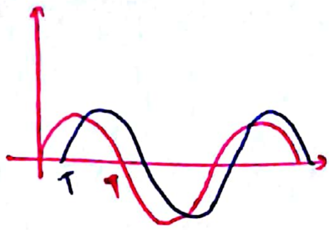
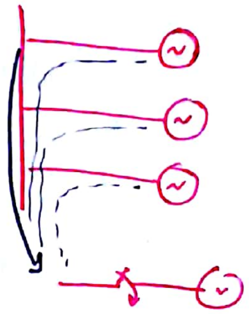
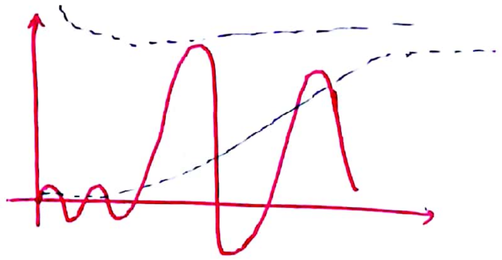
Second Material
Lecture #1





→ other generator [infinite bus] will produce a counter current to provide the zero voltage, maximum current condition.

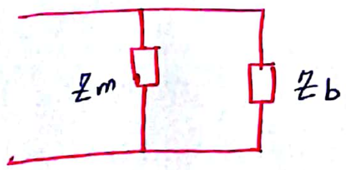
→ This counter ~~current~~ current is a DC component equal and opposite to required (AC) current condition.

→ DC component will disappear after time L/R (time constant of the system)

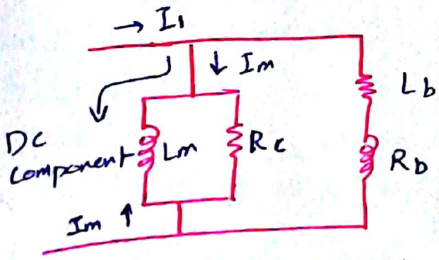
→ the DC component will appear as low frequency AC that will saturate the CT core

→ inaccuracy, maintenance and distortion.

→




⇓




in saturation region Im increase.

$$i_1(t) = I_{max}\left(\cos(\omega t - \theta) - e^{-t/\tau}\cos\theta\right)$$

↖ time constant of the system.

$$i_2(t) = I_m \cos\theta \left(\frac{R_c}{R_c + R_b}\right)\left[e^{-t/\tau}\left\{\frac{T}{\tau - T}\sin\psi\cos\phi\sin\theta\right.\right.$$

subtransient

$$- e^{-t/\tau}\left(\frac{\tau}{\tau - T}\right) - \omega\tau\,\frac{\cos\phi}{\sin\theta}$$

transient

$$\sin(\omega t - \psi - \theta)$$

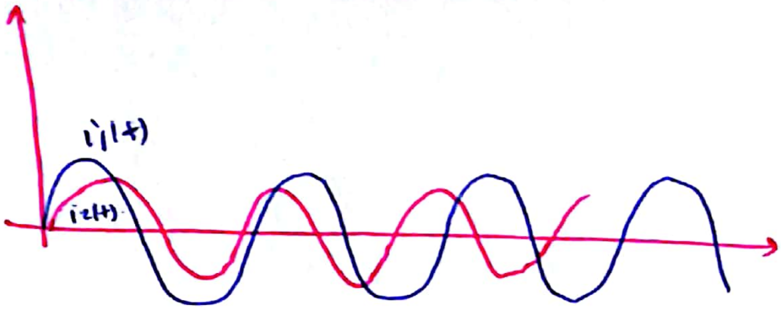
steady state.

T : time constant of the system

τ : Rc lm + Ra lm

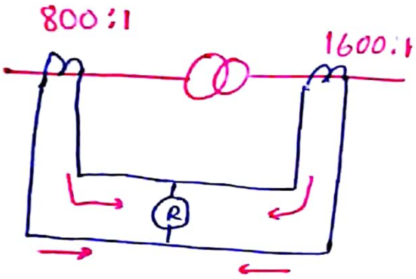
ψ : $\tan^{-1}(\omega T)$

θ : pf angle



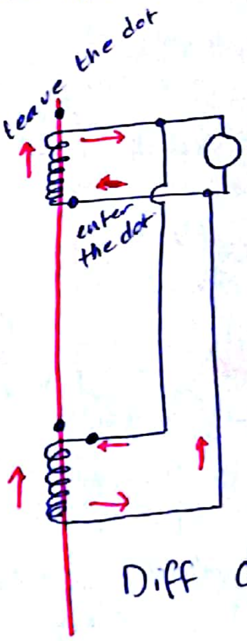

→ Distortion of a signal.

→ Differential protection is highly affected by the distortion of signal → malfunctions.

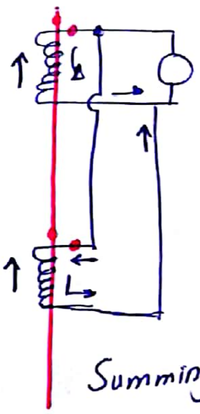



## * CT'S Connection and polarities.

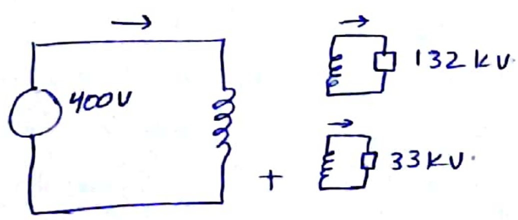

Current enter the dot then leave the dot in other side.



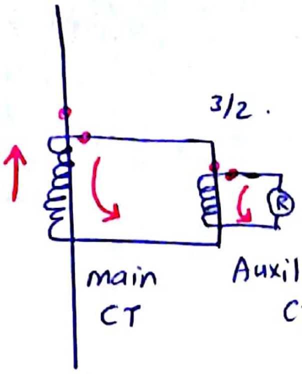

Diff Connection.



Summing Connection



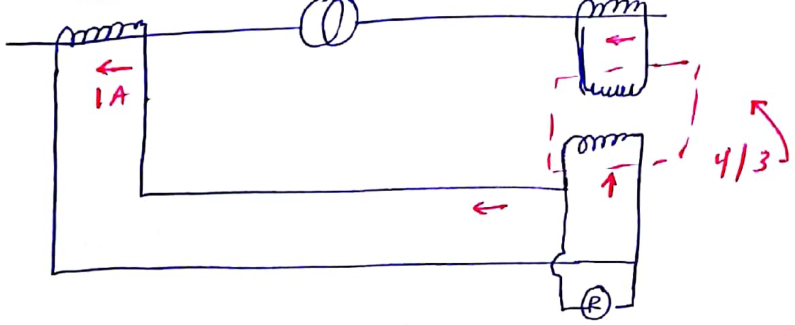

differential.



