

# Power System Protection

## Overcurrent Protection of Transmission Lines

Day 4

# Application of Overcurrent Relays

- Mason-Chapter 2, pages 44-49
- Computation of minimum fault current
- Setting & Coordination of Overcurrent Relays
- Effect of Instantaneous Overcurrent Relays
- Directional Overcurrent Relays
  - Relay inputs
  - Polarizing quantities

# Application of Overcurrent Relays

- Transmission Lines Protection
  - Overcurrent Relaying Schemes
  - Step Distance Relaying Schemes
  - Pilot Relaying Schemes
    - Blocking
    - Tripping
- We get to determine the settings of:
  - Instantaneous Overcurrent
  - Time Overcurrent

Note: Order of importance is the inverse of order of appearance.

# Overcurrent Relay

- Instantaneous Overcurrent
  - This relays provide primary and remote *phase or ground fault* protection for transmission lines
- Time Overcurrent Relay
  - This relays provide:
    - Primary protection
    - Back-up protection (specially remote)

# Overcurrent Relay

- Settings
  - Pickup-taps adjust the operating coil
    - Typical taps 1.0-12.0
  - Time-time dial adjust contact spacing to change operating time

$$\begin{array}{rcccl} & > & > & \longleftarrow & \text{Operate} \\ I_{RELAY} = I_{PU} \Rightarrow F_{OP} = F_{RES} & & & \longleftarrow & \text{Balance} \\ & < & < & \longleftarrow & \text{Restraining} \end{array}$$

# Overcurrent Relay

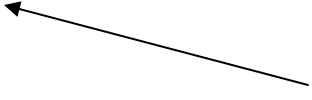
- Pickup
- Based on minimum fault and maximum load current

$$I_{LOAD} < I_{PU} < I_{MinF}$$

- For proper application verify:

$$I_{MinF} \geq 2I_{LOAD}$$

Rule of Thumb



# Time Overcurrent Relays

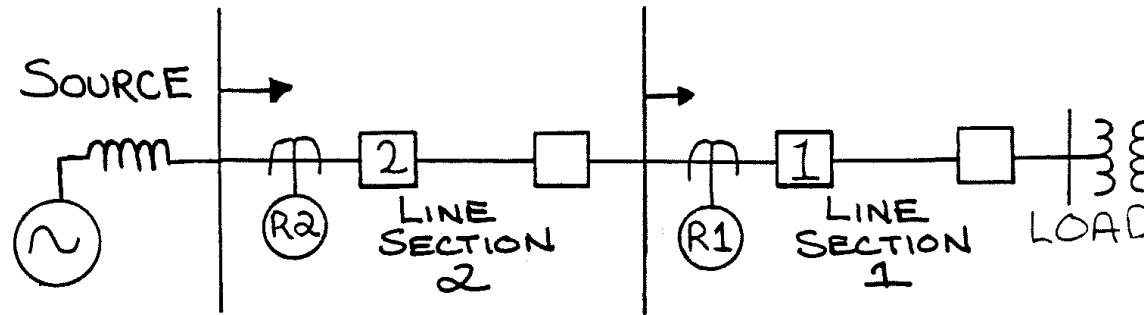
- Considerations for minimum Fault

- Where the fault is located
- Phase to Phase Fault

$$I_{\phi-\phi} = \frac{\sqrt{3}}{2} I_{3\phi} = 0.866 \cdot I_{3\phi}$$

- Minimum generation
- System configuration
- Generator impedance
- Arc resistance

