Transmission Protection Overview

2012 Hands-On Relay School

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Transmission Line Protection

Objective

General knowledge and familiarity with transmission protection schemes

Transmission Line Protection
Topics

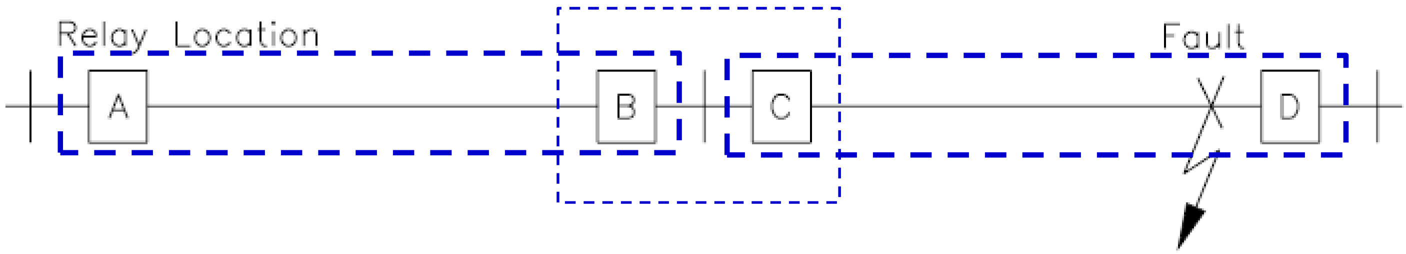
- Primary/backup protection
- Coordination
- Communication-based schemes
- Breaker failure protection
- Out-of-step relaying
- Synchronism checking

Primary Protection Function

Trip for abnormal system conditions that may

- Endanger human life
- Damage system equipment
- Cause system instability

Protection Zones



- Primary protection
  - first line of defense
- Backup protection
  - operates when primary fails

How Can A Protection System Fail?

- Current or voltage signal supply
- Tripping voltage supply
- Power supply to the relay
- Protective relay
- Tripping circuit
- Circuit breaker

Two Types of Backup

- Remote backup
  - Located at different station
  - No common elements
- Local backup
  - Located at same station
  - Few common elements
    - Separate relays
    - Independent tripping supply and circuit
    - Different current and voltage inputs

Remote vs Local Backup

- Speed
  - Remote is slower
- Selectivity
  - Remote disconnects larger part of the system
- Price
  - Local requires additional equipment

Primary and Backup Coordination

- Best selectivity with minimum operating time
- Achieved through settings
  - Pick up values
  - Time delays

Coordination Types Considered

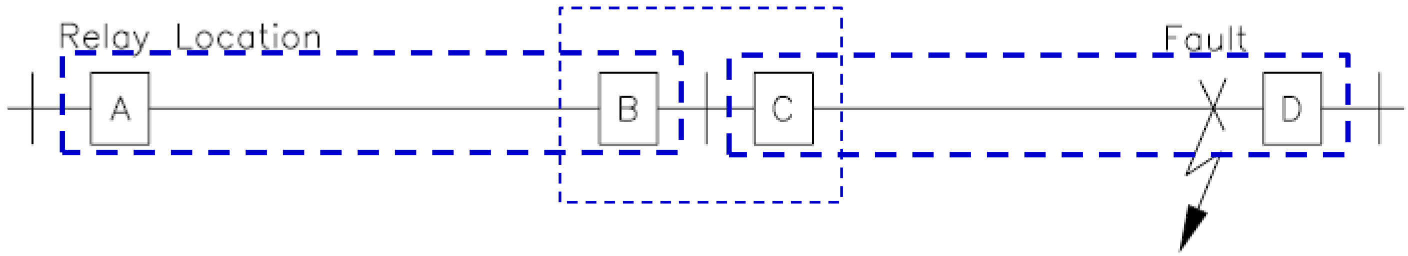
- Time-Overcurrent
- Time-Stepped Distance
- Communication-Aided Schemes

Time-Overcurrent Relays

- Definite-Time Overcurrent
  - Operate in a settable time delay when the current exceeds the pickup value
  - Instantaneous operation – no intentional time delay
- Inverse-Time Overcurrent
  - Operating curve defined by limiting the total fault energy ($K_d = I^2 \cdot t$)

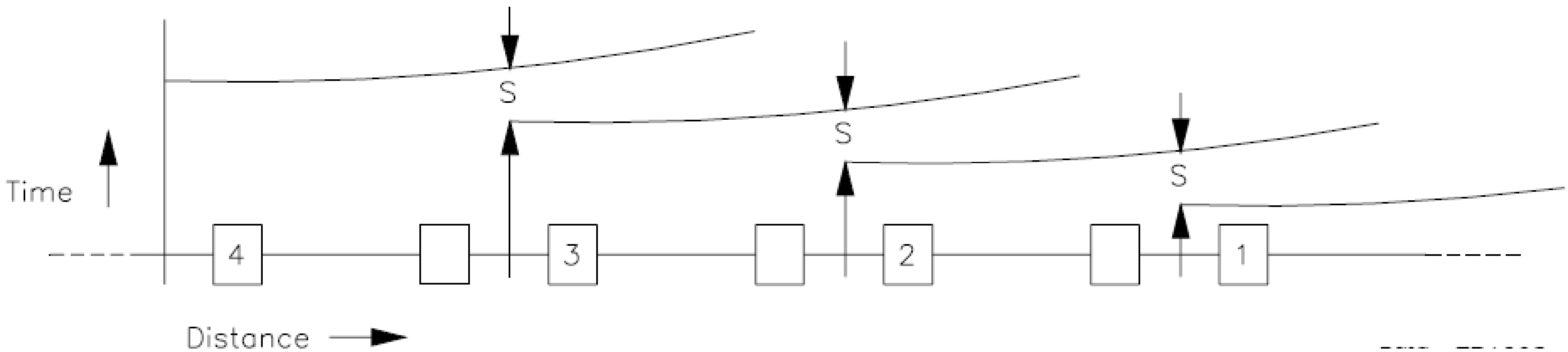
Time-Overcurrent Coordination

Inverse-Time Overcurrent



- Pickup of relay A set low enough to see the fault shown and backup relay C
- Pickup should be above emergency load conditions (phase relays)
- Time delay of relay A should allow relay C to clear the fault first