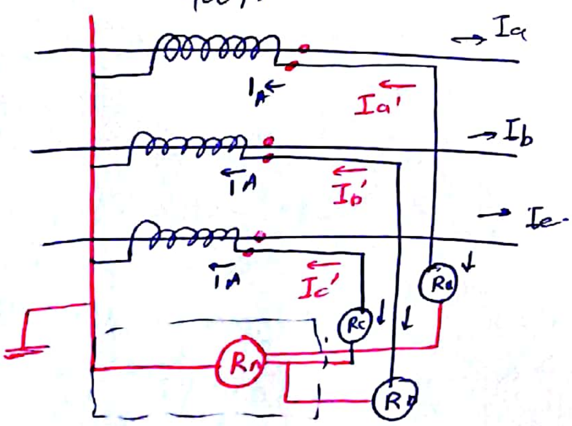

غالباً # of turns بيكون كبير صغير

Obsolete in numerical Relays.

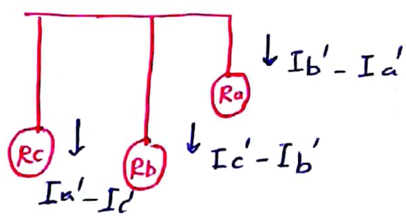
**Example** For a differential protection Relay we have the following.




CT connection for 3Ø configration.




Assume Ia = 400A




$I_b' - I_a' = \sqrt{3} \angle 30^\circ$

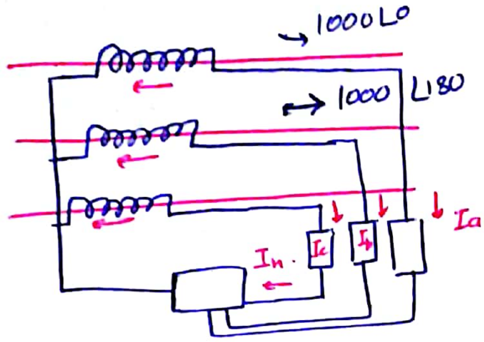
μp in digital Relay.

$I_n = I_a + I_b + I_c$

if $I_n >> 0.005$

**Ex.** Find the Current in the secondary

CTR 600/5




L-L fault

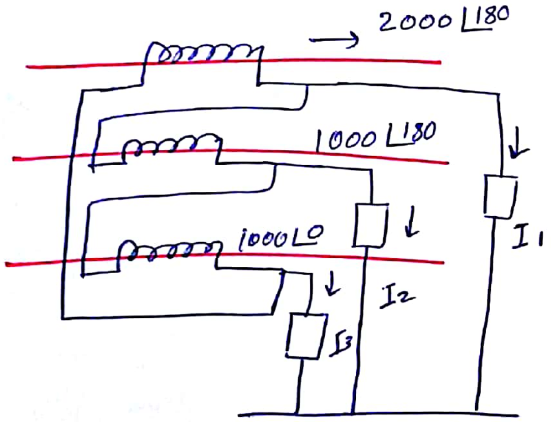
With Neutral.

$I_1 = -1000\angle 0 \times \frac{5}{600} = 8.3\angle 180$

$I_2 = -1000\angle 180 \times \frac{5}{600} = 8.3\angle 0$

$I_3 = 0$

$I_n = I_1 + I_2 + I_3 = 0 \qquad I^{(0)} = \frac{I_n}{3}$




with out Neutral.

$I_1 = I_b - I_a$

$-2000\angle 180 \times \frac{5}{600} + 1000\angle 0 \times \frac{5}{600}$

$= 25\angle 0$

$I_2 = I_c - I_b = 8.3\angle 0 - 8.3\angle 0 = 0A$

$I_3 = I_a - I_c = 16.67\angle 180 - 8.3\angle 0 = 25\angle 180\ A$

Lecture #2.

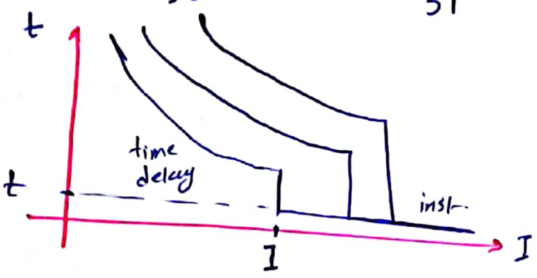
# O/C Relays.

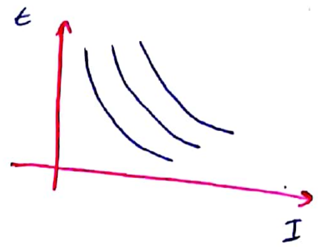
**Distribution network** [main protection]

- Instantaneuos (50)
- with time delay. (51)

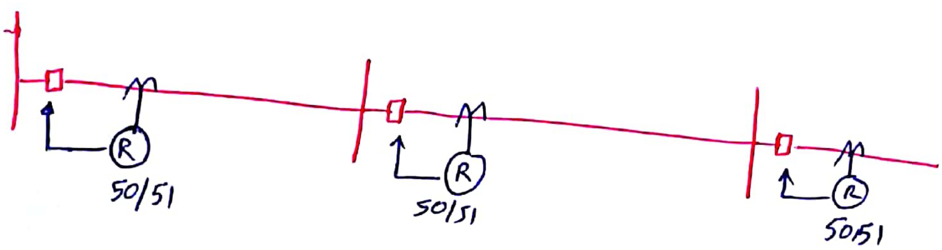
**Transmission network.** [Backup protection]

- only with time delay. (51)




operation time of a Relay ⇒ $t = 0.005$ sec.




→

## CT's

- never o/c
- Transient response is important (30 times)
- Protection Vs metering

## VT's

- never s/c
- Transient isn't important.
  ($0 - 69 \times \sqrt{3}$)
  ↳ 3ϕ fault, ↳ L-L fault.
- System Relay decide { VT / CCVT

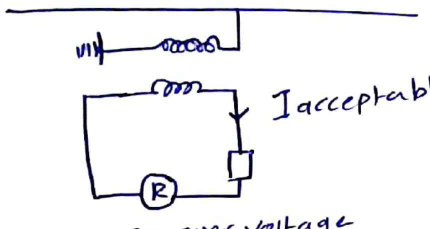
## * Transmission line protection.

→ In order of ascending Coast and Complexity.

→ Fuses
→ sechianalizers, recloser } Distribution Network
[fault location]

- Instantanuos over current Relay [50]
- Inverse time delay overcurrent Relay [51]
- Directional overcurrent relay.
- Distance
- Pilot [Distance + Communication]
- Differential

تزيد أهمية الخط




"expensive"

59 over voltage
27 under voltage.
R ≈ ∞

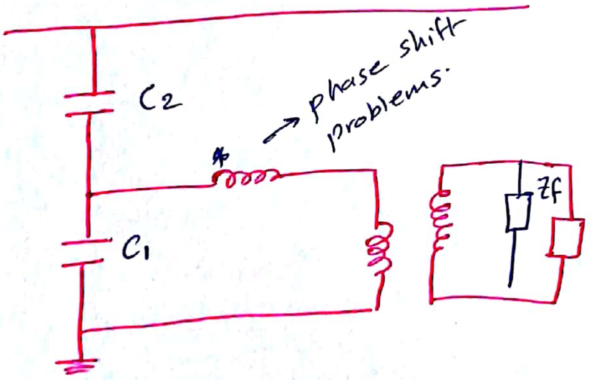
→ Solution.

