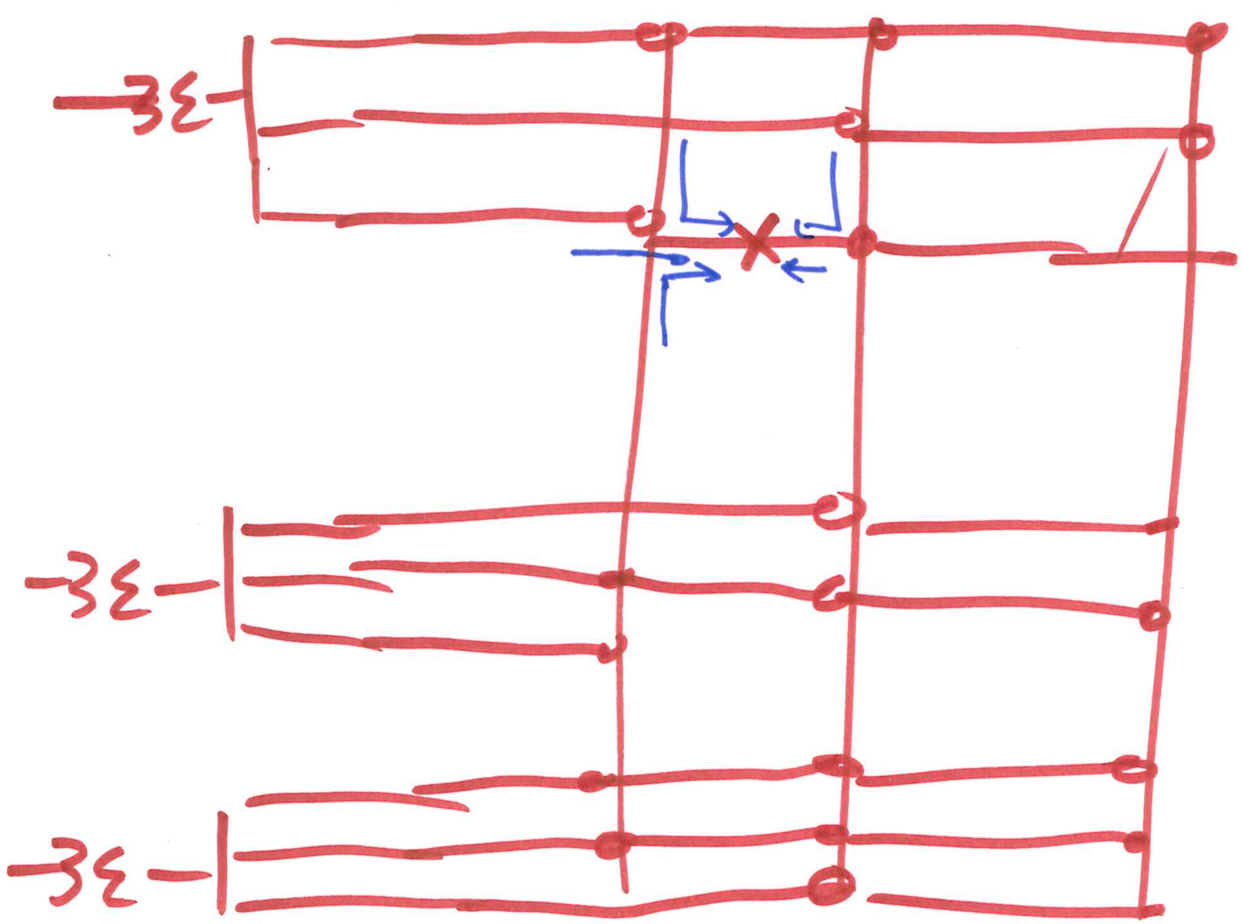
ECE 525

POWER SYSTEM PROTECTION AND RELAYING

SESSION no. 11

Meshed distribution systems



- Distribution system protection for radial systems
  - Utility distribution
  - Industrial distribution system
  - Buildings