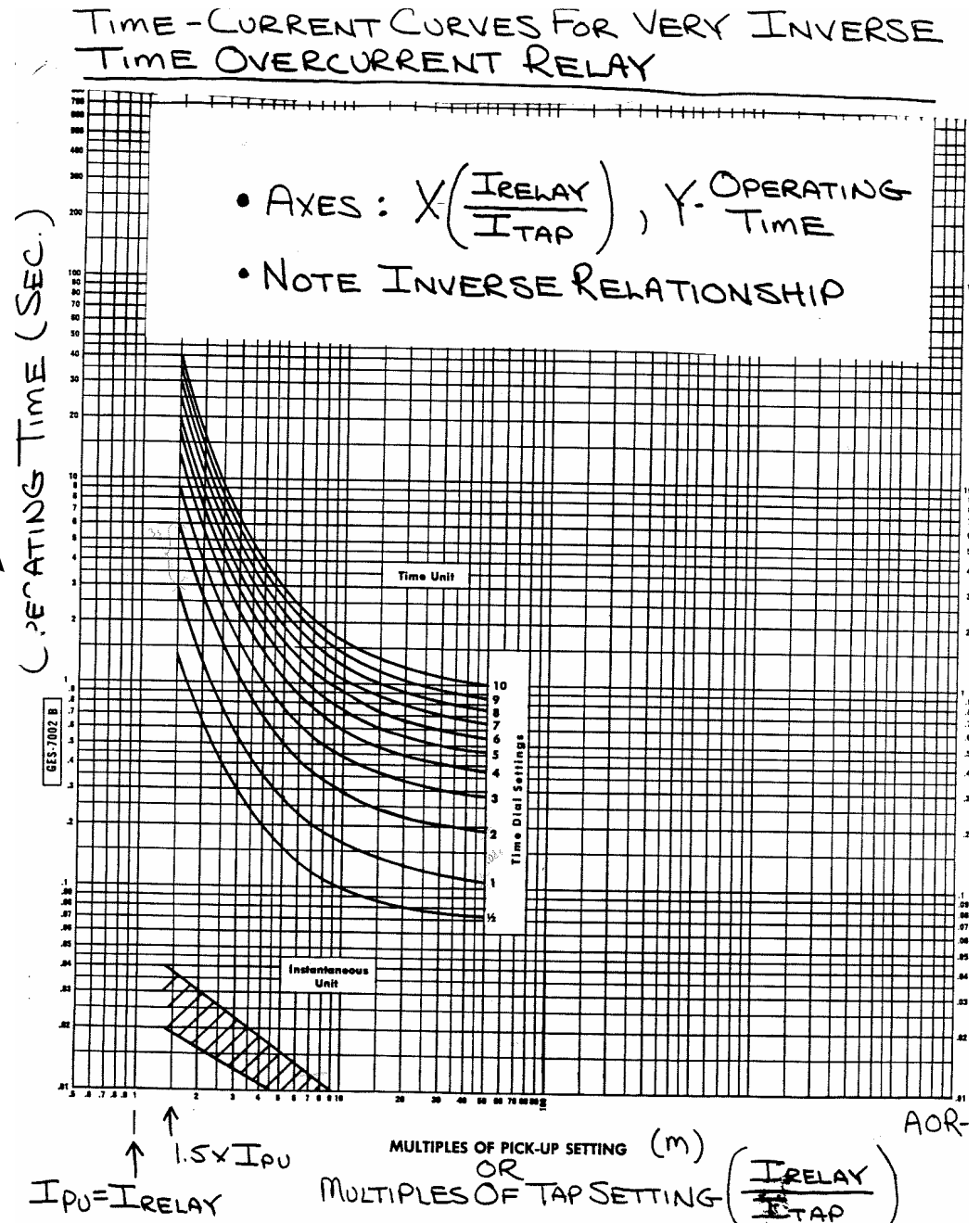
# Radial System



- R1 provides primary protection to line 1
- R2 provides primary protection to line 2 & remote back-up for line 1
- Farthest relay from the source is set first
- Relays located on source side of the line
  - Trip direction towards the line
  - The radial system is inherently directional

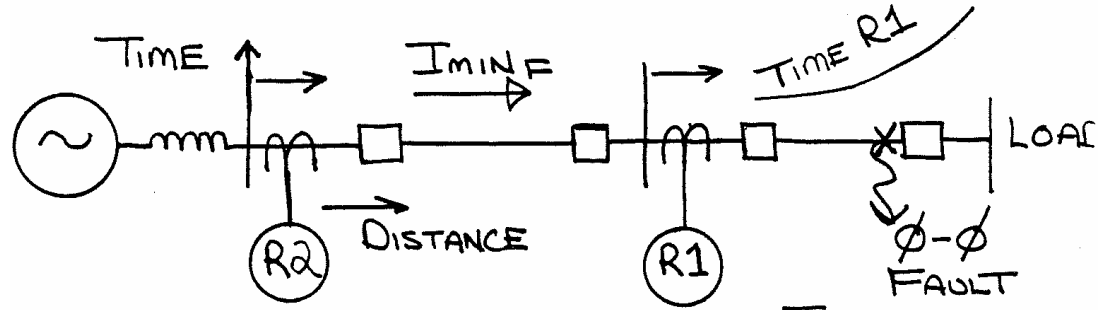
Recall that Time Overcurrent Relays Behaves like this

$$I_{MPU} = \frac{I_{OP}}{I_{PU}} = \frac{I_{RELAY}}{I_{TAP}}$$



# To determine Pickup and Time Dial setting of Time Overcurrent R1

- $I_{PU}$  is current for  $F_{OP}=F_{RES}$
  - $I_{PU}$  can be changed using taps
1. Determine  $I_{MINF}$
  2. Determine  $I_{PU}$



$$I_{MINFR} = \frac{I_{MINF}}{2 * CTR}$$

For R1 Pickup tab based on:

$$I_{PU} = \frac{I_{MINFR1}}{1.5} = \frac{2}{3} I_{MINFR1}$$

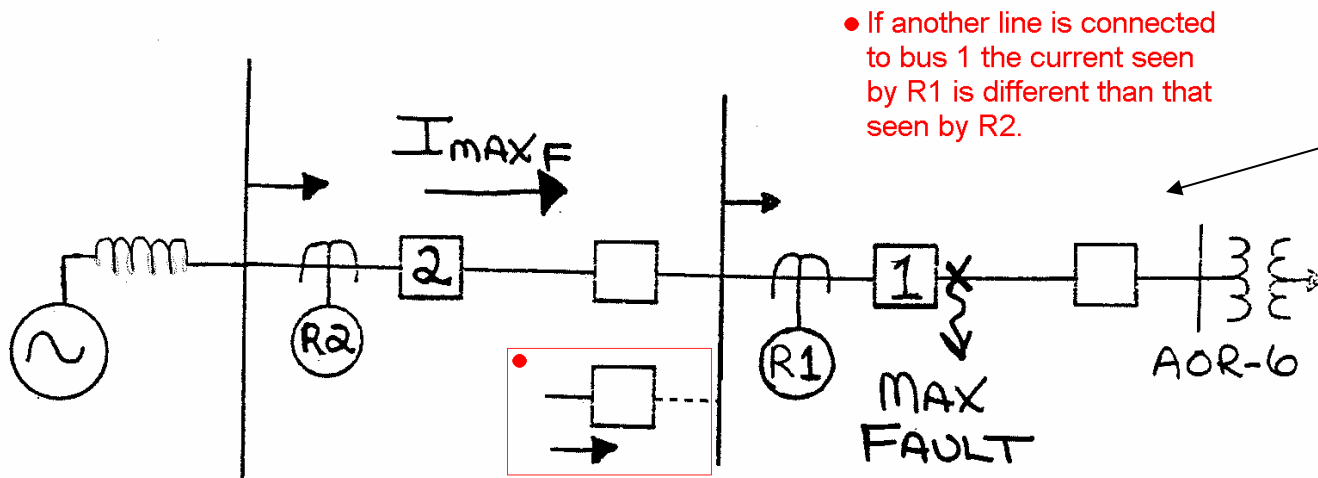
$$I_{MINFR} = \frac{I_{MINF}}{2CT_R} = \frac{0.866 \cdot I_{3\phi}}{2CT_R}$$

Arc Resistance Factor

- Definite contact closing force occurs at  $1.5I_{PU}$ ,  $F_{NET}=0$  at  $I_{PU}$
- R1 time dial will be  $\frac{1}{2}$  or 1-No coordination is necessary for R1

# To determine Pickup and Time Dial setting of Time Overcurrent R2

- R2 must provide backup protection for R1
  - Must operate for  $I_{MINF}$ 
    - Therefore,  $I_{PUR2} = I_{PUR1}$
  - Must operate slower than CB1
    - Therefore,  $TD_{R2} > TD_{R1}$