Time-Overcurrent Coordination



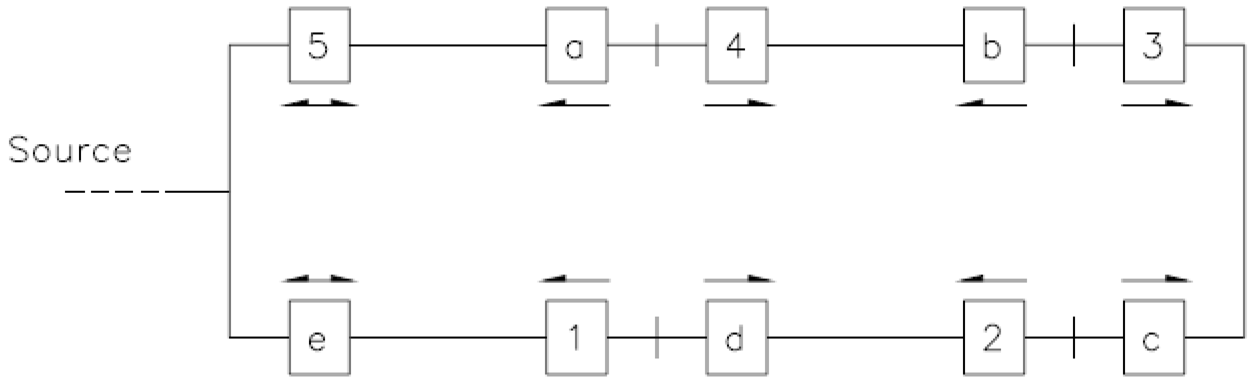
S - Selectivity time delay (aka CTI):

- Breaker operating time
- Overtravel (impulse) time (E/M relays)
- Safety margin

$$0.2s \leq CTI \leq 0.4s$$

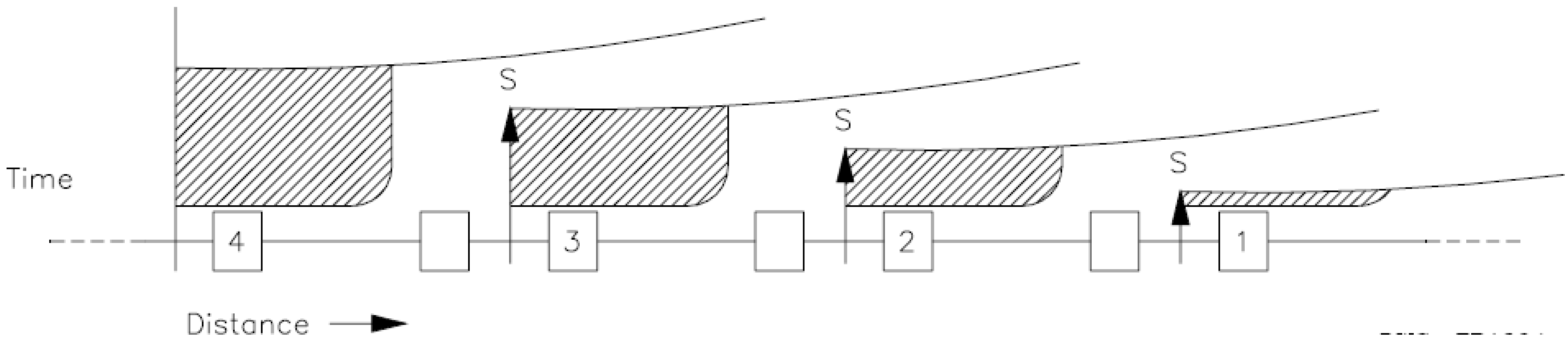
Time-Overcurrent Coordination

Looped Systems



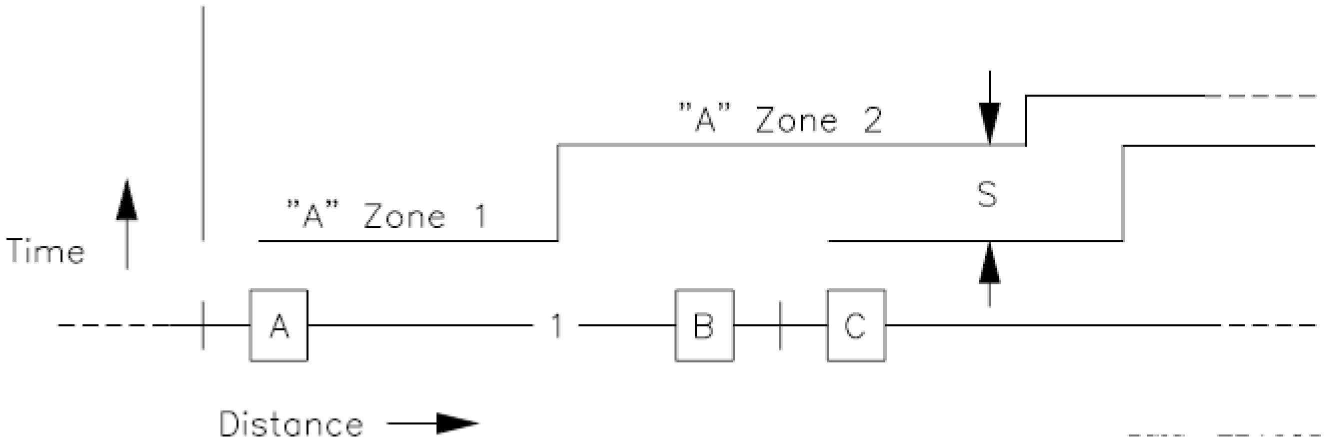
- Directionality required for most relays
- 1-2-3-4-5
- a-b-c-d-e
- Relays at '5' and 'e' can be nondirectional