- Primary mode of detection is current magnitude

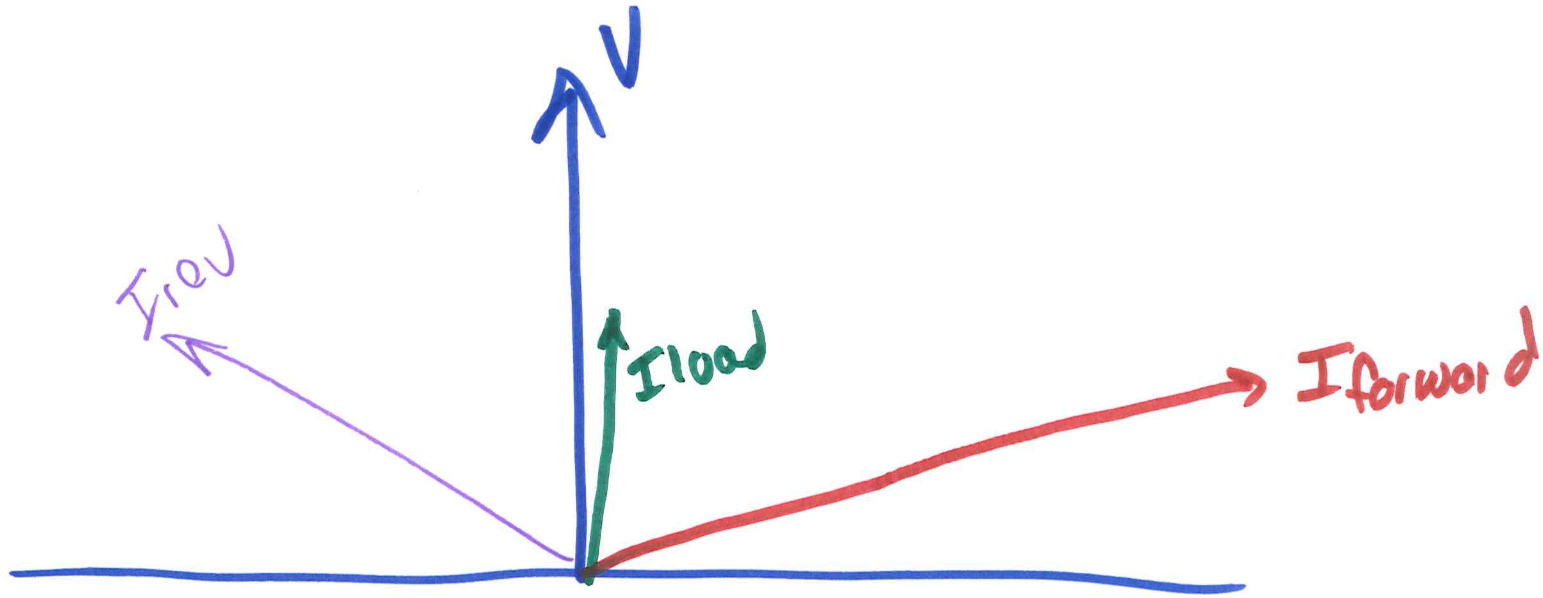
  (1) Detect presence of fault

  (2) Operate appropriately

  → coordinate with downstream & upstream devices

- Assume (1) fault current larger than load current
  - (2) fault current decreases if fault ~~current~~ occurs farther from substation (more impedance)

- If add direction sensing (classical type)
  - assume fault current at lagging angle relative to voltage