Using (CCVT) : Coupling Capacitor voltage transformer.

① it is Used for EHV system.

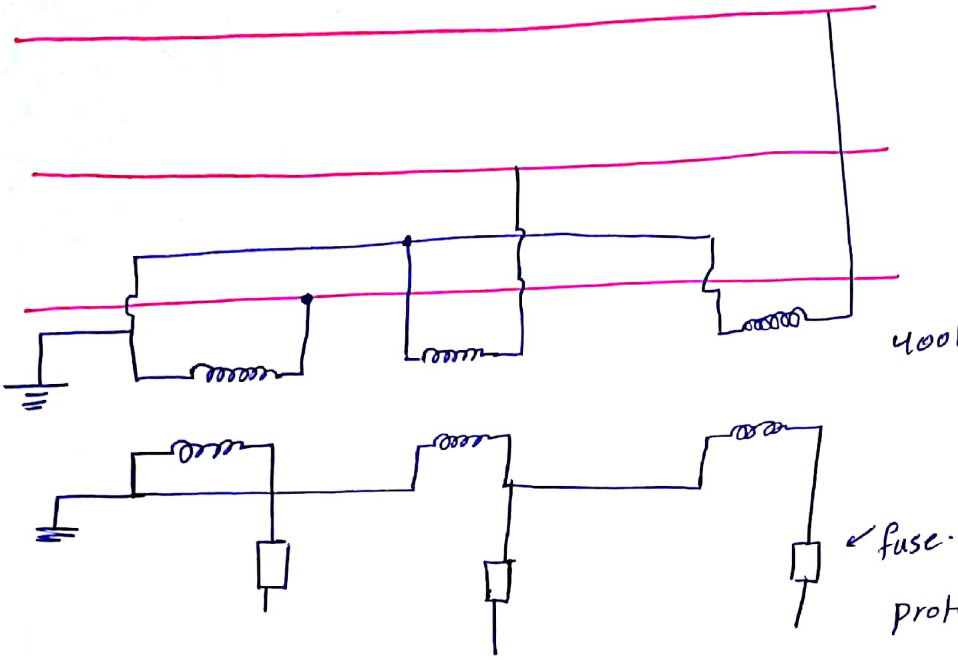
② more economics.

③ They Can be Used in Communication System
5V/4000HZ , 400kV/5kHZ




→ Can transform the Voltage to 120V
→ So magnitude is ok
→ problem in phase. (solution put inductor *)
→ Ferroresonance : oscillation between L and C frequently happend at High Voltage.
→ Zf, to eliminate ferroresonance oscillation.

* Voltage transformer
→ Transducer that transfer the Voltage to Voltage the relay can deal with it
→ [phase - Neutral], [L-L → 120V, L-N → 69]



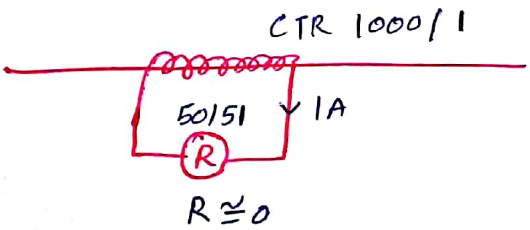

400kV/120V

$V_1 >>>> V_2$

$I_1 <<<< I_2$

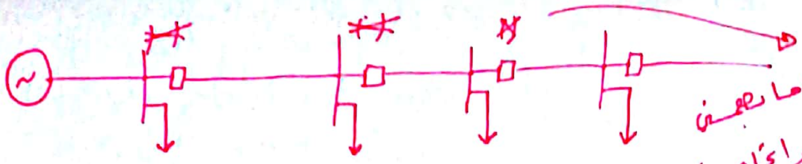
protect High current.

never o/c a CT, never s/c a VT

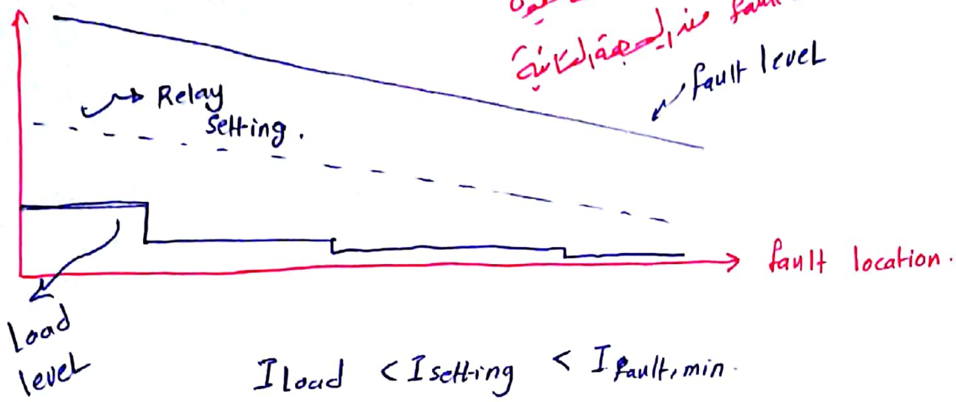



V → 400kV/1kA.

# Lecture #3



بصراحة بالحالة الأولى ما بنعرف نتطلع بأي واحد أو التانيين لأنه ما حيكون في تغذية للـ fault من الجهة التانية

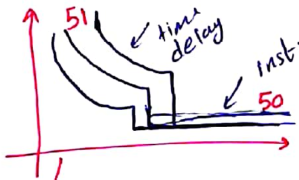


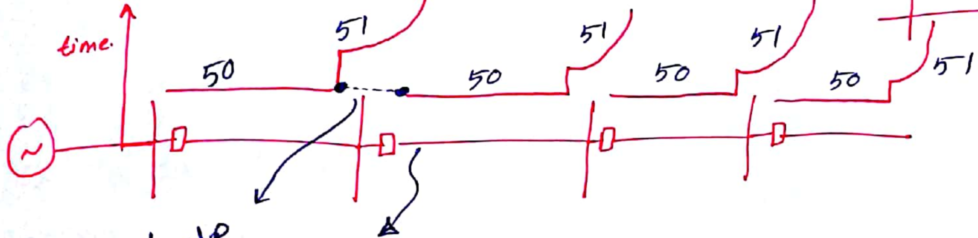

$I_{load} < I_{setting} < I_{fault,min}$.