Instantaneous Overcurrent Protection



- Inverse-Time O/C coordination may result in long time delays
- Instantaneous O/C relays set to trip for faults for ~80% of the line section
  - Significantly reduced tripping times for many faults

Time-Stepped Distance Protection



- Coordination similar to that of inverse-time O/C
- Relay at A set to trip instantaneous for faults in its Zone 1 (reaching ~80% of the line section)
- Relay at A backs up relay at C after Zone 2 timer times out
- Faults at the end of the line also cleared in Zone 2 time

Communication-Based Protection
Rationale

- Distance protection can clear faults instantaneously for 60% to 80% of the line length
- Protection speed may be critical to maintain system stability
- High-speed autoreclosing application

Communication-Based Protection

Communication Mediums

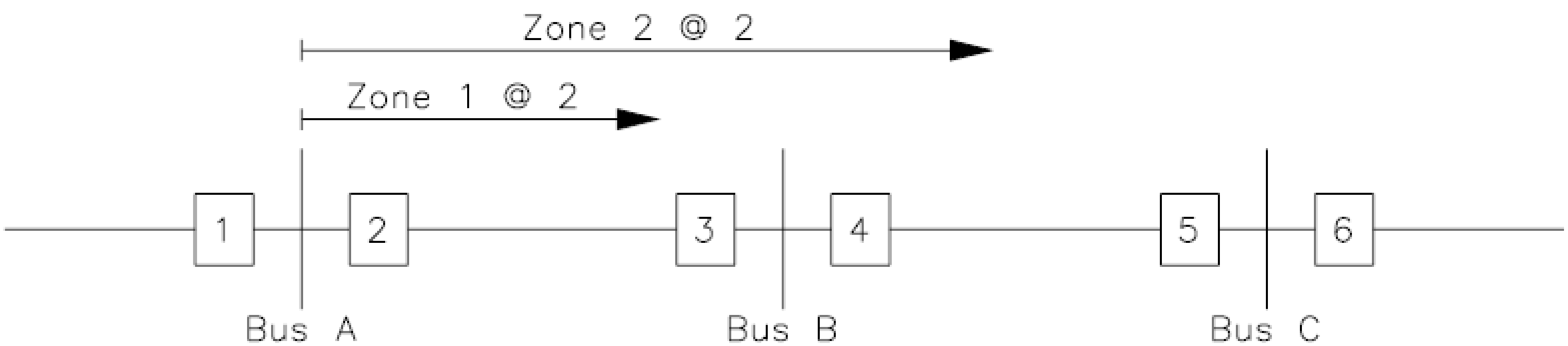
- Power Line Carrier
- Microwave
- Fiber-Optics
- Private and Leased Pilot Channels

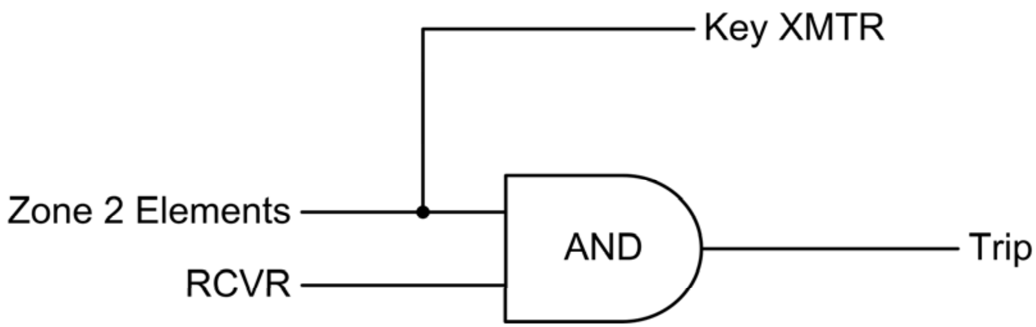
Communication-Based Protection
Scheme Types

- Permissive Overreaching Transfer Trip (POTT)
- Permissive Underreaching Transfer Trip (PUTT)
- Directional Comparison Blocking (DCB)
- Directional Comparison Unblocking (DCUB)
- Direct Underreaching Transfer Trip (DUTT)
- Direct Transfer Trip (DTT)

Permissive Overreaching TT

Protective Zones





Permissive Overreaching TT

- Permissive signal must be detected from the remote end for the communication-aided trip
- Absence of communication channel disables the accelerated tripping

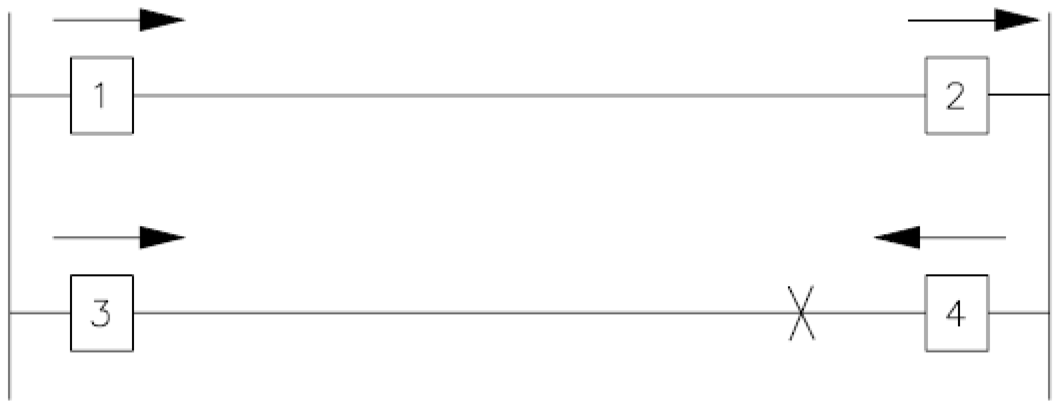
Permissive Overreaching TT

Complications and Concerns

- Desensitization due to infeed
  - Dependability issue – failure to trip high speed
- Current reversal
  - Occurs in parallel lines with sequential tripping
  - Security issue – coupled with long channel reset times may cause trip of the healthy parallel line