For the case of a strictly radial line,  $I_{R1}$  and  $I_{R2}$  will be the same, also  $C_{TR1}$  and  $C_{TR2}$

# To determine Pickup and Time Dial setting of Time Overcurrent R2

$$t_{OPR2} \geq t_{OPR1} + t_C, \quad t_C = t_{B1} + t_{OT} + t_{SF}$$

- $t_C$  is the critical coordination time
- $t_{B1}$  is the CB time to operate
- $t_{OT}$  is the over-travel time
- $t_{SF}$  is safety factor

- Coordination achieved for all currents if achieved at  $I_{MAXFR}$  at maximum multiple of pickup

1. Calculate  $I_{MAXFR}$  for

$$\frac{I_{MAXFRn}}{I_{PURn}} = M_{MAXn}$$

$$t_{OPR2}(M_{MAX2}) \geq t_{OPR1}(M_{MAX1}) + t_C$$

2. Determine time from curves

3. Choose time delay in R2  $TD_{R2}$

## OVERTRAVEL

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Owing to inertia of the moving parts, motion will continue when the actuating force is removed. This characteristic is called “overtravel.” Although overtravel occurs in all relays, its effect is usually important only in time-delay relays, and particularly for inverse-time overcurrent relays, where selectivity is obtained on a time-delay basis. The basis for specifying overtravel is best described by an example, as follows. Suppose that, for a given adjustment and at a given multiple of pickup, a relay will pick up and close its contacts in 2.0 seconds. Now suppose that we make several tests by applying that same multiple of pickup for time intervals slightly less than 2.0 seconds, and we find that, if the time interval is any longer than 1.9 seconds, the relay will still close its contacts. We would say, then, that the overtravel is 0.1 second. The higher the multiple of pickup, the longer the overtravel time will be. However, a constant overtravel time of approximately 0.1 second is generally assumed in the application of inverse-time relays; the manner of its use will be described when we consider the application of these relays.

# Example

$$t_{B1} = 15 \text{ cycles (0.25s)}$$

$$t_{OT} = t_{SF} = 0.1s$$

$$TD_{R1} = 1/2 \text{ and}$$

$$\frac{I_{MAXFR1}}{I_{PUR1}} = 5$$

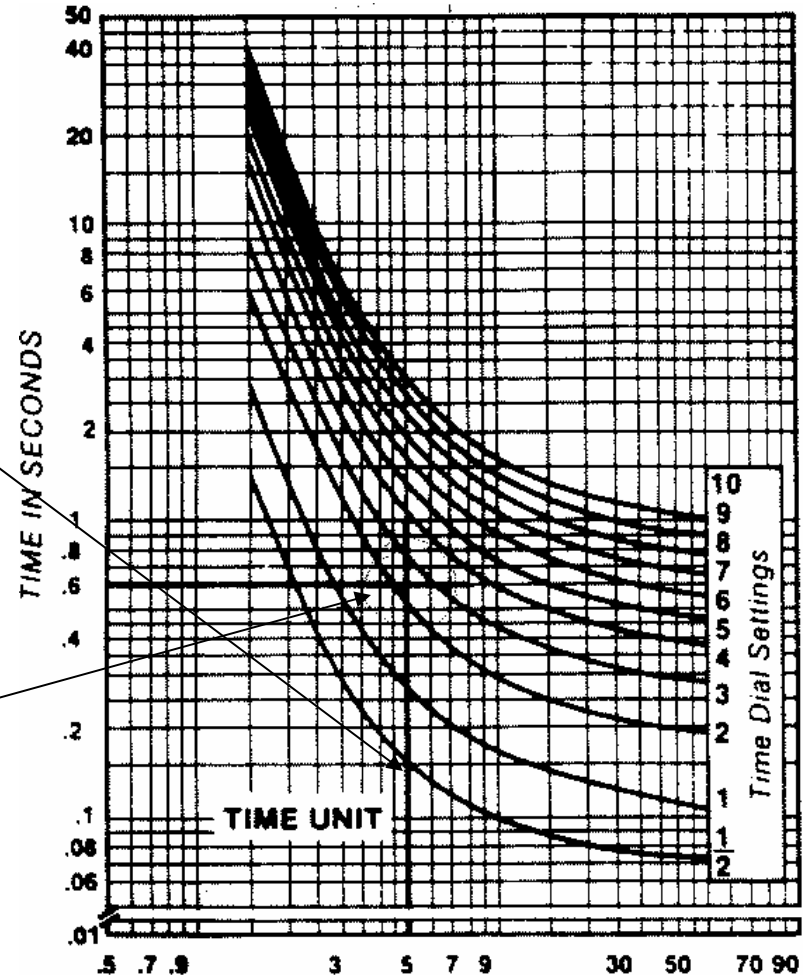
Therefore,

$$t_{OPR1}(5) = 0.15$$

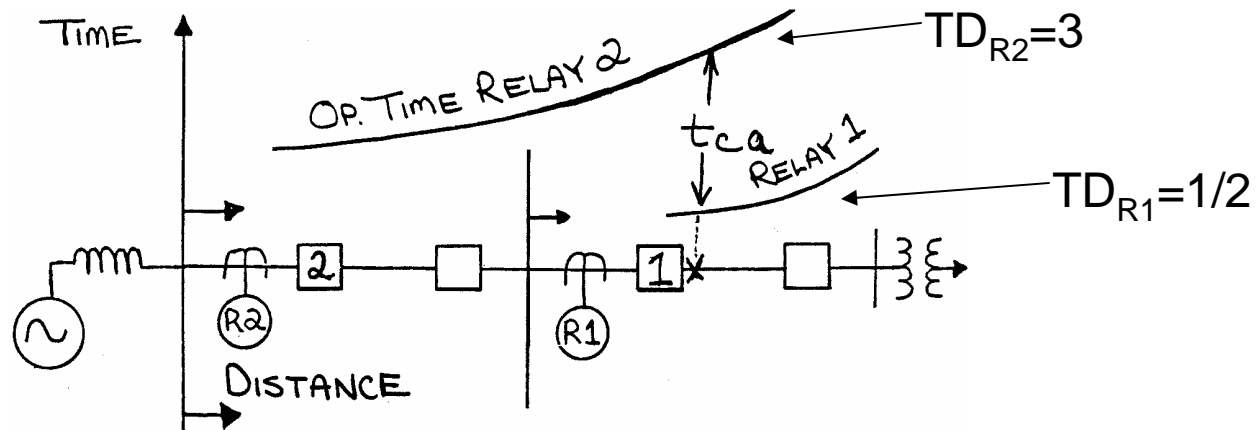
$$t_{OPR2} \geq 0.15 + 0.25 + .1 + .1 = 0.6s$$

