachment
- Fault resistance
- Power swings

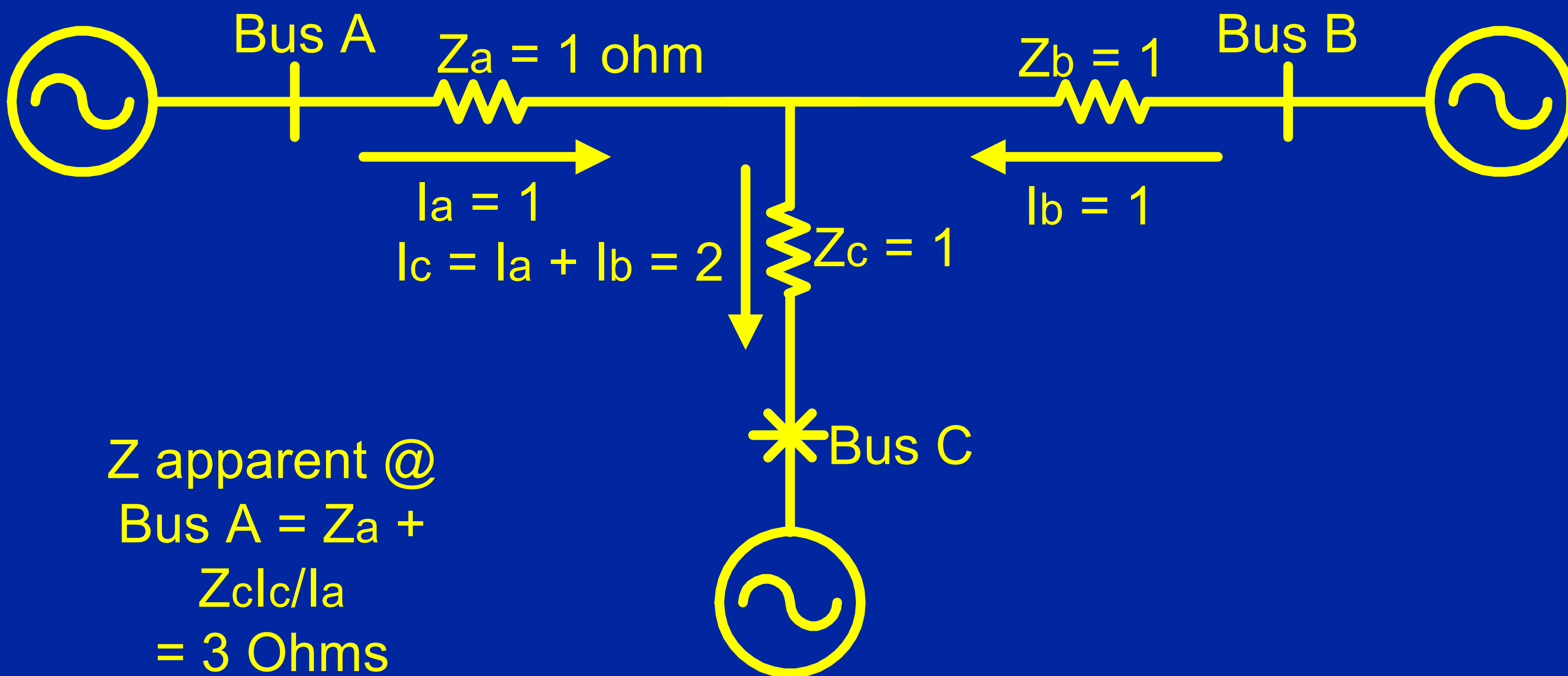
3 Phase Fault in Front of Relay

- No voltage to make impedance measurement
  – Use a potential memory circuit in distance relay
- Use a non-directional, instantaneous overcurrent relay (50-Dead line fault relay)
- Utilize switch into fault logic
  – Allow zone 2 instantaneous trip

Apparent Impedance

- 3 Terminal lines with apparent impedance or infeed
- Fault resistance also looks like an apparent impedance
- Most critical with very short or unbalanced legs
- Results in
  - Shorter zone 1 reaches
  - Longer zone 2 reaches and time delays
- Pilot protection may be required
- Fault studies necessary to determine settings

Apparent Impedance



Z apparent @
Bus A = Z_a +
$Z_c I_c / I_a$
= 3 Ohms

Apparent Impedance

Coordination Considerations

- Zone 1
  - Set to 85 % of actual impedance to nearest terminal
- Zone 2
  - Set to 125 + % of apparent impedance to most distant terminal
  - Zone 2 time delay must coordinate with all downstream relays
- Zone 3
  - Back up for zone 2