Current Reversal

All Sources In



- Z2 at Breaker 1 picks up and sends permissive signal to Breaker 2
- Z2 at Breakers 3 and 4 send permissive signals to each other
- Z1 at Breaker 4 trips instantaneously

Current Reversal

System After Breaker 4 Opens

- Current reverses through the healthy line
- Z2 at Breaker 2 picks up
- If the permissive signal has not reset, Breaker 2 trips on POTT

Current Reversal

Possible Solution

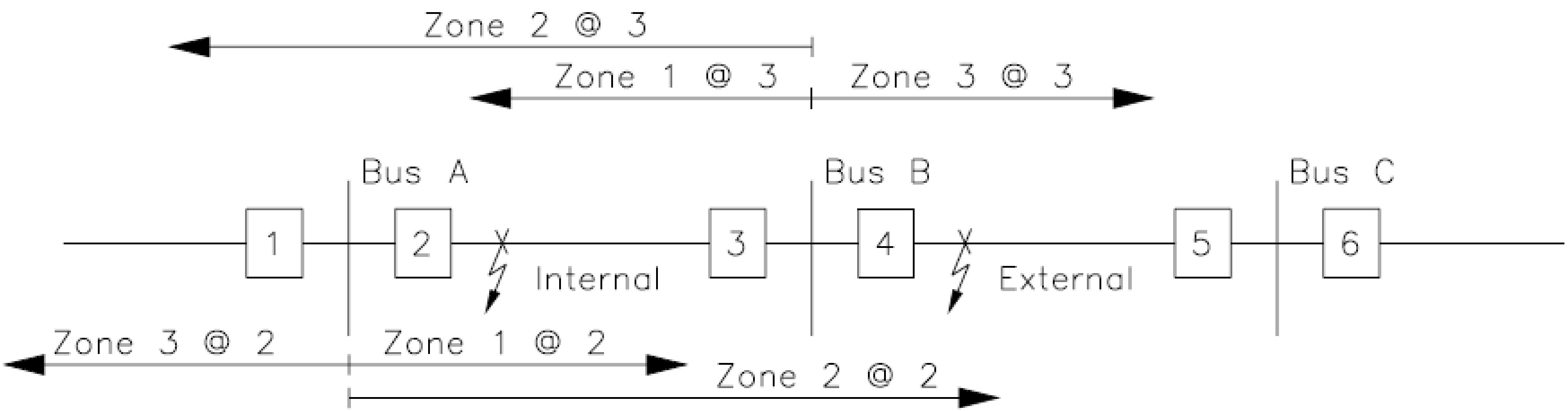
- Timer with instantaneous pickup and time delayed dropout, initiated on reverse Z3
- Delay trip with POTT until the timer drops out

Permissive Underreaching TT

- Similar to POTT but permissive signal sent by underreaching Z1 elements
- At the receiving end, Z2 elements qualify the permissive signal
- No problems with current reversal since Z1 doesn't overreach

Directional Comparison Blocking

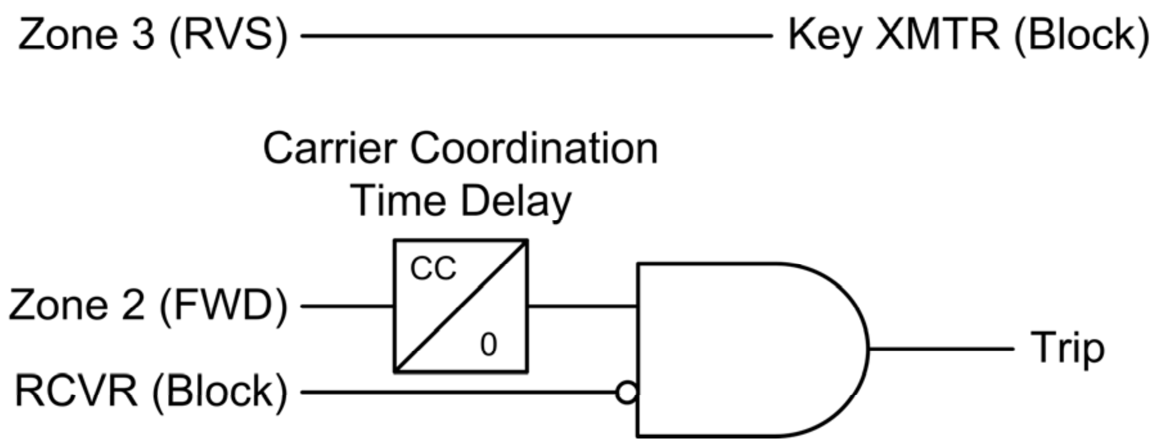
Protective Zones



- Zone 2 elements cover the entire line
- Reverse Zone 3 elements must reach further than the opposite Zone 2 overreach

Directional Comparison Blocking

Basic Logic



- In-section faults will not key transmitter and both ends trip high-speed
- Out-of-section fault will key the transmitter at the nearest end to block the trip at the opposite end

Directional Comparison Blocking

Complications and Concerns

- Coordinating time at fault inception
  - Z3 faster than Z2, but channel delay time reduces the margin
  - Z2 must be slowed down
- External fault clearing
  - Z3 and Z2 race to drop out, if Z3 drops out first Z2 overtrips
  - Z3 operates faster and drops slower
  - Channel reset time helps
  - Slower transmitter key dropout time helps

Directional Comparison Blocking
Complications and Concerns

- External fault clearing failure
  - Local backup provided by time-delayed Z3 or external BF relay clears the near bus
  - Remote backup provided by Z2 clears the line
- Stop preference over start