Mesh connected dist system

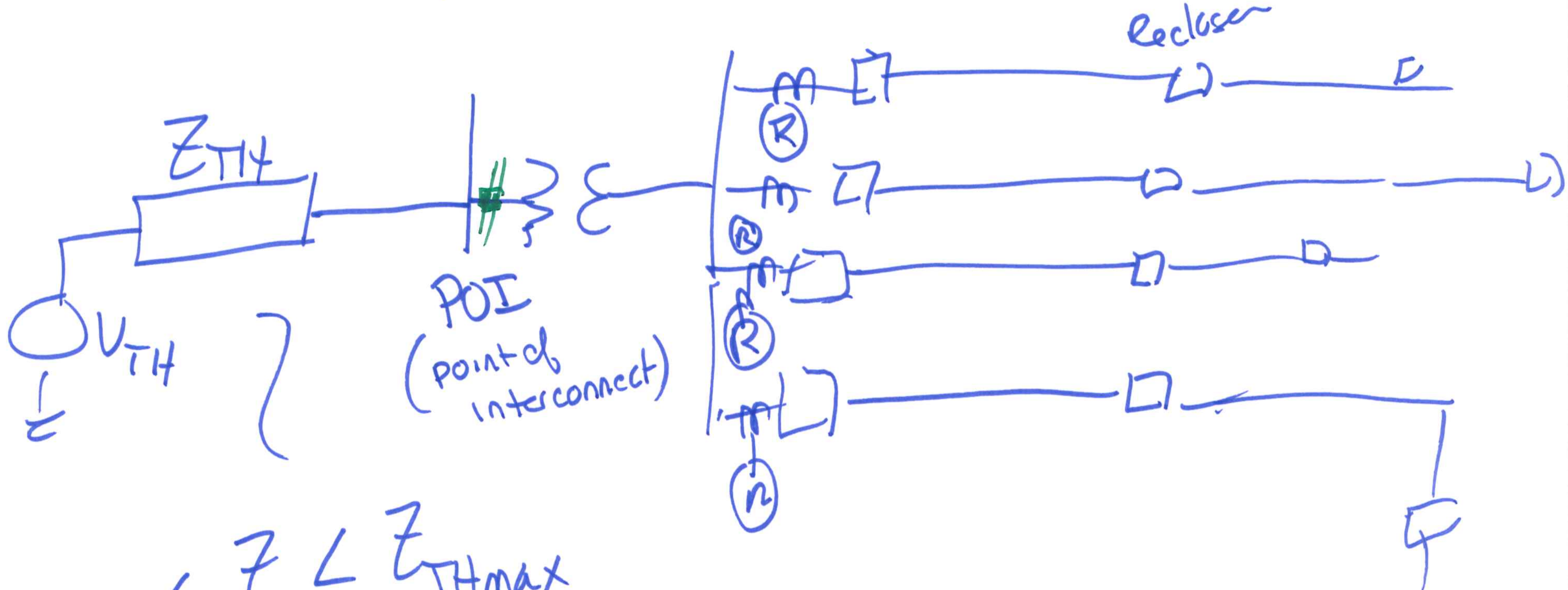
Challenges for regular overcurrent protection

1. Load current
   - challenge differentiate fault (especially R_f) from worst case load current
   - especially using phase currents
     - ⇒ using ground current for ground fault detection
   - ⇒ negative sequence

2. Inrush current

- transformer magnetizing current
- energization of circuit/feeder
  - parasitic capacitances
  - pf correction capacitors
- motor starting
- cold load/warm load pickup

3. variability in source impedance



$Z_{THmin} < Z < Z_{THmax}$

$I_{short\ circuit}$ (I_{sc})