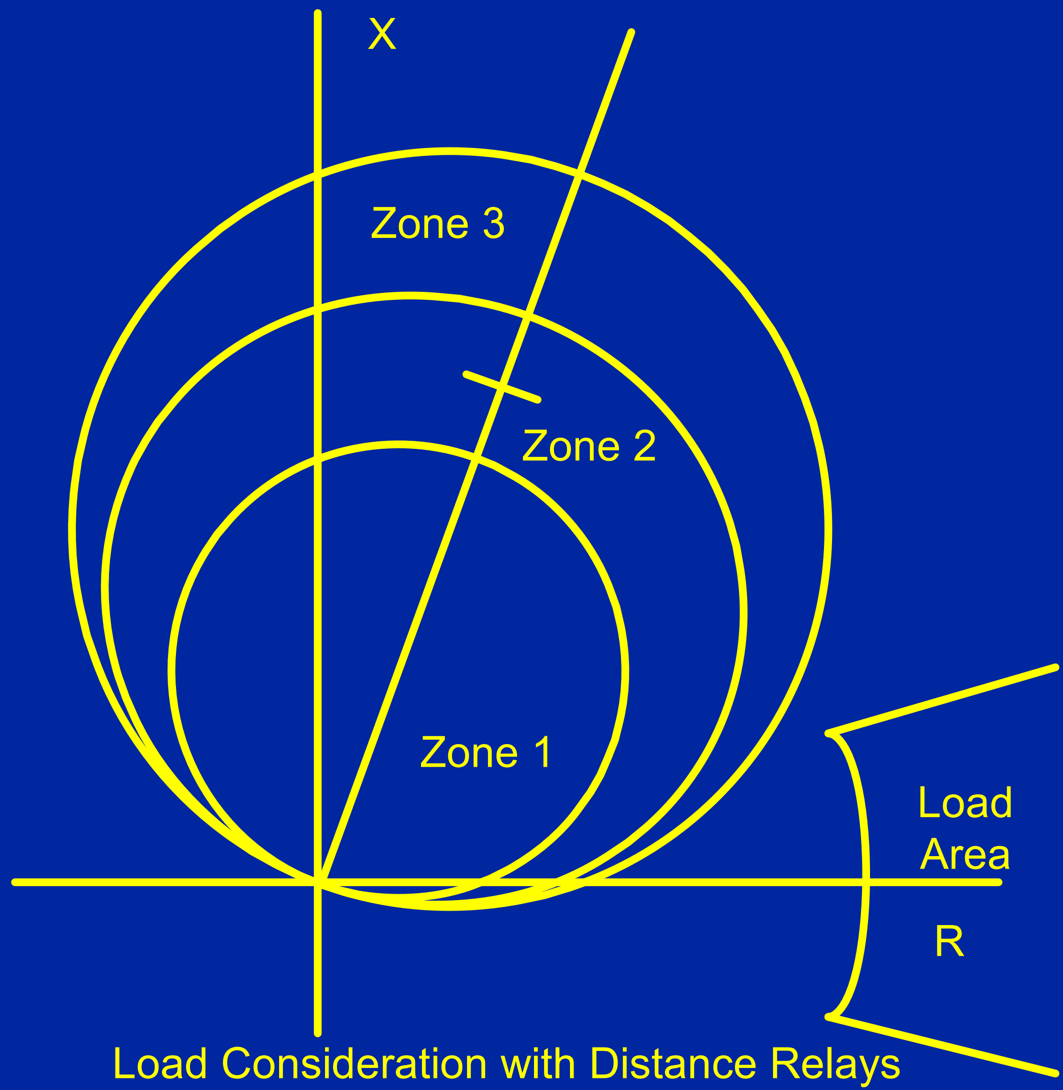
Load Encroachment

- Z Load = kV^2 / MVA
  - Long lines present biggest challenge
  - Heavy load may enter relay characteristic
- Serious problem in August, 2003 East Coast Disturbance
- NERC Loading Criteria
  - 150 % of emergency line load rating
  - Use reduced voltage (85 %)
  - 30° Line Angle
    - Z @ 30° = Z @ MTA cos (∠MTA° -∠30°) for mho characteristic