→ CT's ratio must adapt the load increase.

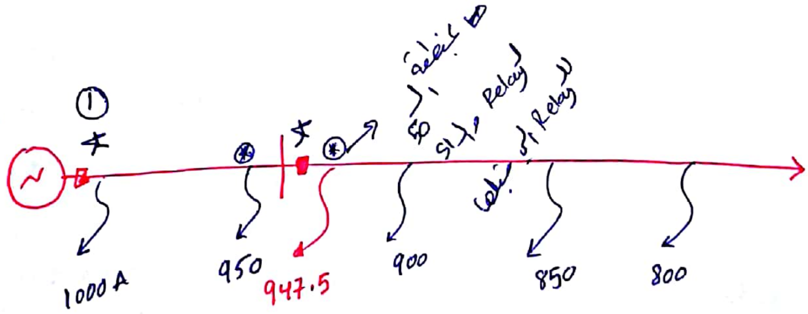
→ Distribution network: Inst. pickup must never overreach another relay.

main protection (over current instantaneous) [50]
Backup protection ( " " time delay) [51]



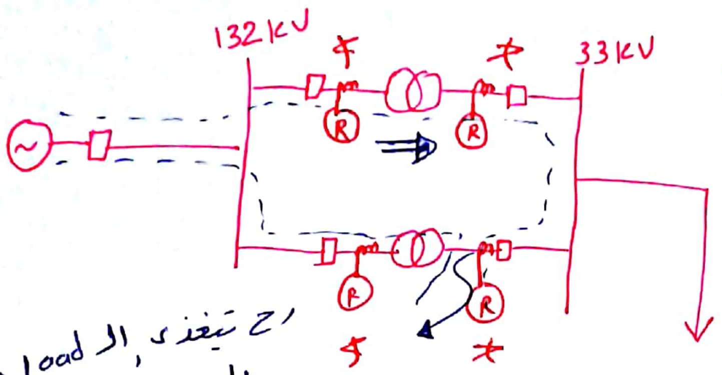

هاي المسافة تقريباً بتكون 200m الـ setting للـ Relay 50 لازم ما يتجاوز هاي المسافة لإنه بيصير بـ region الـ 51




صار عندي مشكلة عند Relay ① لإنه راح تشوف الـ 950 fault

بس ما رح تشوف الـ 947.5 انه fault.

# * Directional overcurrent Relay.

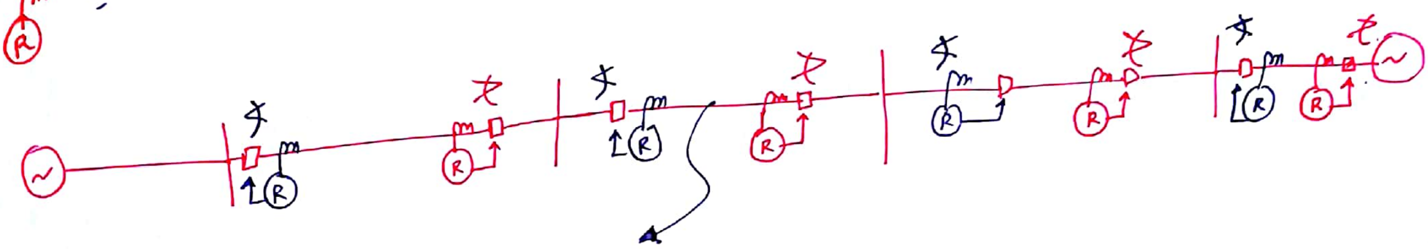



* لما بدي افصل واحد من ال ① لازم
اتأكد انو ال Transformer التاني
يقدر يتحمل ال Load كامل

التصميم على مبدأ N-1 Conjunsy.
يعني اذا واحد من ال generator او
ال Transformer فصل لازم ال System
يضل شغال

ح تتغذى ال load من
الجهتين لصيدك ح
يفصل الخطين

* الحل اني احط
Relay على اطراف
ال transformer من الجهتين




صوت للزمن وصمم يكون Bi-directional

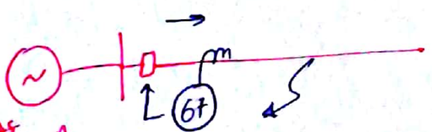
the ~~system~~ line.

⟹ CB and Relays are required at both ends of the line.

⟹ Polarization: Current value is not sufficient to have a directional o/c scheme.

⟹ Voltage signal are used to define the direction
- Operating Quantity: Current
- Polarizing Quantity: Voltage. — Reference

Does not depend on the fault

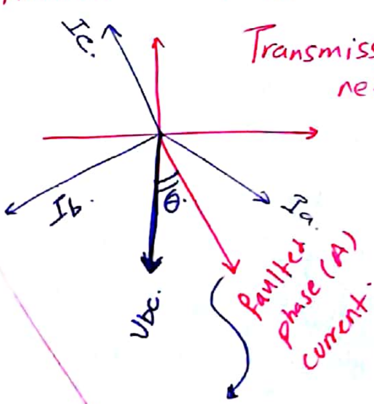



~~Phas~~ phase A

V = 0

ما بقدر اجيب ال polarizing Quantity من نفس
ال phase لازم تكون من مكان ثاني
لازم ما يكون معتمد على

Assume SLGF @ phase A




Transmission network.

if ∠Vbc and ∠Ia < 20°

it's (FAULT)

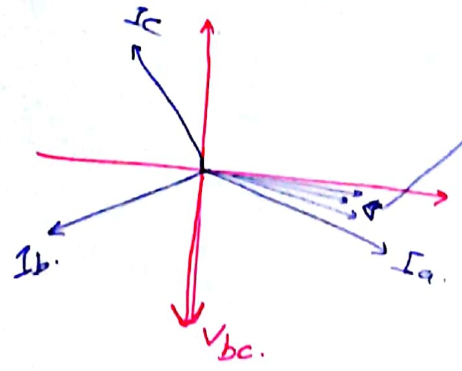
عندي شرطين

① The current > Isetting (Fault)