MVA_{sc}

I_{sc} : place 3∅ fault
at point of interconnect
with transformer open circuited

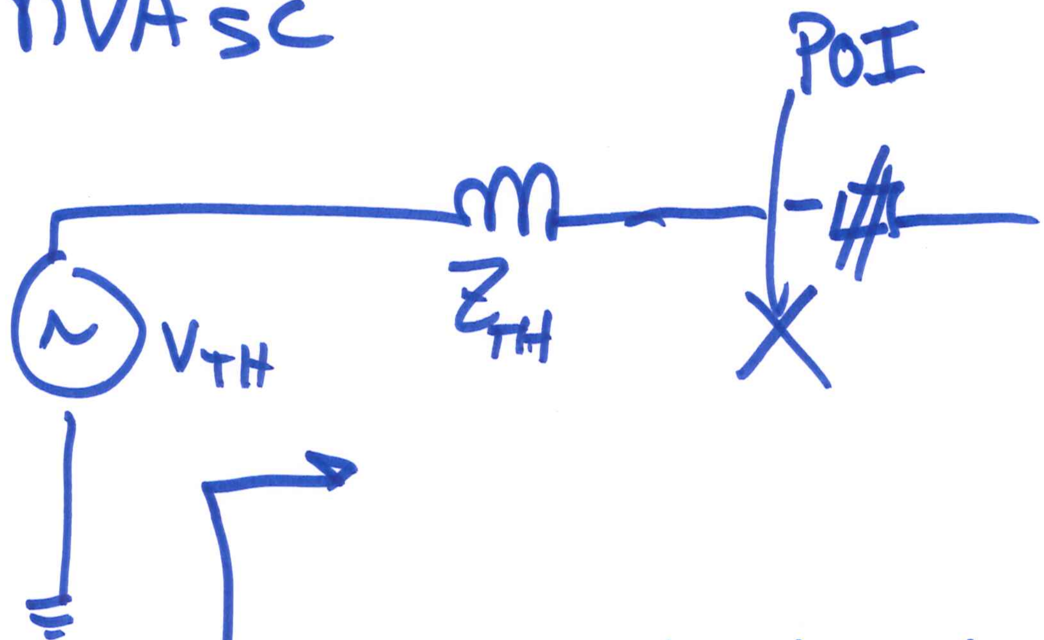
$$I_{sc} = \frac{V_{TH}}{Z_{TH}}$$ V_{TH} → 1pu ($13.2kV_{LL}$ for ex)

⇒ gives positive sequence impedance

⇒ might also get X/R ratio

⇒ Also get ratio of Z_0/Z_1 or $I_{sc_{SLG}}$

MVA SC



$$MVA_{SC} = 3|V_{TH}||I_{SC}|$$

(V_{TH} is V_{LN})

in per unit

$$MVA_{SC_{pu}} = |V_{TH}||I_{SC}| = \frac{|V_{TH}|^2}{|Z_{TH}|}$$

($|V_{TH}|$ = 1.0 pu)