Load Encroachment

- NERC Loading Criteria
  - Applies to zone 2 and zone 3 phase distance
    - Other overreaching phase distance elements
  - All transmission lines > 200 kV
  - Many transmission lines > 100 kV
- Solutions
  - Don't use conventional zone 3 element
  - Use lens characteristic
  - Use blinders or quadrilateral characteristic
  - Tilt mho characteristic toward X axis
  - Utilize special relay load encroachment characteristic

Load Encroachment

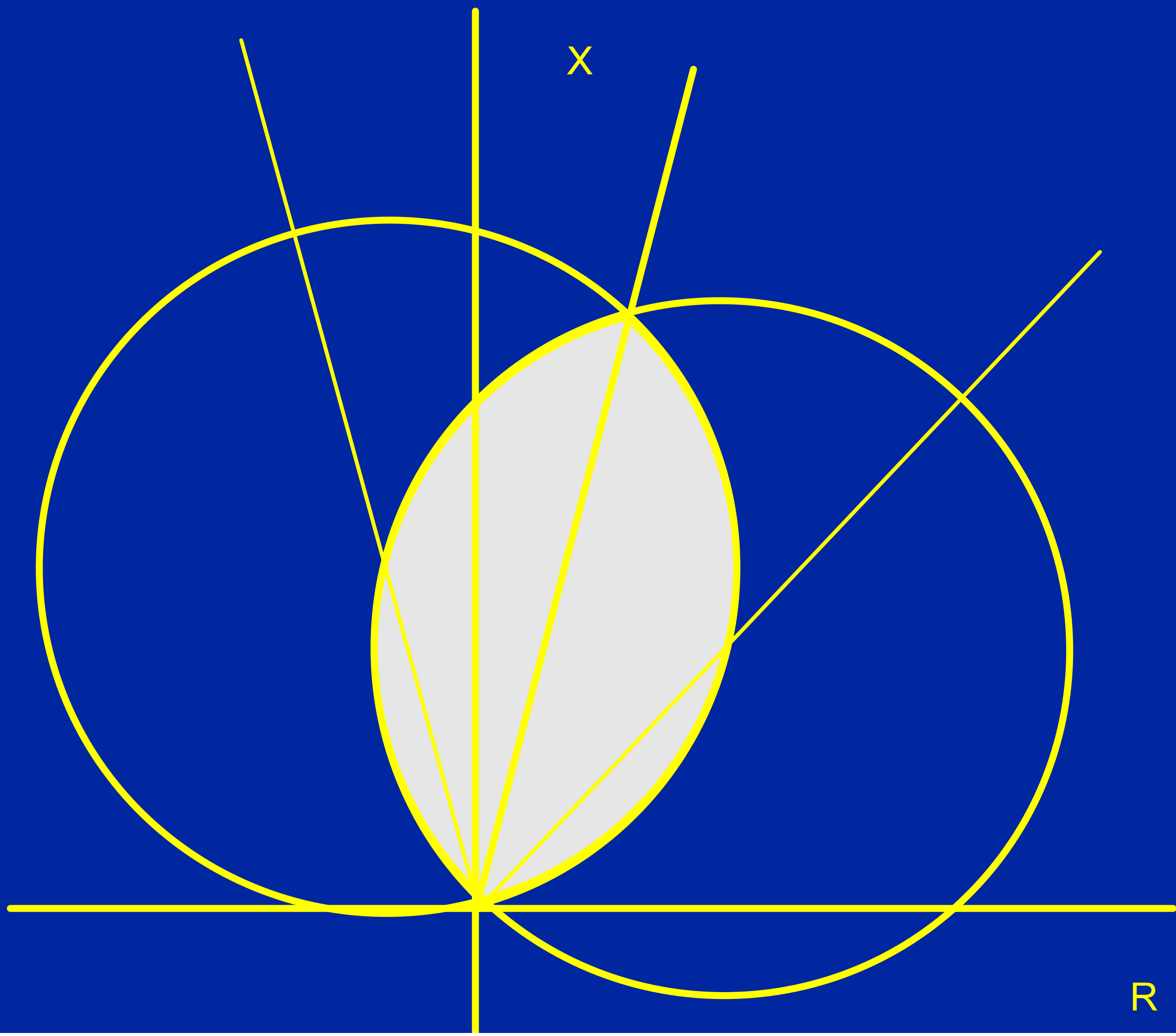


Load Consideration with Distance Relays

Lens Characteristic

- Ideal for longer transmission lines
- More immunity to load encroachment
- Less fault resistance coverage
- Generated by merging the common area between two mho elements