Directional Comparison Blocking

Complications and Concerns

- Current reversal
- Reach Margin
  - Z3 reaches farther back than remote Z2 by at least 50% of Z2 overreach

Directional Comparison Unblocking

- Essentially the same as POTT
- Requires FSK
- In-section fault may impede communication
- In case of channel loss, a 150 ms window is open when permissive signal is bypassed and Z2 allowed to trip high speed

Direct Underreaching TT

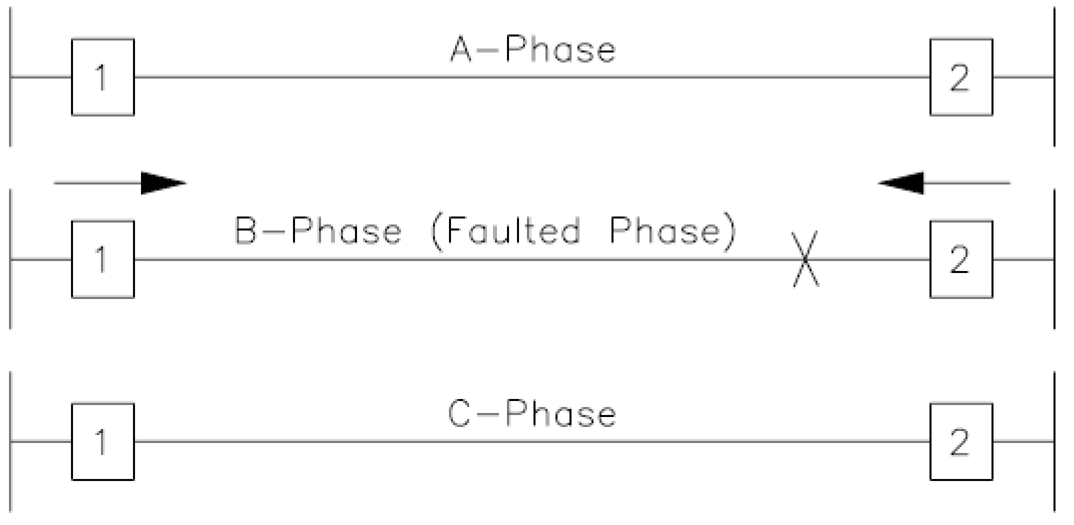
- Underreaching Z1 elements send direct transfer trip
- Noisy channel can cause false trip
- Very secure channel required

Pilotless Accelerated Trip Schemes

- Communication equipment not justifiable in lower voltage transmission applications
- In-section faults may be uniquely determined by system conditions
- Detecting these conditions is all that is needed for high speed tripping

Pilotless Accelerated Trip Schemes

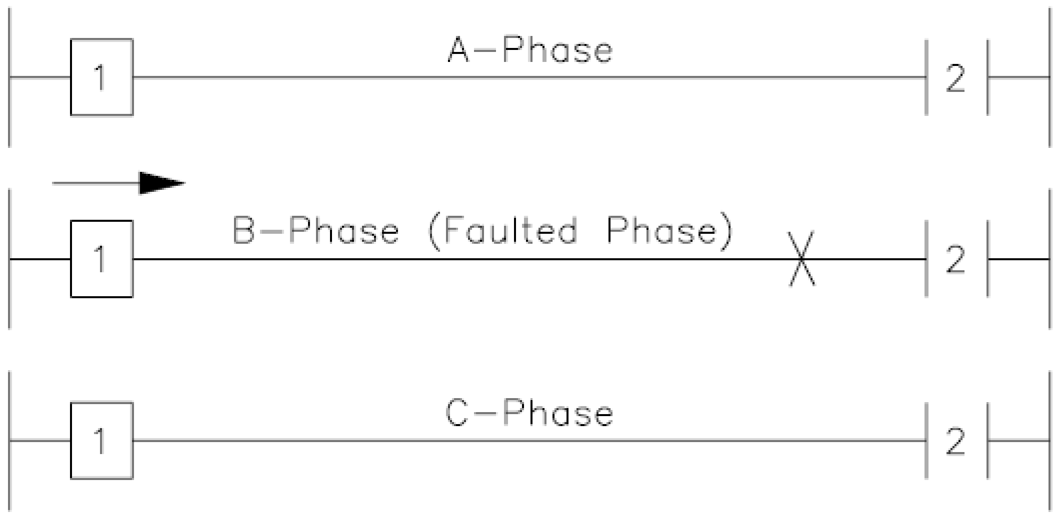
Faulted System with Breakers Closed



After Breaker 2 opens the only current that can flow is the fault current

Pilotless Accelerated Trip Schemes

Faulted System with Breaker 2 Open



Tripping conditions:

- Three-phase load was present before the fault
- Three-phase current was lost
- Current above the threshold detected in at least one phase

Breaker Failure Relaying

- Minimize the damage when a breaker fails to clear a fault
- Trips all sources locally within the critical clearing time to maintain system stability