- Determine intersection of 5 and 0.6s

- Choose  $TD_{R2}$  setting 3



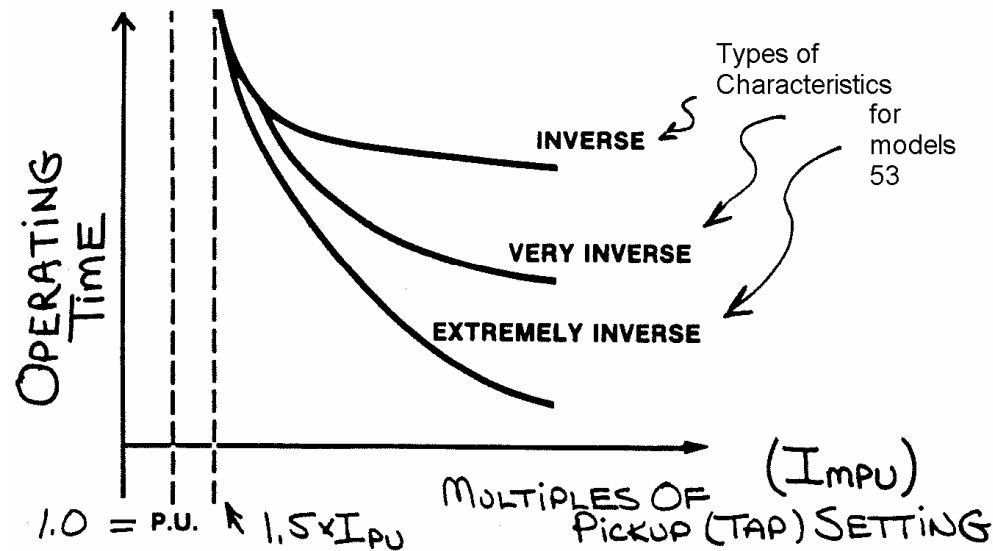
# Coordinated Relays for Two Line Sections



$$t_{ca} = t_{OPR2}(M_{MAX2}) - t_{OPR1}(M_{MAX1})$$

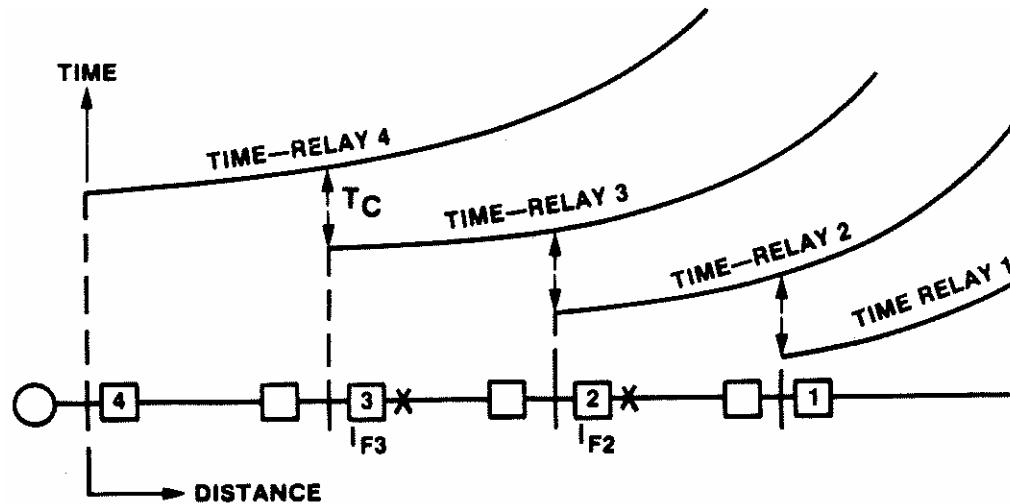
- Note that the difference in operating times varies with fault location
  - Time increases as fault current decreases
- Make sure relays have the same type of characteristics so time-current curves don't crossover

# Selection of Time Characteristic



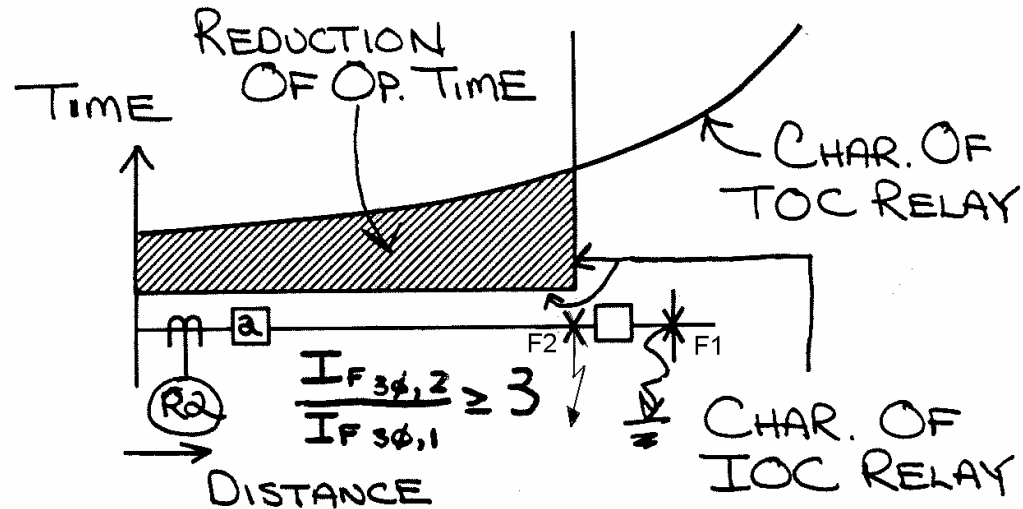
- Inverse – used when  $I_F$  is dependent on generation – not fault location
- Very Inverse – used when  $I_F$  is dependent on fault location
- Extremely Inverse – used when  $I_F$  is dependent on fault location, coordinates with fuses and reclosers