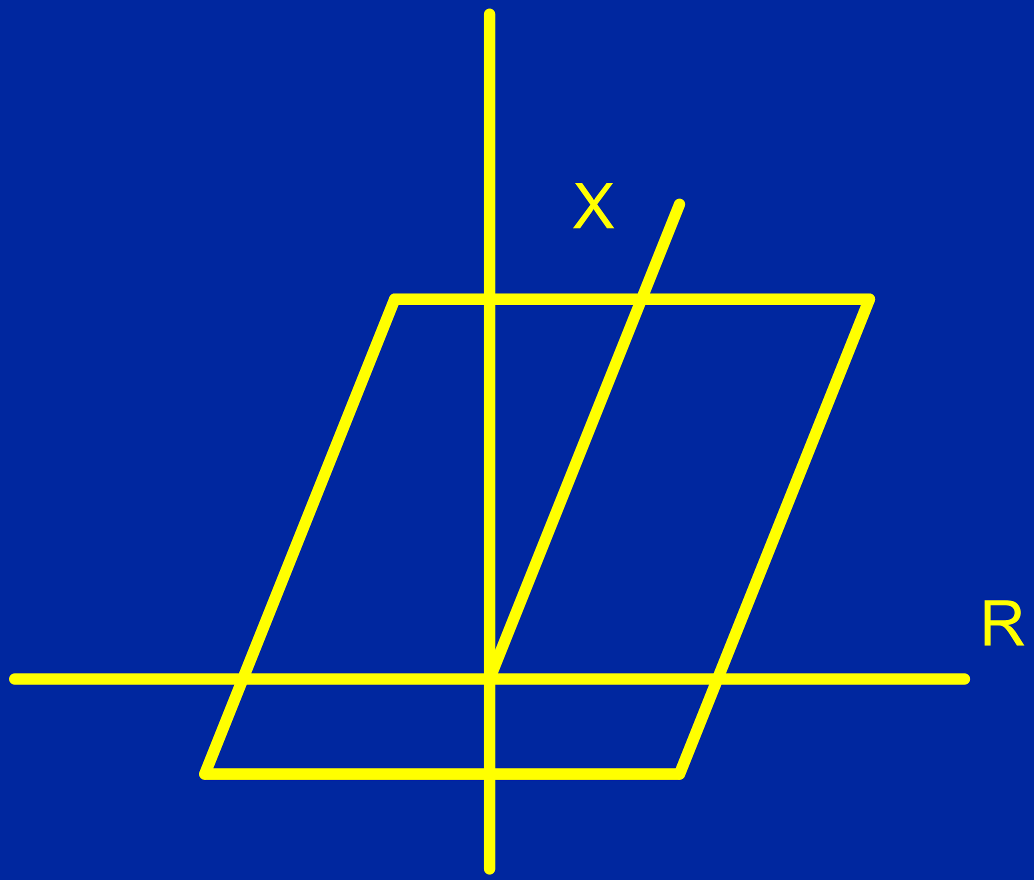
Lens Characteristic



Quadrilateral Characteristic

- High level of freedom in settings
- Blinders on left and right can be moved in or out
  - More immunity to load encroachment (in)
  - More fault resistance coverage (out)
- Generated by the common area between
  - Left and right blinders
  - Below reactance element
  - Above directional element