② انا بقطع بالاتجاه الصحيح

2

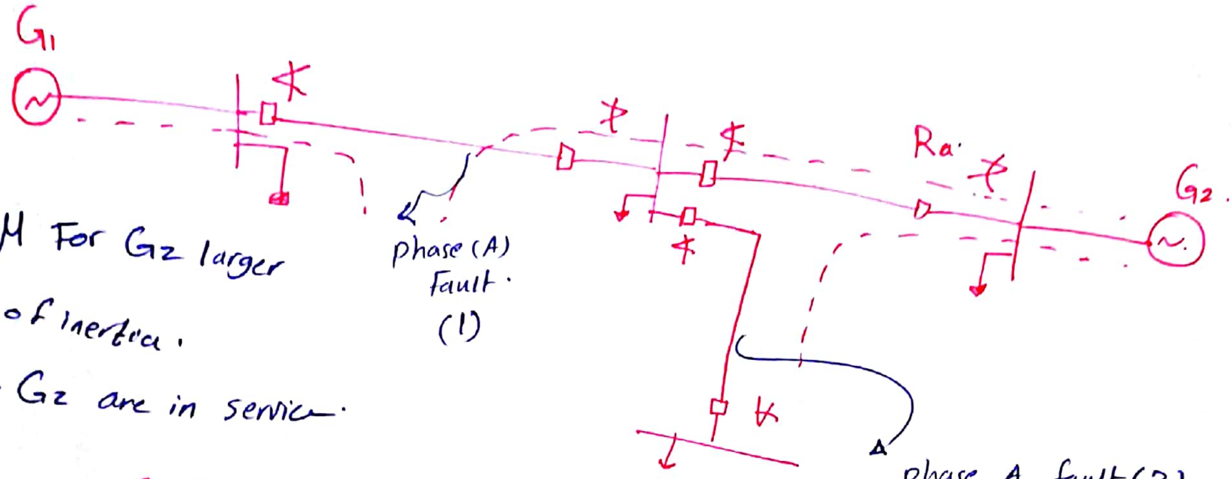
## - Distribution network.




100% resistive fault. Some where here.

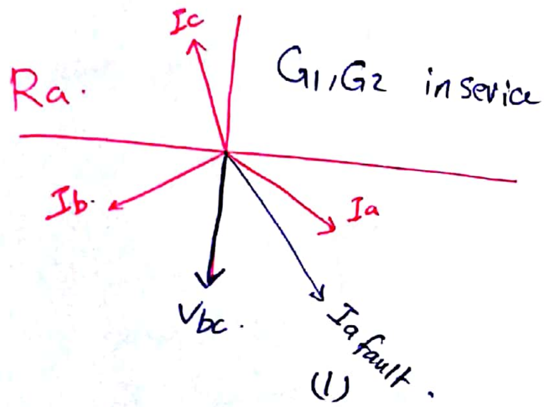
$\angle V_{bc}$ and $\angle I_c < 90$

مكان ال fault بعطينا



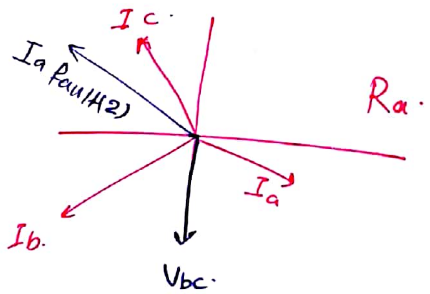

M For G2 larger
moment of Inertia.

G1, G2 are in service.

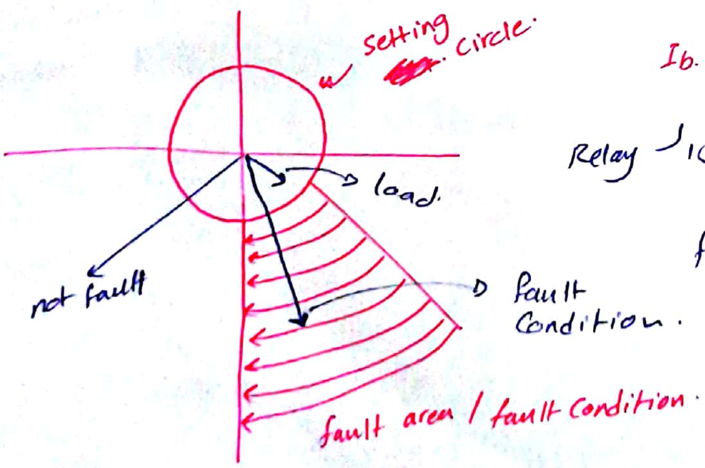



G1, G2 in service.

Case ② G2 is off.




صار خارج يفصل ال Relay
على صدار ال fault.

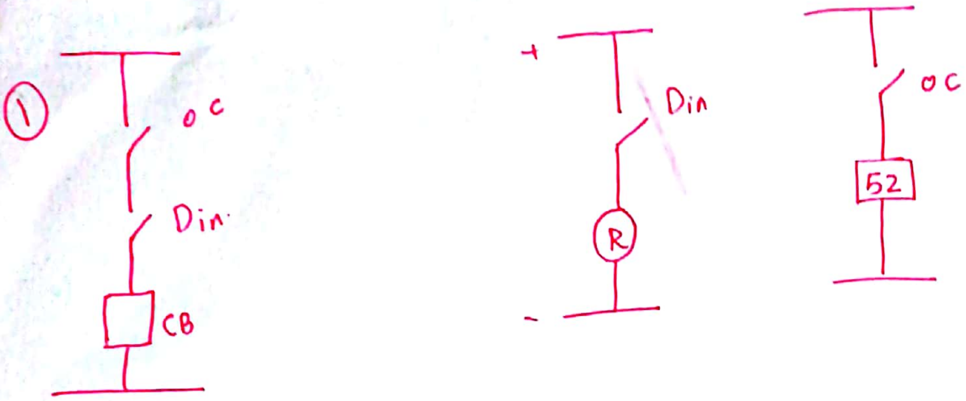



→ 3Ø fault Can detect the fault depend on +ve sequence voltage.

$V^{(1)} = V_a + a V_b + a^2 V_c$.

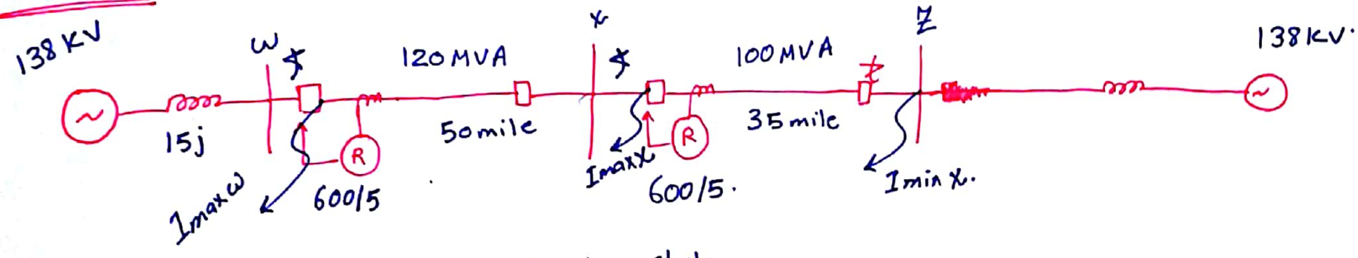
Lecture # 4

# Control logic of DOC.




## Example

$Z = 0.7 \angle 75$ /mile.




Consider a distribution network style.

| | Rx | Rw |
|---|---|---|
| 50 | 10.3 = I pick up. | 15.38 |
| 51 TMS | K = 0.5. | K = 1 |
| 51 PSM | Is = 5A | Is = 6 A |

أسرع علشان

[redacted]

$I_{Lmax} < I_s < I_{fault,min}$.