# Coordinated Relays for Four Line Sections



- Note the long  $t_{OP}$  for relays protecting against faults on line segments near the source
- Very undesirable – for faults close to the source,  $I_F$  has to be very big & the relay will work latter than desired
- Use instantaneous overcurrent relay to reduce fault clearing time

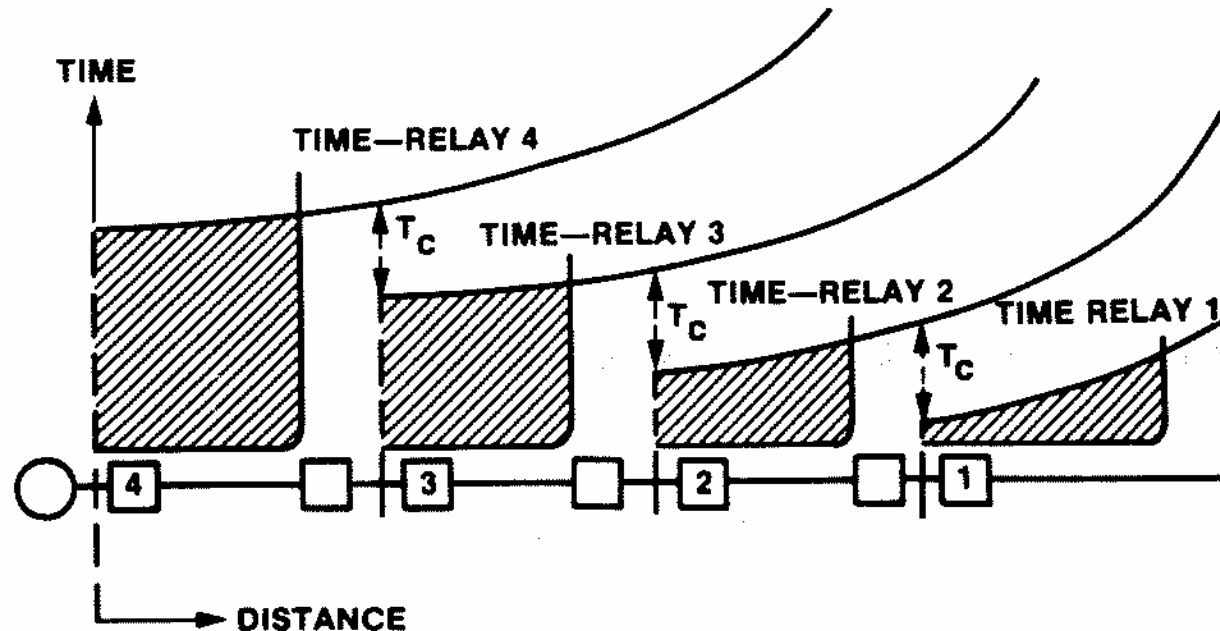
# Instantaneous Overcurrent Relays



- Used to reduce primary fault clearing times
- Provide no backup protection
- IOC Relay must NEVER operate for faults beyond line section end

- Find  $I_{3\phi MAX}(F1)$   $I_{PU OC} = I_{3\phi MAX}(F1) \times k$   
 $1.25 \leq k \leq 1.5$

# Reduction of Operating Times With Instantaneous Overcurrent Relays



- Note the significant reduction in operating time at line Section 4
- Instantaneous relay provides Primary protection for close-in faults

# Directional Overcurrent Relays

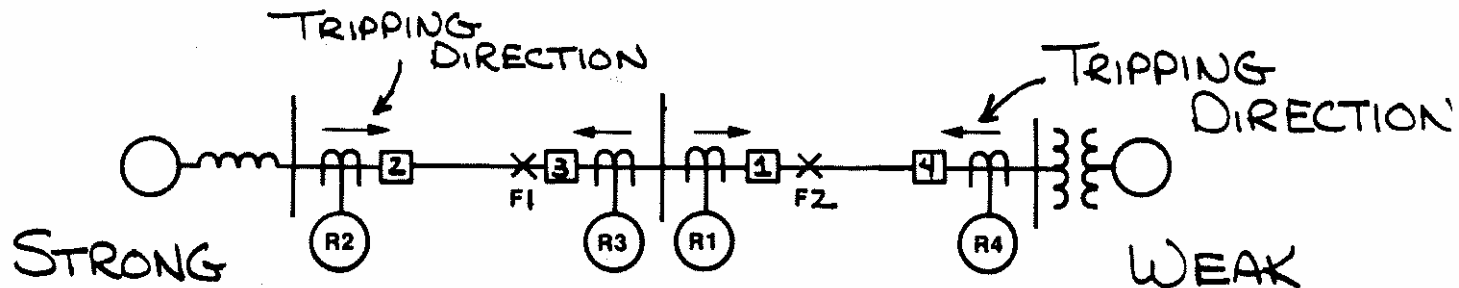
- Why & where are they needed
- Having polarizing sources
- Needing torque control or directional supervision

# Why & where are they needed

- Why directional relays?
  - Fault current can flow in either direction
- Where?
  - Interconnected or looped systems