$$MVA_{SC} = 50{,}000 \text{ MVA}$$

$$\rightarrow MVA_{BASE} = 100 \text{ MVA}$$

$$\frac{MVA_{SC}}{MVA_{BASE}} = MVA_{SC_{pu}}$$

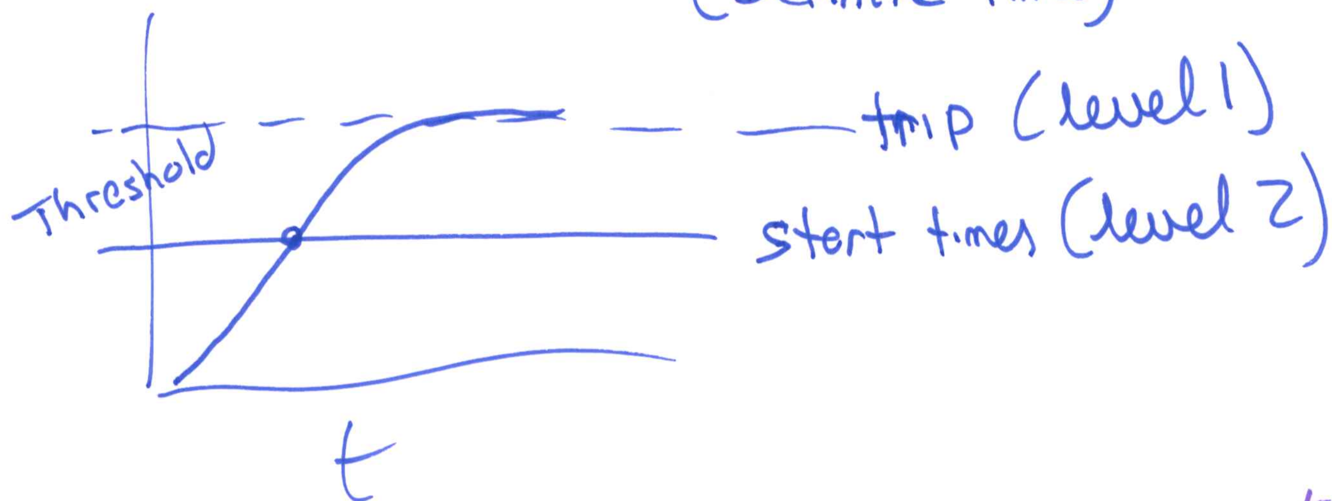
MVA_{SC} -3ϕ

$-SLG$ (assumes $Z_1 = Z_2$)

Common overcurrent elements

- ANSI designations

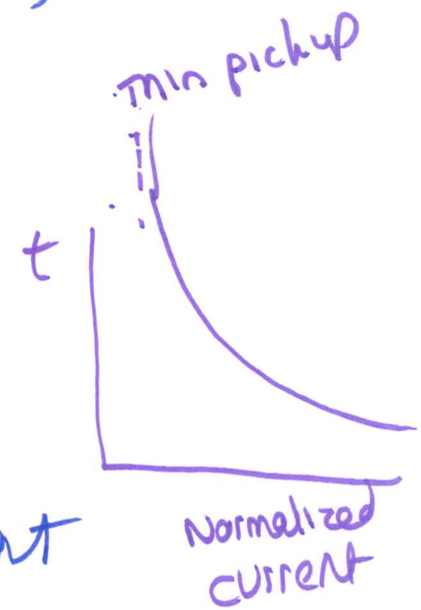
(1) 50 → instantaneous or (Definite time)



(2) 51 → Time overcurrent

Inverse time overcurrent

Indefinite Time Overcurrent



Time Overcurrent Relays

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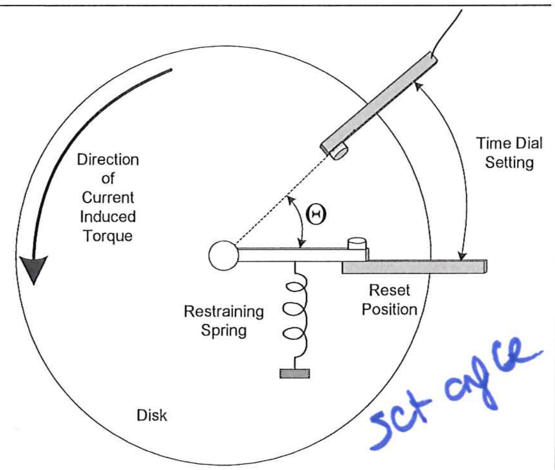
- More or less approximates thermal fuse
  - » Allow coordination with fuses



set angle is called Time Dial Setting

Basic equation

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Operating torque — *Restraining Torque*

$$T=\tau_s\left(\left(\frac{I}{I_p}\right)^2-1\right)-K_d\left(\frac{\partial\theta}{\partial t}\right)$$

like i^2t — minimum pickup

↓ integrating i^2

- τ_s = restraining spring torque
- I = applied current
- I_p = pick up current
- K_d = disk damping factor
- θ = angle of disk rotation (proportional to Time Dial Setting (TDS))

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Relay Response

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balance point

1. Operating torque = Restraining Torque

$$\tau_s\left(\left(\frac{I}{I_p}\right)^2-1\right)=K_d\left(\frac{\partial\theta}{\partial t}\right)$$