($\times 2$) ($\times 1.5$)

* Step ①

Load current.

$$I_{LXZ} = \frac{S_{3\phi}}{\sqrt{3} \times 138K} = \frac{100 \times 10^6}{\sqrt{3} \times 138 \times 10^3}$$

$= 418.4 A$ (Max ILoad)

assume $3\phi$ fault.

→ Fault Calculations.

$I_{min\,x} = I_{min\,w}$

$$I = \frac{138K}{\sqrt{3}\left(j15 + 24.5\angle 75 + 35\angle 75\right)}$$

$I = 1075 \angle -78$ A

in over current relay/protection don't care about current angle.

$Z_{xz} = 35 \times 0.7 \angle 75°$

$= 24.5 \angle 75$

$Z_{wx} = 50 \times 0.7 \angle 75$

$35 \angle 75$.

Note

→ $I_{F,min} = I_{L-G}$ fault.

→ We calculate $3\phi$ fault, it should be SLGF.

→ $I_N = 3 I^{(0)}$

$$I^{(0)} = \frac{V_{ff}}{Z^{(0)} + Z^{(1)} + Z^{(2)} + Z_n}.$$

→ $I_{max\,xz} = \dfrac{138k/\sqrt{3}}{j15 + 35\angle 75} = 1605\angle -79$

$I_{max\,w} = \dfrac{138k/\sqrt{3}}{j15} = 5311.62\angle -90$

→ Relay (X) settings. [51] ← Time delay settings. [min fault] [50] ↳ max fault.

$418.4 < I_{setting} \times \dfrac{600}{5} < 1075$

$I_{setting}(x) = 5$

$418.4 < \boxed{600} < 1075$

↙ $I_{setting} \times \dfrac{600}{5}$

→ Relay w

$I_{max\ Load} < I_{setting} < I_{f,min}$

$I_{max\ Load\ wx} = \dfrac{120 \times 10^6}{\sqrt{3} \times 138k} = 502\ A$

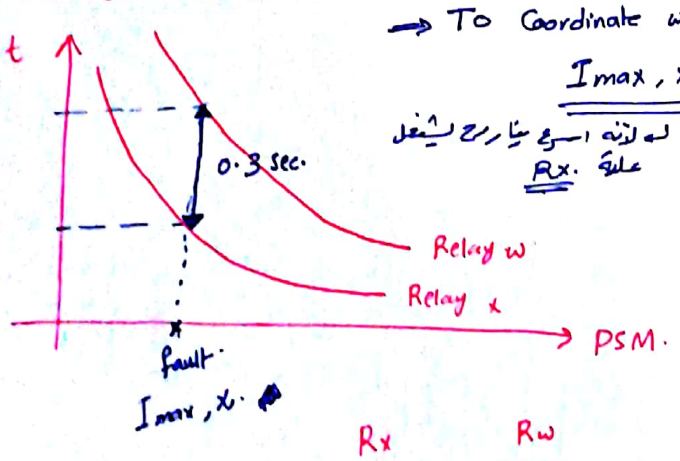
$502 < I_s < 1075$

Choose $I_{pickup} = 6A = I_{setting}$

So

$502 < 720 < 1075$

→ time Setting




→ To Coordinate with relay Rw, find the time at which $I_{max,x}$ will operate.

لأنه اسرع يا ريح ليشغل
Rx. علية

$I_{max,x} = 1605 \times \dfrac{5}{600} = 13.375\ A$

$PSM = \dfrac{13.375}{5} = 2.675 = \dfrac{I_{fault,Relay}}{I_{Pickup}}$

time = 0.35 sec (operating time for Relay x)

$Rw_{time} = 0.3 + 0.35 = 0.65$ sec.

| | Rx | Rw |
|---|---|---|
| If, primary | 1605 | 1605 |
| If, sec. | 13.375 | 13.375 |
| PSM. | 2.675 | 2.229 ⇐ $\frac{13.375}{6}$ |

K = 1 → the curve at PSM = 2.229 the relay time = 0.65

2

→ Inst. Settings.

$I_{inst}(x) = [I_{max}(z) * 1.15]$ (1075)

$= 1236.25$

$I_{pickup} = 10.3\ A = I_{fault} \times \frac{5}{600}$

→ $I_{inst}(w) = I_{max}(x) * 1.15$. (1605)

$1845.75$

$I_{pickup} = 15.38$

$I_{max}(z) = I_{min}(x)$ — to cover ~~all~~ The T.L.

## Homework

27/11

For the previous example.

→ Relay → detect (Figure (1)), → Trip

① → fault at Begining of Line (WX)
W side 1Ø $Z_f = 0$.

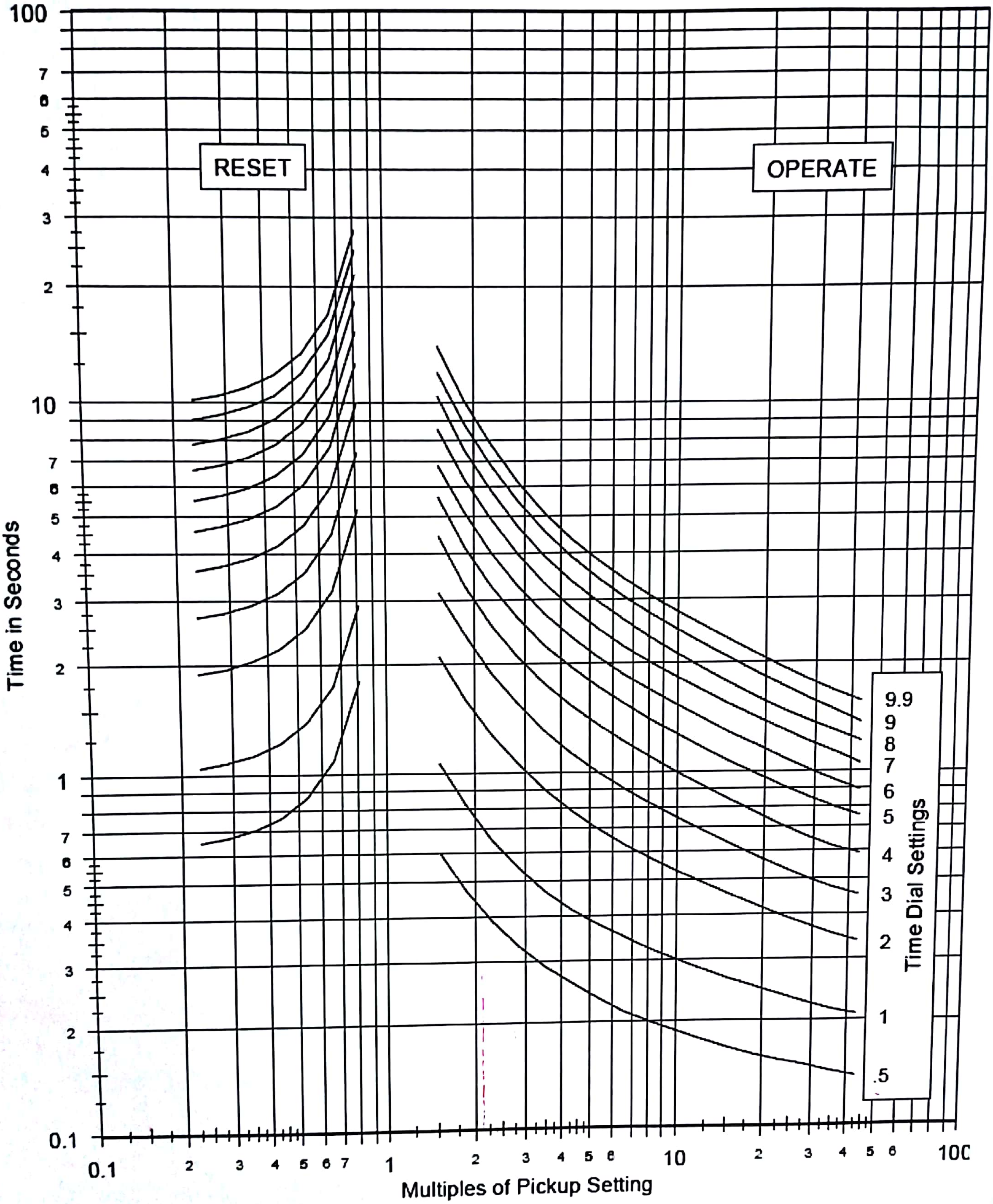
② → Begining of line (XZ)
X side 1Ø ~~[crossed out]~~ $Z_f = 40\ \Omega$.