Quadrilateral Characteristic

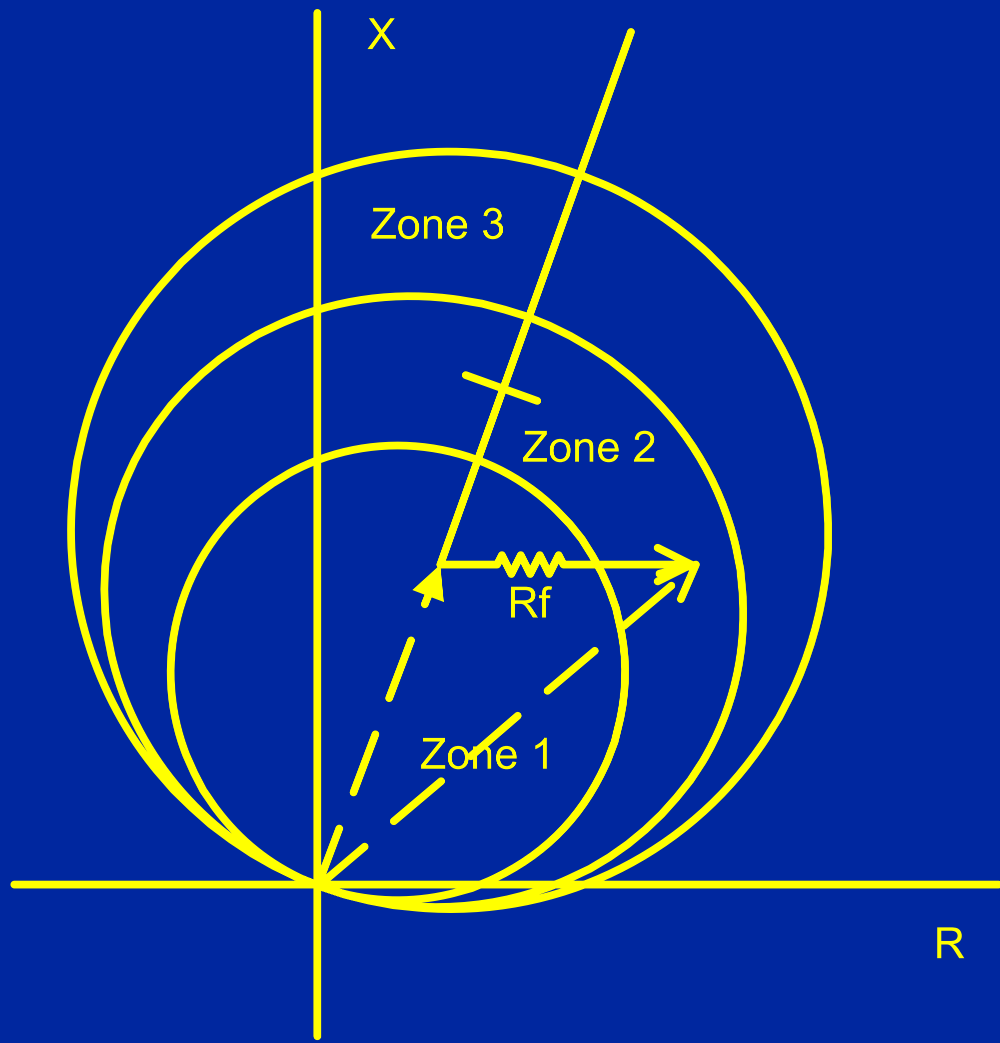


Quadrilateral Characteristic

Fault Resistance

- Most severe on short lines
- Difficult for ground distance elements to detect
- Solutions:
  - Tilt characteristic toward R axis
  - Use wide quadrilateral characteristic
  - Use overcurrent relays for ground faults