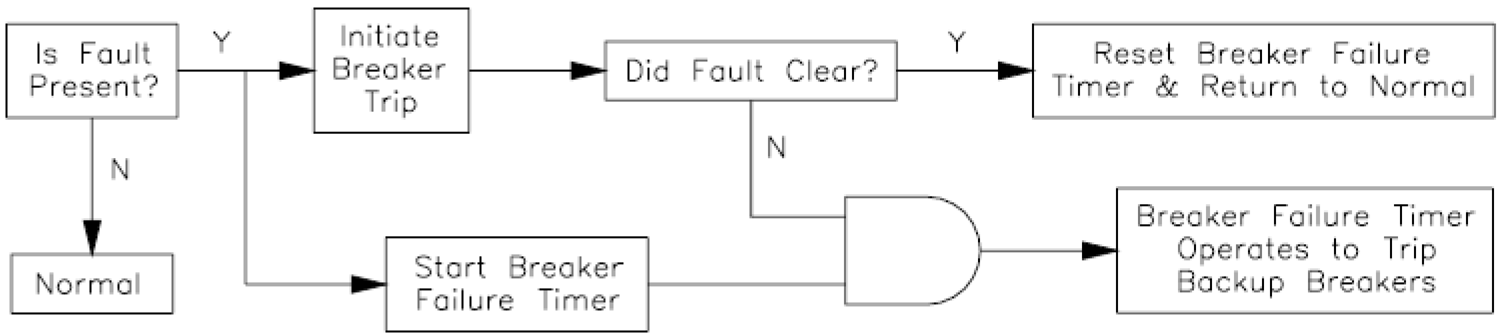
Breaker Failure Relaying

Common Causes of Breaker Failure

- Main breaker poles failed to clear the fault due to inadequate insulating medium
- Open trip coil or trip coil circuit
- Loss of tripping dc
- Mechanical failure of the breaker trip mechanism

Breaker Failure Relaying

Operating Philosophy



- Activated only when a trip signal is issued from protective relay
- If current is above threshold after a pre-set time period, breaker failure condition is declared

Breaker Failure Relaying
Considerations

- Timer settings must take into account the clearing time of the slowest breaker and the reset time of the fault detector
- The effect of any opening resistors in the circuit breakers on the reset time of fault detector
- Substation bus configuration must be taken into account to trip minimum number of breakers
- In multi-breaker schemes, possible transfer trip to the remote end

Out-of-Step Detection and Blocking

Causes of Out-of-Step

- Power swings result from faults, switching, or big changes in load or generation
- Magnitude of the swing depends on the system impedance change during such conditions
- Swings can be stable or unstable

Power Transfer Equation

$$P = P_S = P_R = \frac{V_S V_R}{X} \sin \delta$$

where:

P – power transferred from the sending to the receiving end

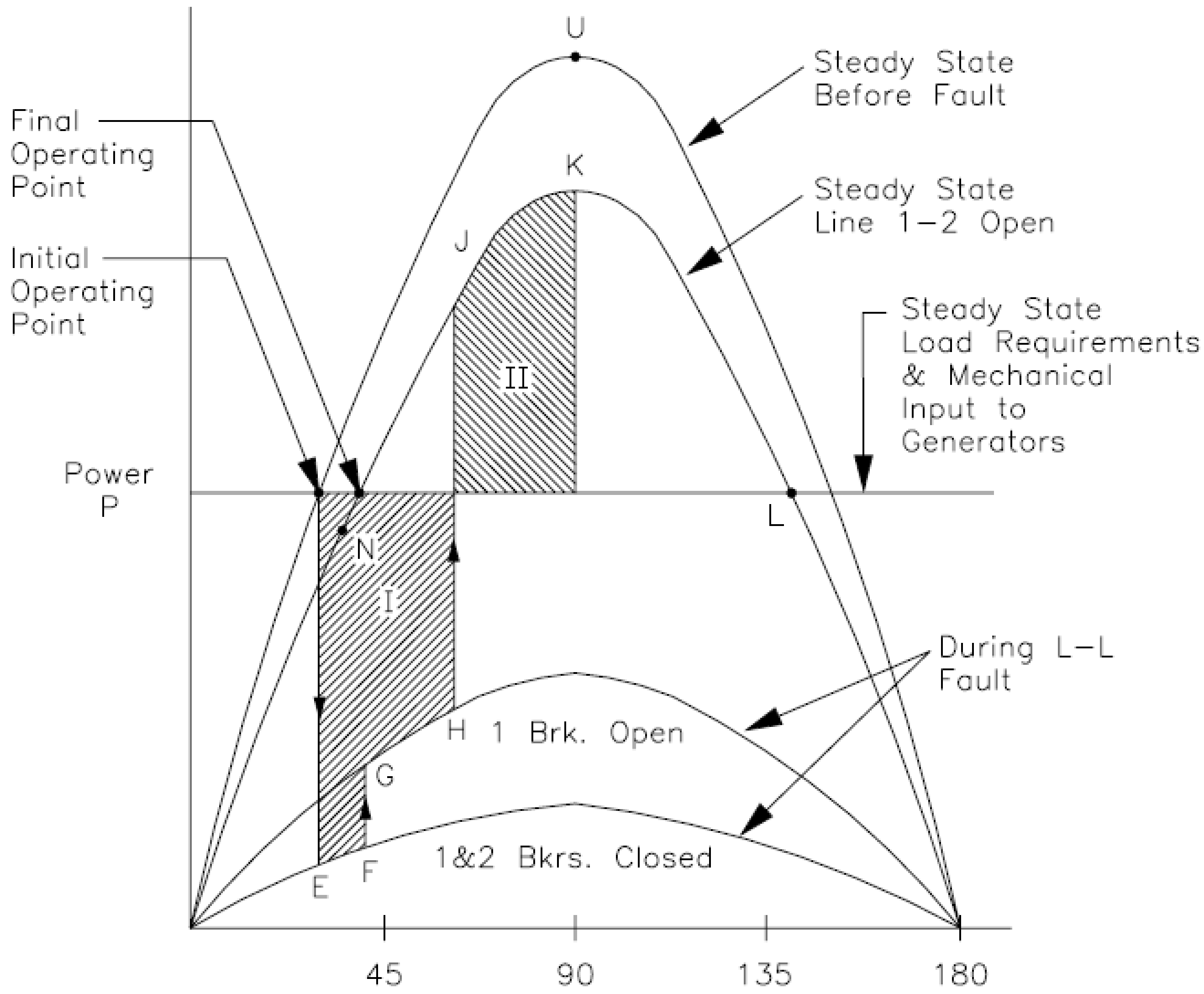
V_S – sending end voltage

V_R – receiving end voltage

δ – angle by which V_S leads V_R

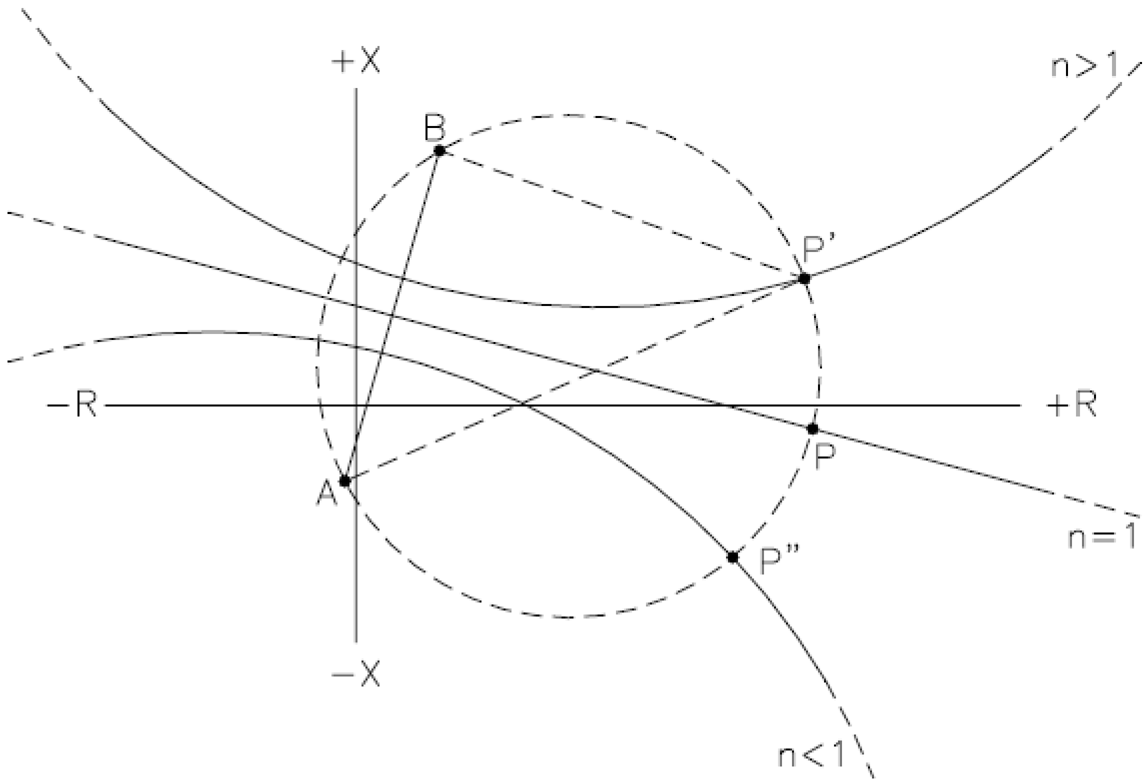
X – total reactance between the sending and receiving end