③ → Fault in the middle of line XZ
1Ø, $Z_f = 40\ \Omega$.

④ → 3Ø fault at the Begining of line XZ, X side.

each situation → 4 Figures.

① Rx detect
② Rw detect.
③ CBx Trip.
④ CBw trip.




OVERCURRENT RELAYS

DIAC, DIFC, & DSFC

0358A1104

GES10023

Power Management

**IAC 51**

Inverse Standard

Frequency: 50/60 Hertz
Time Dial Range: (0.5 - 9.9)
Current Range: 0.5 - 15.9 ( 5 Ampere Relays)
0.1 - 3.18 (1 Ampere Relays)

General Electric CO., 205 Great Valley Parkway, Malvern, PA 19355

*GEK 105570A*

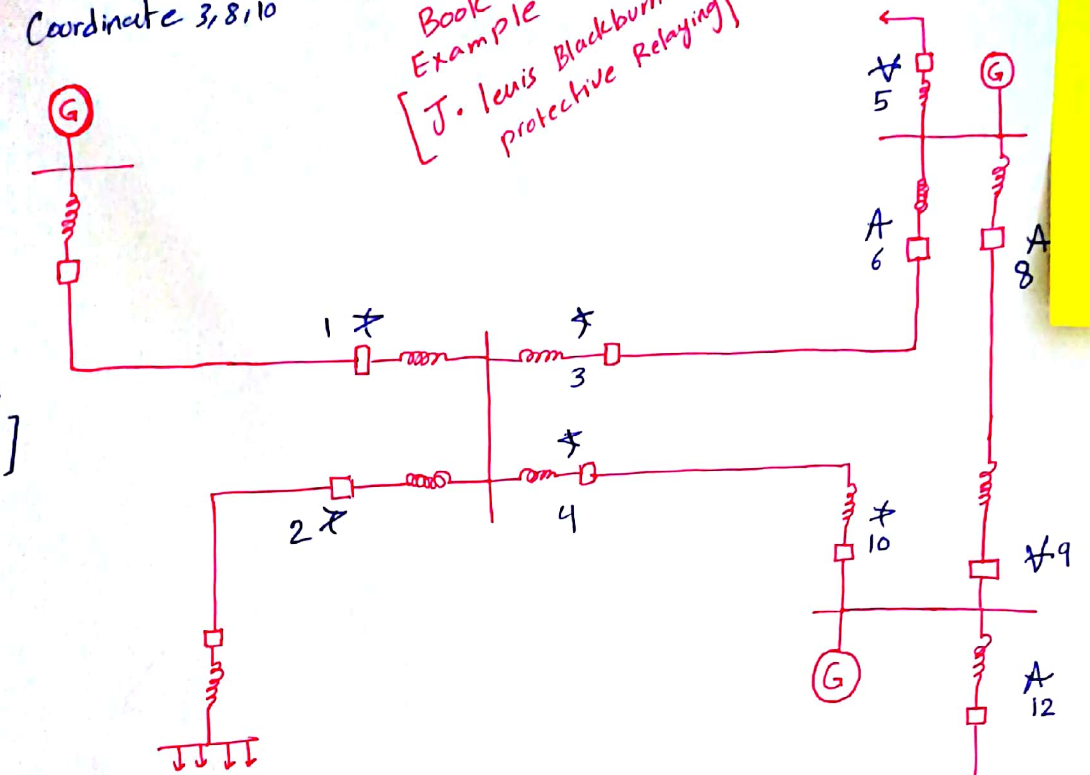
**FIGURE 1 IAC51 TOC Curve**

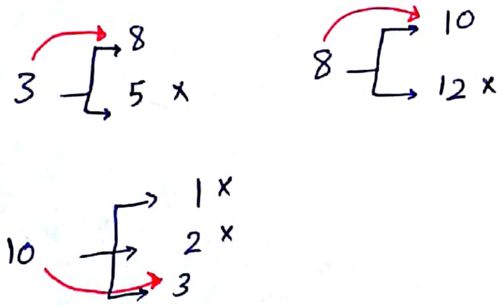
Coordinate 3,8,10

Book Example [J. Lewis Blackburn protective Relaying]

Lecture # 5

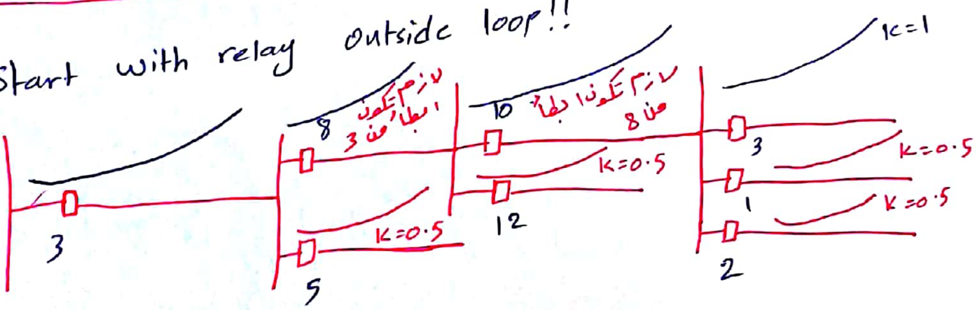
D.OC [67]




→ 3 → 8 → 10 ↵

* Start with relay outside loop!!