Fault Resistance

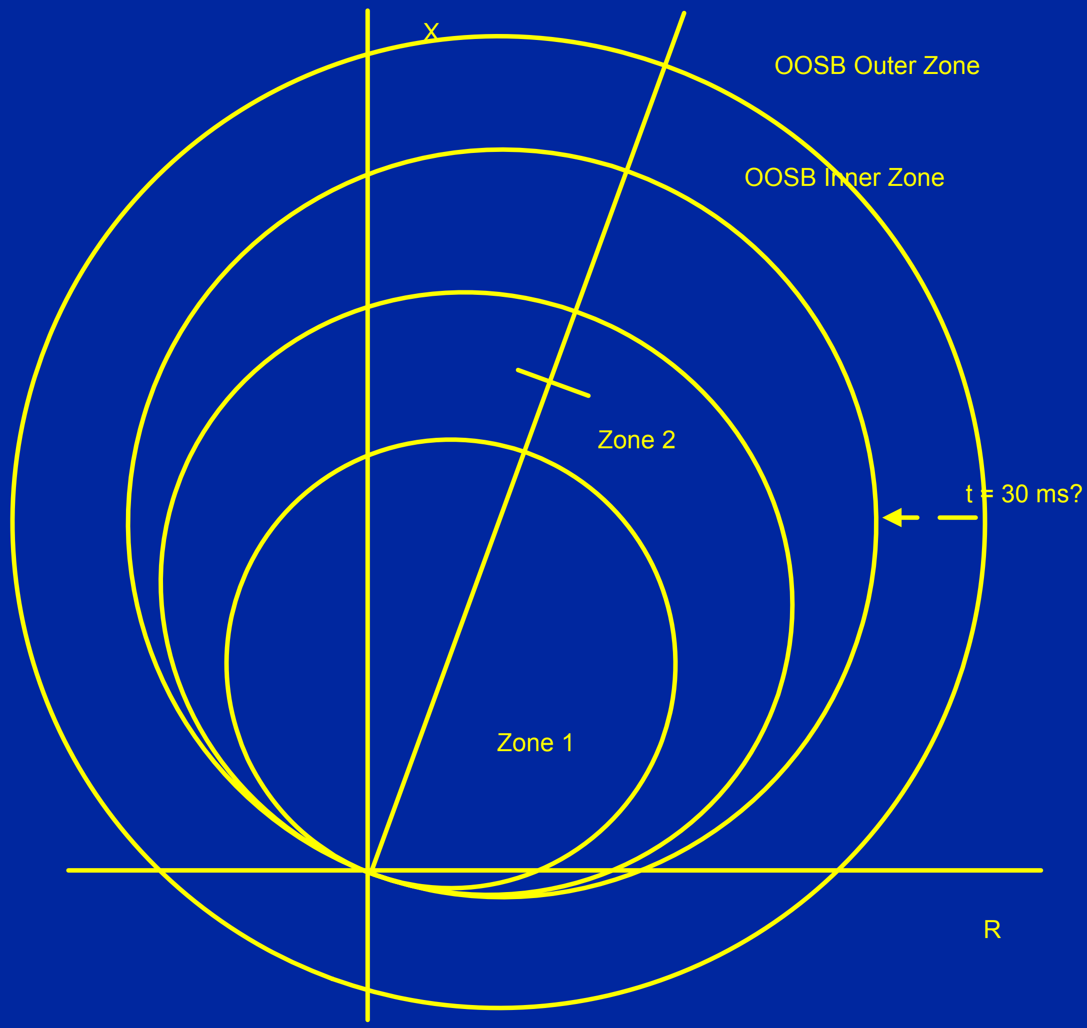


Fault Resistance Effect on a Mho Characteristic

Power Swing

- Power swings can cause false trip of 3 phase distance elements
- Option to
  - Block on swing (Out of step block)
  - Trip on swing (Out of step trip)
    - Out of step tripping may require special breaker
    - Allows for controlled separation
- Extra, outside element starts timer
- Inner element stops timer
  - Faults move faster than swings