2. Integrate w.r.t. Time

$$\theta_2-\theta_1=\frac{\tau_s}{K_d}\left(\left(\frac{I}{I_p}\right)^2-1\right)(t_2-t_1)$$

change in angle

change in time

3. TDS (setting angle), where triptime = t_2 -t_1

$$TDS=\frac{\tau_s}{K_d}\left(\left(\frac{I}{I_p}\right)^2-1\right)(trip\,time)$$

setting

Relay Response

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4. Finding trip time

$$(trip\,time)=TDS\frac{\frac{K_d}{\tau_s}}{\left(\left(\frac{I}{I_p}\right)^2-1\right)}=TDS\frac{A}{(M^2-1)}$$

Where: $M = I/I_p$

$A = K_d/t_s$ 2 τ_s

Standard Curves -- standard formats

Reset Time (M < 1)

$$tr = TDS\left(\frac{C}{1-M^2}\right)$$

Trip time (M ≥ 1)

$$tt = TDS\left(\frac{A}{M^p - 1} + B\right)$$

Some manufacturers include disk inertia in B

US and IEC curve parameters

Curve	A	B	C	P
U.S. Moderately inverse (U1)	0.0104	0.2256	1.08	0.02
U.S. Inverse (U2)	5.95	0.180	5.95	2.00
U.S. Very inverse (U3)	3.88	0.0963	3.88	2.00
U.S. Extremely inverse (U4)	5.67	0352	5.67	2.00
U.S. Short-time inverse (U5)	0.00342	0.00262	0.323	0.02
I.E.C. Class A - Standard inverse (C1)	0.14	0.0	13.5	0.02
I.E.C. Class B – Very inverse (C2)	13.5	0.0	47.3	2.00
I.E.C. Class C – Extremely inverse (C3)	80.0	0.0	80.0	2.00
I.E.C Long-time inverse (C4)	120.0	0.0	120.0	2.00
I.E.C Short-time inverse (C5)	0.05	0.0	4.85	0.04

US Inverse (U2) Characteristic

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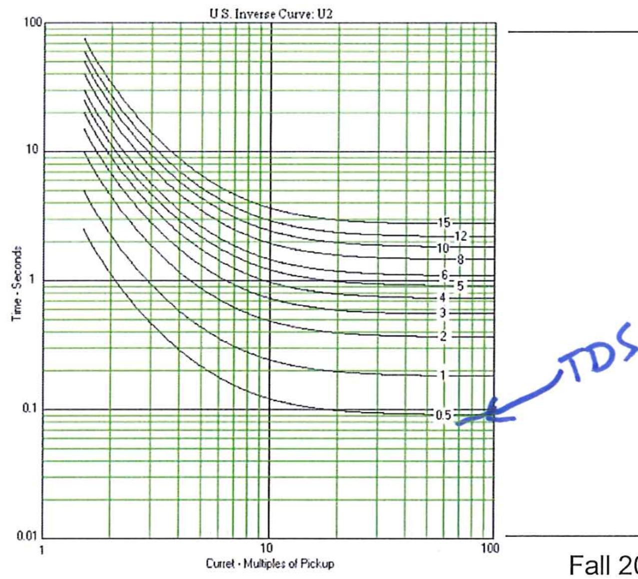

Comparison of curves

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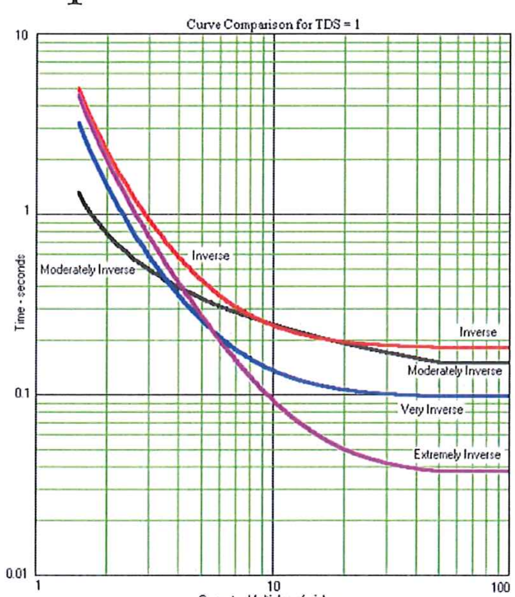