# Sources at Each End

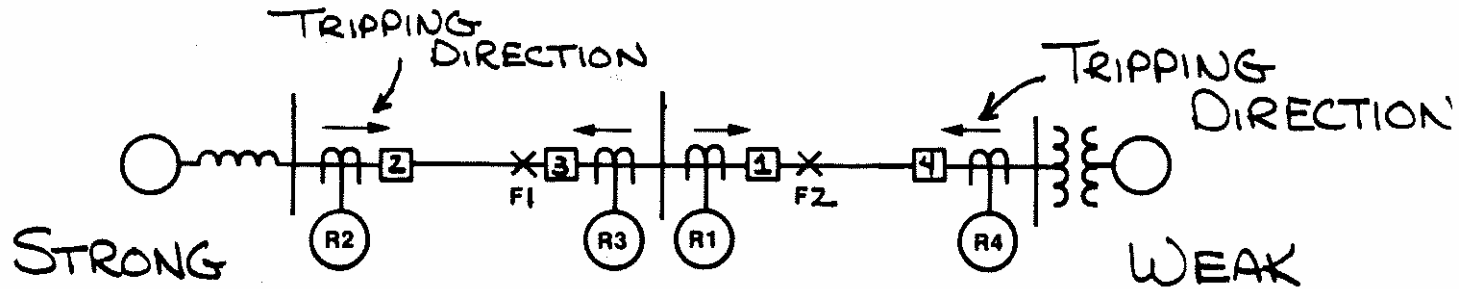
## Directional Overcurrent Relays



- For selectivity on a system
- When  $I_F$  can flow in either direction, directional relays are required
- Strong source, high  $I_F$  – high  $I_{PU}$
- Weak source, low  $I_F$  – low  $I_{pu}$

# Sources at Each End

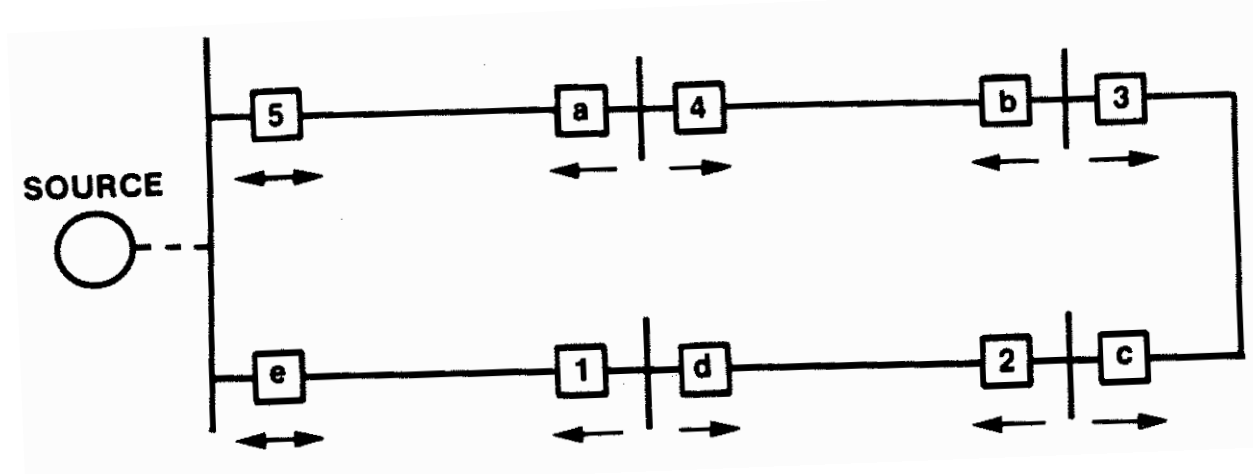
## Directional Overcurrent Relays



If no directional relaying:

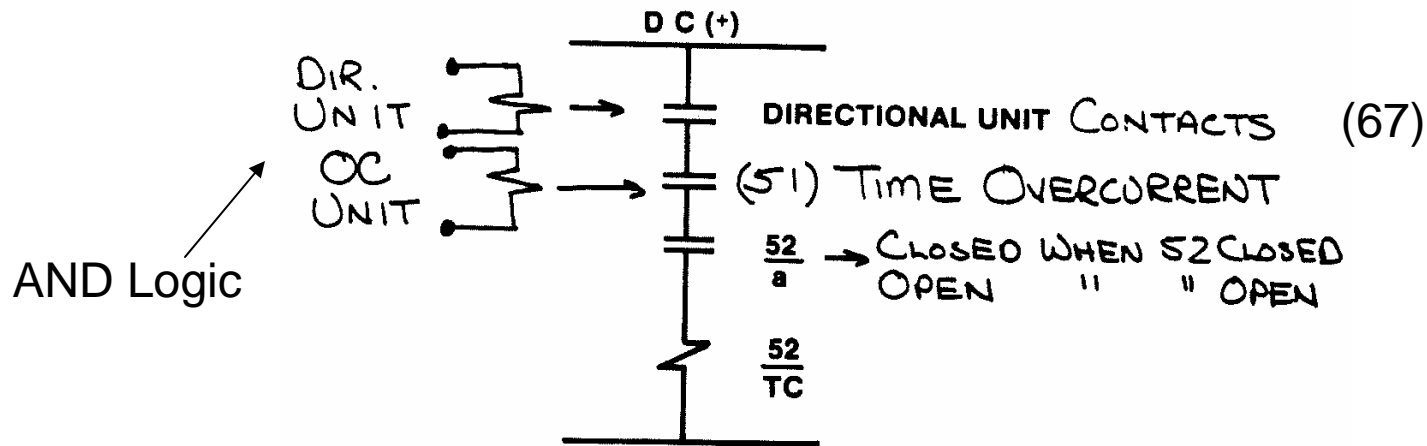
- For  $F_1$ ,  $R_3$  will operate faster than  $R_1$ ,  $R_2$  operates – OK
- For  $F_2$ ,  $R_3$  may operate with  $R_1$ , faster than  $R_4$  – Not OK
- $R_3$  and  $R_4$  must be directional
- In general, All overcurrent relays must be directional
- All directional Overcurrent relays can be set as in radial system