Out Of Step Blocking

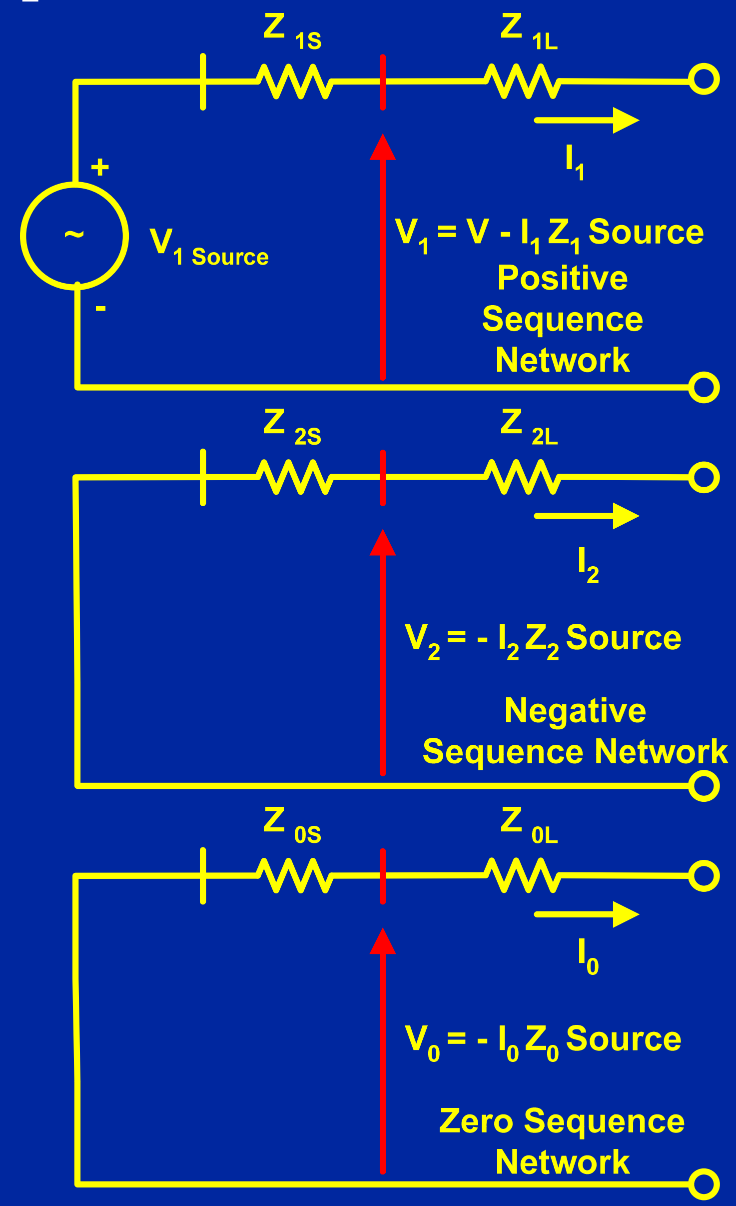


Typical Out Of Step Block Characteristic

Fault Types

- 3 Phase fault
  - Positive sequence impedance network only
- Phase to phase fault
  - Positive and negative sequence impedance networks in parallel
- One line to ground fault
  - Positive, negative, and zero sequence impedance networks in series
- Phase to phase to ground fault
  - Positive, negative, and zero sequence impedance networks in parallel

Sequence Networks



What Does A Distance Relay Measure?

- Phase current and phase to ground voltage

  $Z_{relay} = V_{LG}/I_L$ (Ok for 3 phase faults only)

- Phase to phase current and phase to phase voltage

  $Z_{relay} = V_{LL}/I_{LL}$ (Ok for 3 phase, PP, PPG faults)

- Phase current + compensated ground current and phase to ground voltage

  $Z_{relay} = V_{LG}/(I_L + 3K_nI_0)$ (Ok for 3 phase, 1LG, PPG faults)

K_n - Why?

- Using phase/phase or phase/ground quantities does not give proper reach measurement for 1LG fault
- Using zero sequence quantities gives the zero sequence source impedance, not the line impedance
- Current compensation (K_n) does work for ground faults
- Voltage compensation could also be used but is less common

Current Compensation, K_n

$K_n = (Z_{0L} - Z_{1L})/3Z_{1L}$

- Z_{0L} = Zero sequence transmission line impedance
- Z_{1L} = Positive sequence transmission line impedance