Power Transfer Curves



Electrical Quantities During Swing

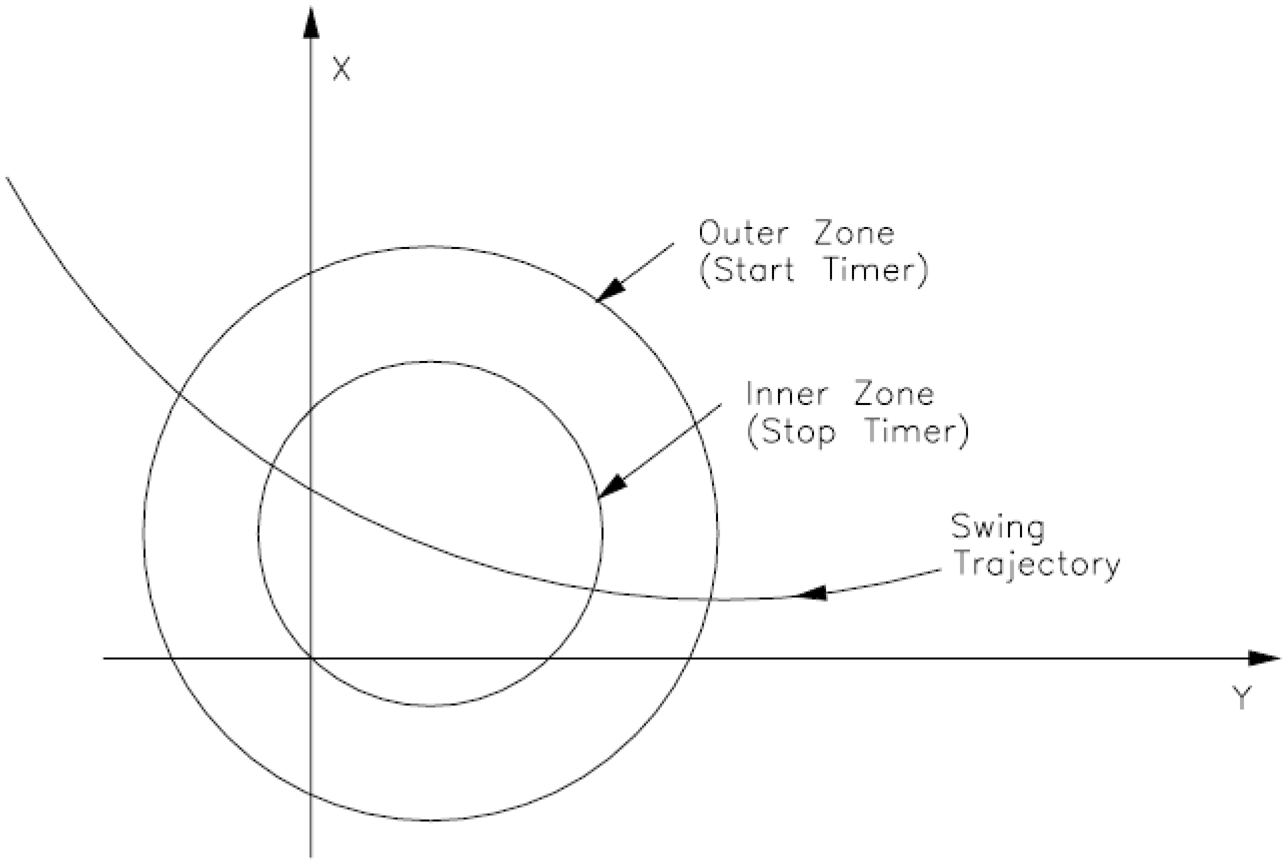
Apparent Impedance Trajectories



Electrical Quantities During Swing
Apparent Impedance Trajectories

- Apparent impedance during power swings can enter into the reach of distance relays
- If the apparent impedance stays longer than the time delay in a given zone, that distance element will trip as for a fault
- To prevent such tripping, out-of-step blocking schemes are employed

Out-of-Step Blocking Distance Elements



If the timer expires between the two zones, out-of-step condition is declared and selected distance elements are blocked

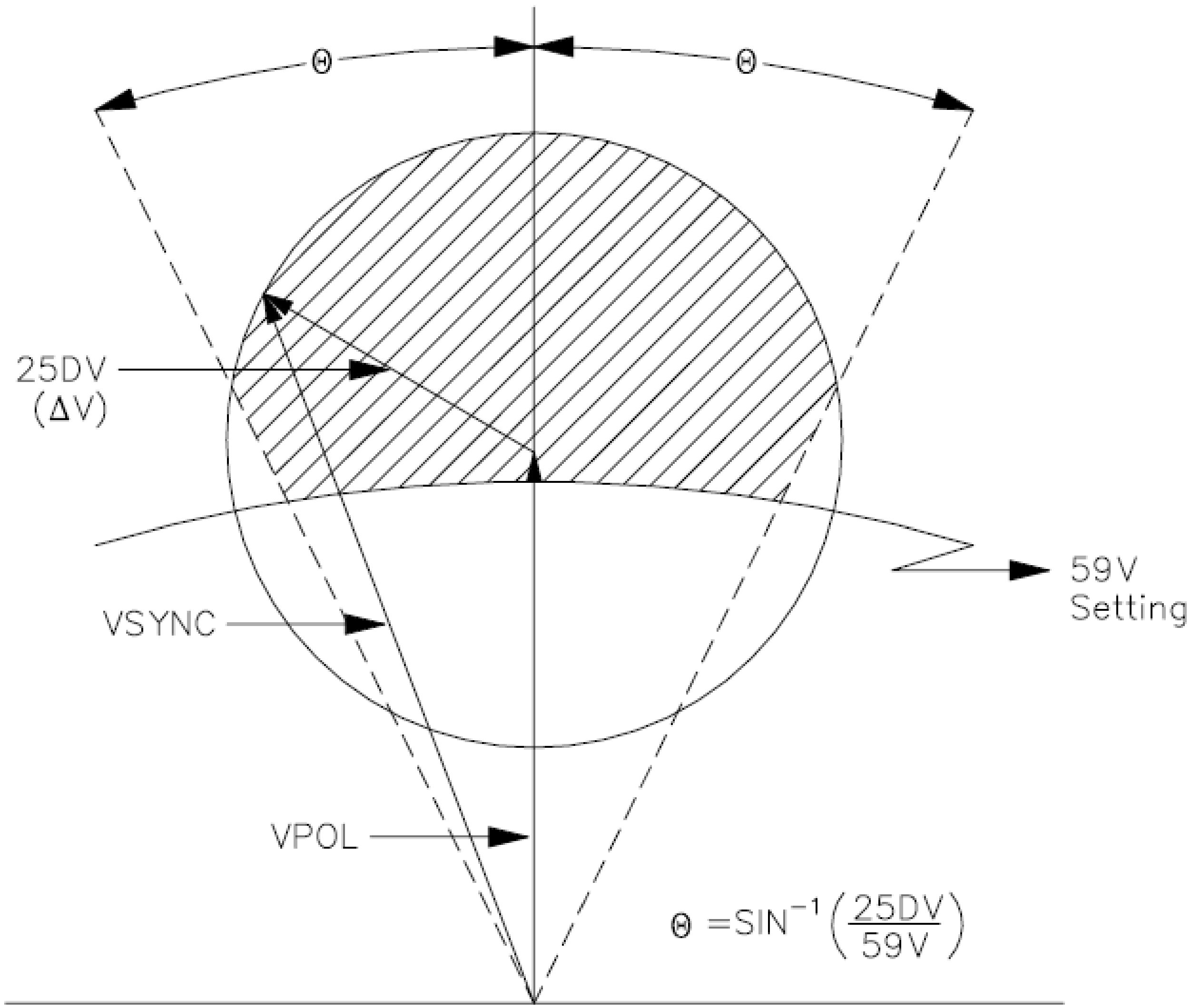
Synchronism Checking

- After clearing a fault, one end of the line will reclose to “test” the line
- If the test is good, the other end can be closed but only if voltages are close enough and there is a small phase angle difference
- If the conditions are not right, the system will undergo a mechanical and electrical shock with a possible unstable swing

Synchronism Checking
Monitored Quantities

- Voltage magnitudes
- Phase angle difference
- Slip frequency

Synchronism Checking
Synchronizer Window



Synchronizer Window

Synchronism Checking
Conditions

- Both voltage phasors are above 59V setting
- Phase angle difference is small
- The above conditions are maintained for a short time, ensuring that the slip frequency is small enough and measurements are valid

Synchronism Checking Relay

- Phasor difference setting

$$25DV = 59V \cdot \sin\theta$$

- Timer setting

$$25T = \frac{2 \cdot \theta}{360 \cdot \Delta f}$$

- The measured phasor difference should be below the setting for the given time
- Different than a synchronizing relay

Questions?