# Directional Relays in Loop Systems



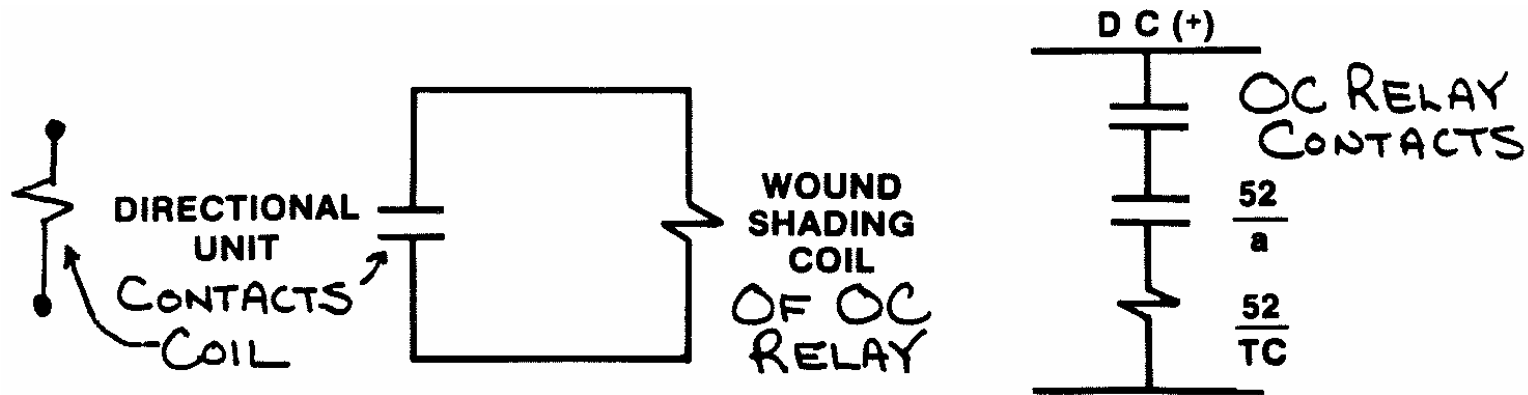
- $I_F$  can flow in either direction
  - Therefore, directional overcurrent relays are used
- Relay tripping direction is towards the line
- Setting Procedure:
  1. Open e
  2. Set relays at 1 (farthest from source)
  3. Set relays at 2, 3, 4, 5
  4. Open 5
  5. Set a, b, c, d, e

# Directional Supervision



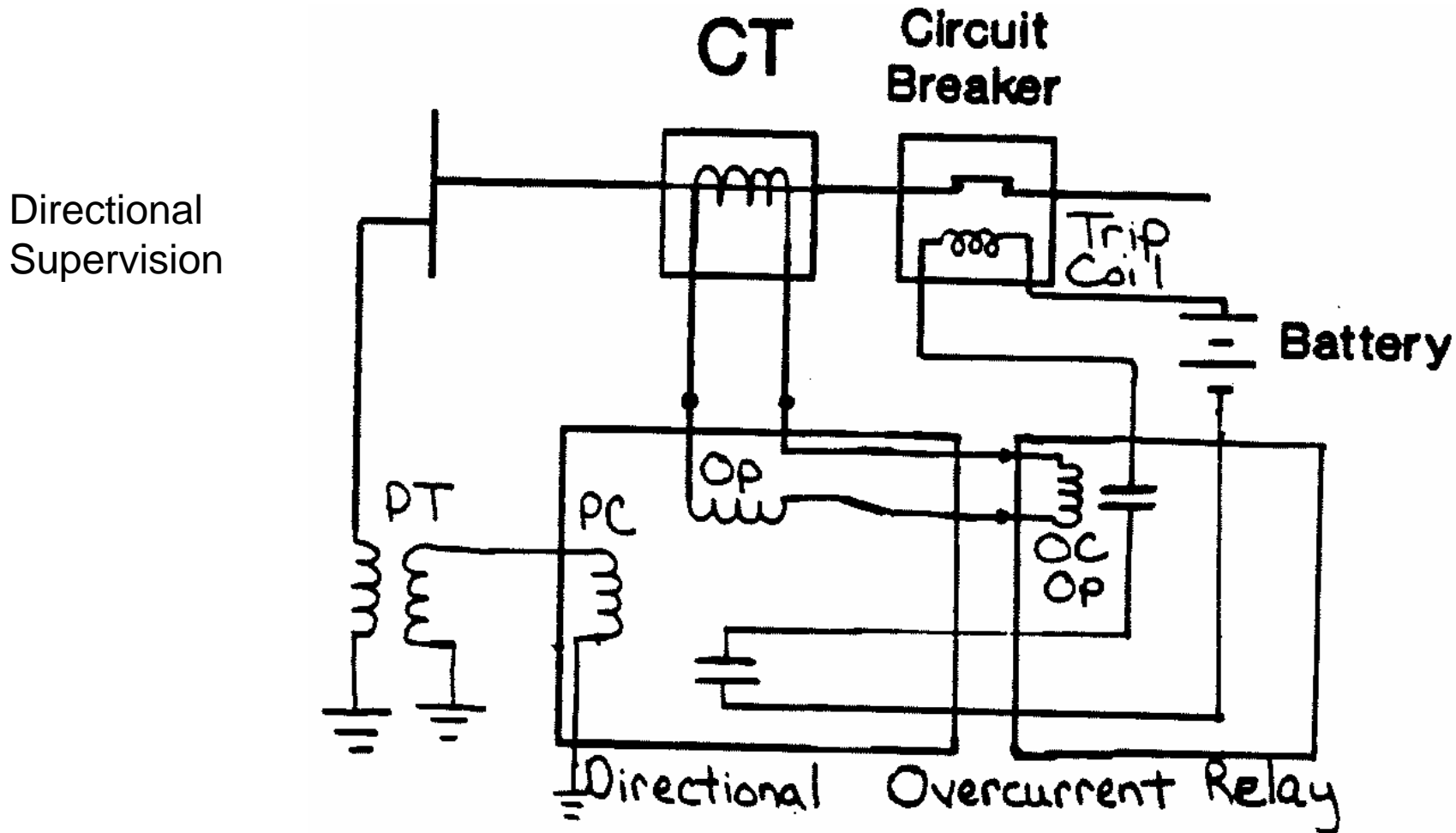
- Directional relay contacts & overcurrent relay contacts in series on trip circuit
- Directional relay & overcurrent relay are separate relay units
- Both operate to trip CB