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Extremely Inverse Curve and 50E fuse

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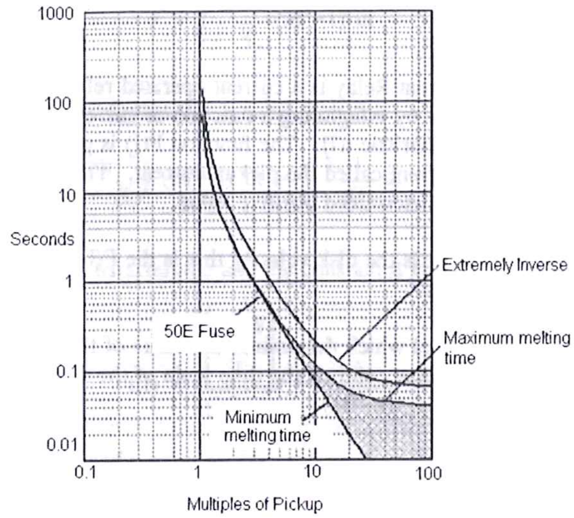

Example

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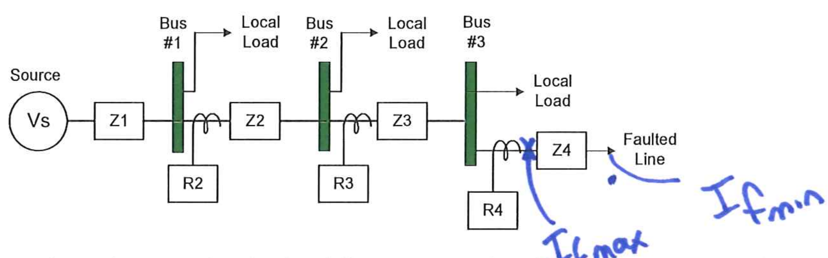

- Want the relay on the faulted line, R4, to be the only relay to trip
- Max and min fault current (based on ends of faulted line)

$$I_{f3phmax} = {V_s}/{Z1 + Z2 + Z3} \qquad I_{f3phmin} = {V_s}/{Z1 + Z2 + Z3 + Z4}$$

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U_I # Example continued

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- The desired coordination can be accomplished by: increasing the time dial settings as one proceeds toward the source.

» If relay R2 is expected to provide backup protection for relay R4,

  » Then R4, the relay with the greatest source impedance, would be set with the lowest time dial setting

U_I # Example continued

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» If I_{MIN} is defined as the minimum fault current,

  » Then the pickup current must be set at or below this current but above maximum load current.
  » Usually with a margin around both

» For relays R2 and R3, the TDS must be set to trip no faster then the next downstream device when the fault current is maximum for an out of zone fault

→ cover response time of the device

→ CB response

EMTP relay simulation

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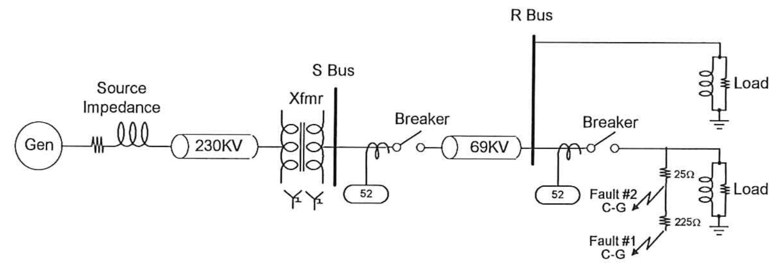

250Ω resistive fault is initiated at 8.3 ms and progresses to a 25Ω fault at 62 ms as can occur by a tree branch coming in contact with the wire.

Example with a trip

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