$I_{Relay} = I_A + 3I_0(Z_{0L} - Z_{1L})/3Z_{1L} = I_A + 3K_nI_0$

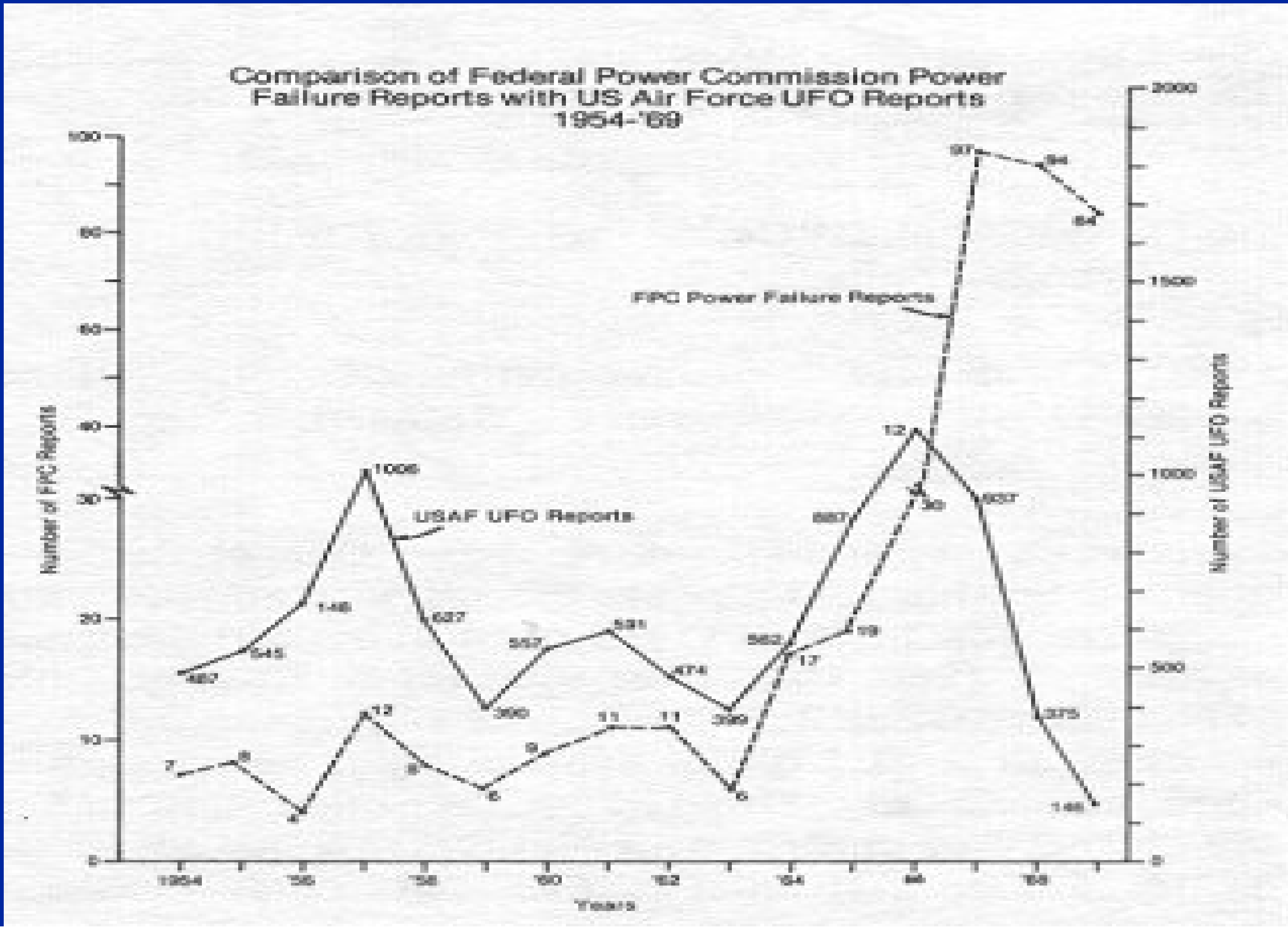
$Z_{Relay} = V_{A\ Relay}/I_{Relay} = V_A/(I_A + 3K_nI_{0)} = Z_{1L}$

Reach of ground distance relay with current compensation is based on positive sequence line impedance, Z_{1L}

Current Compensation, K_n

- Current compensation (K_n) does work for ground faults.
- $K_n = (Z_{0L} – Z_{1L})/3Z_1$
  - K_n may be a scalar quantity or a vector quantity with both magnitude and angle
- Mutual impedance coupling from parallel lines can cause a ground distance relay to overreach or underreach, depending upon ground fault location
- Mutual impedance coupling can provide incorrect fault location values for ground faults

UFOs vs. Power Outages



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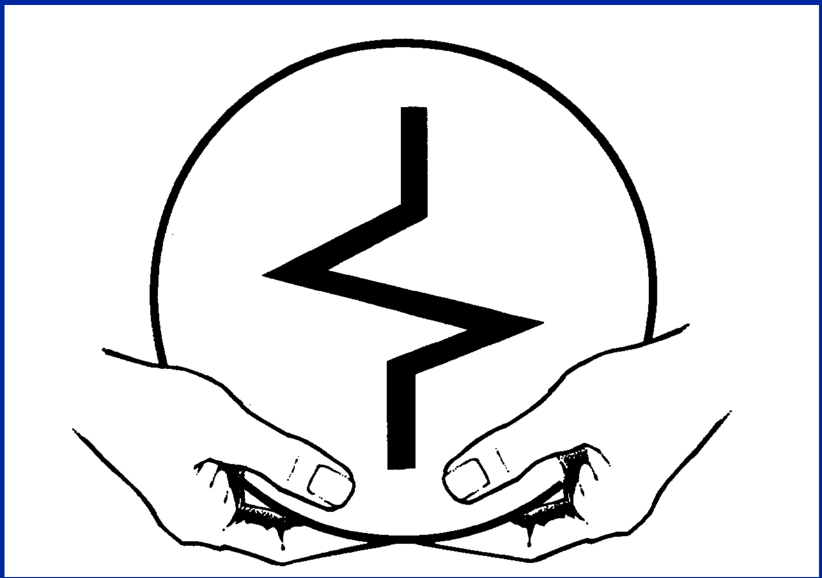

Jon F. Daume (retired)
System Protection & Control,
Bonneville Power Administration

937-642-4349
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