# Torque Control

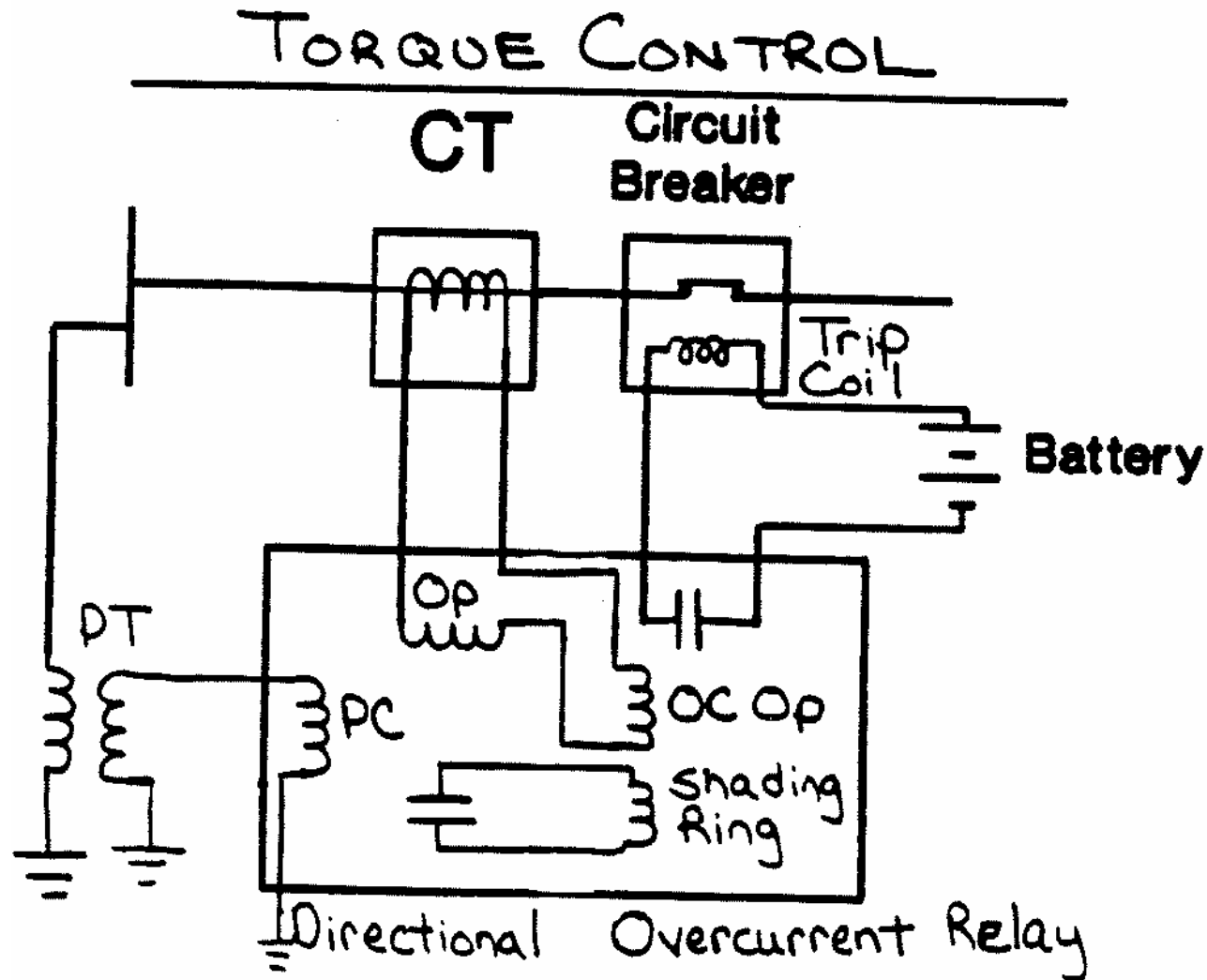


- Torque on OC Relay is controlled
- Directional Relay contacts in series with shading coil
  - Recall, single quantity induction relay works strictly with shaded & unshaded pole face
  - Short Circuited shading coil produces out of phase flux
  - If directional relay closes contacts, OC relay can operate
  - If directional relay does not operate, no torque developed in OC relay & contacts remain open

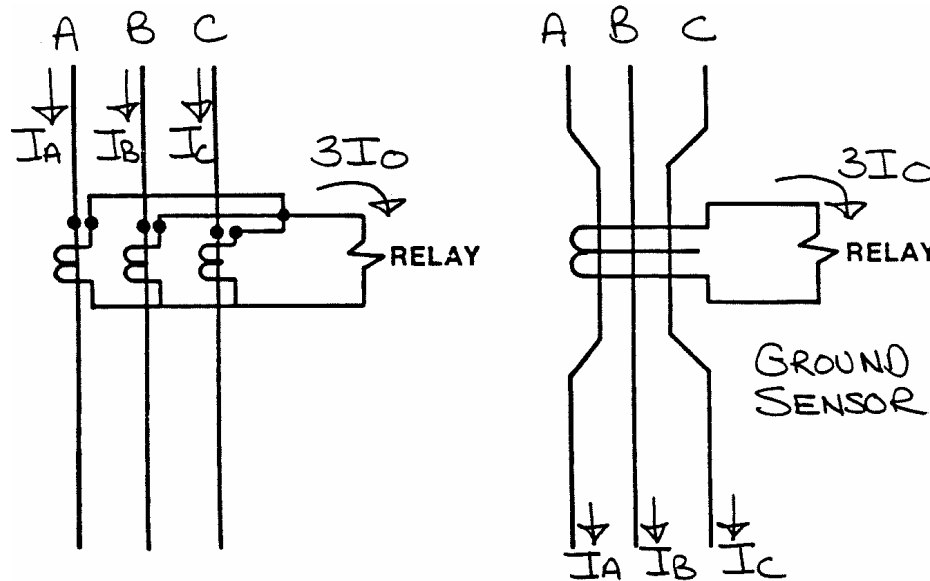
# Two Methods of Giving Overcurrent Relays Directionality



# Two Methods of Giving Overcurrent Relays Directionality



# Inputs to Ground Directional Overcurrent Relays



- Sensing zero sequence currents in phase conductors
- Overcurrent inputs:
  - $I_A, I_B, I_C$
- Directional inputs:
  - Operating: from  $I_A, I_B, I_C$
  - Polarizing:  $I_0$

# Overcurrent Relays for Ground Fault Protection

- Same setting considerations as phase relay except for ground fault
- Easier to set than phase relays
  - Because  $Z_0 < Z_1$  ground fault currents varies with fault location more than phase fault currents
- $I_{PU}$  does not have to be greater than  $I_{LOAD}$ , normally  $I_{LOAD}$  approx to zero