Choose fastest curve for relay outside the loop.

## (*) Distance protection

51 Can be very slow

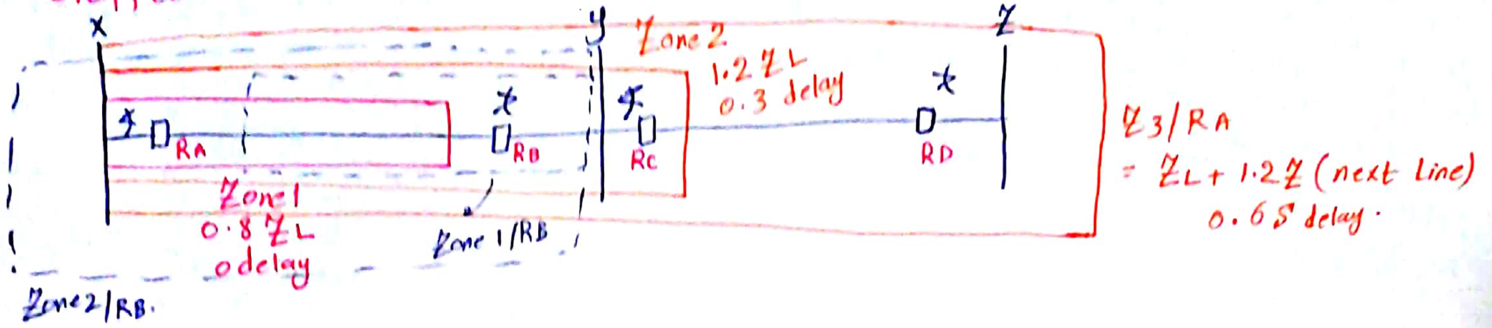
50 Coverage is limitted

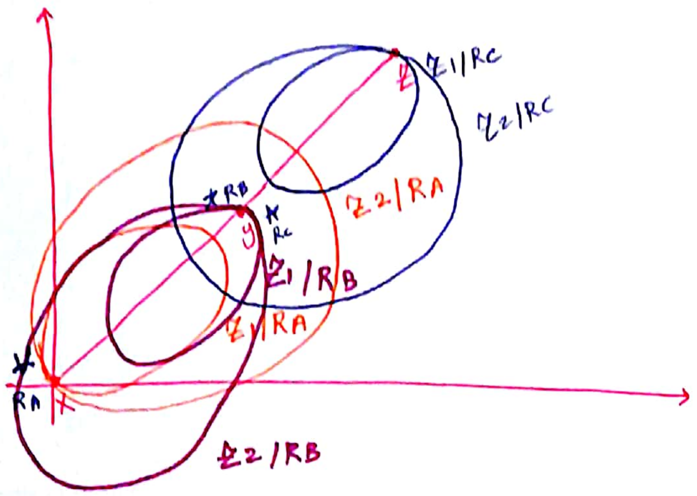
→ Load should be Considered !!

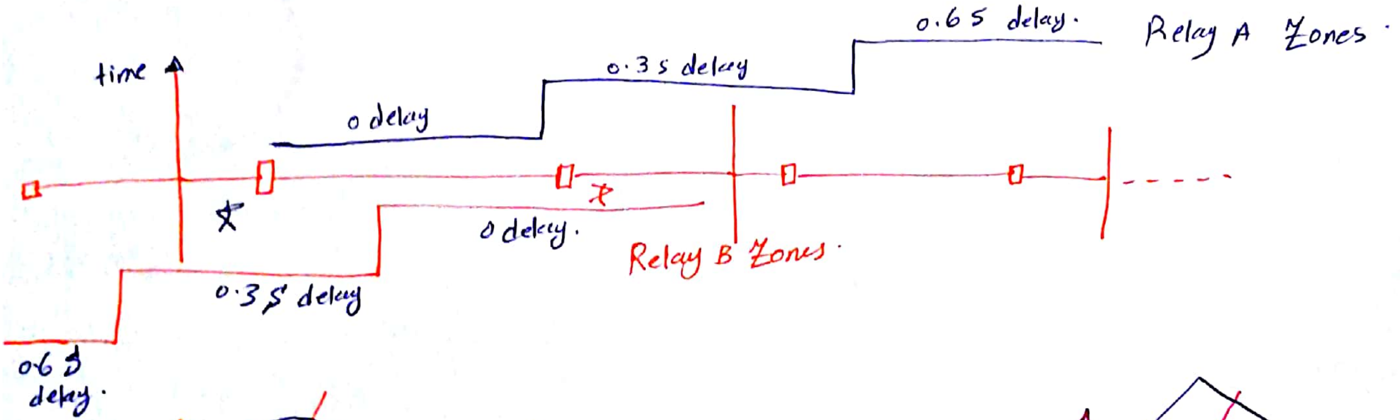
The Solution : Using Impedence dependent Relay.

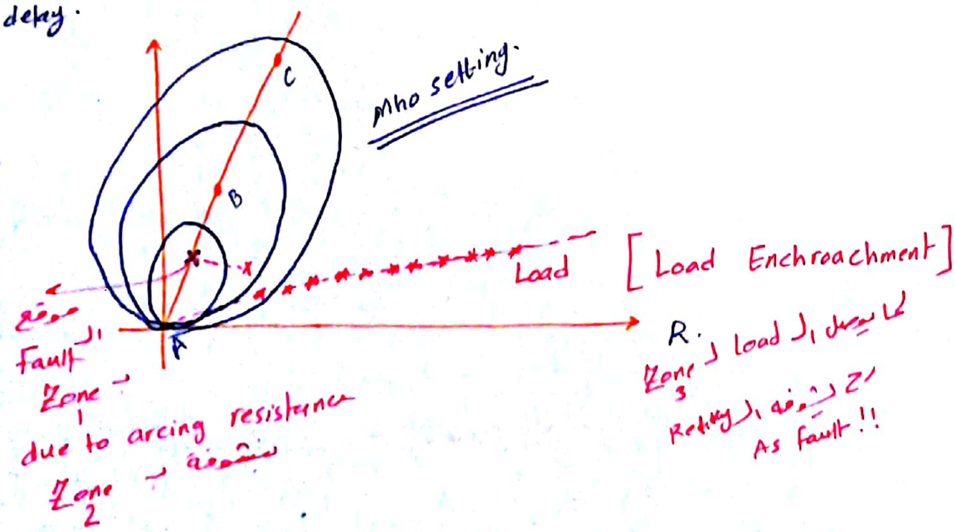
Relaying scheme that responds to $\left(\frac{V}{I}\right)$ "distance Relay"

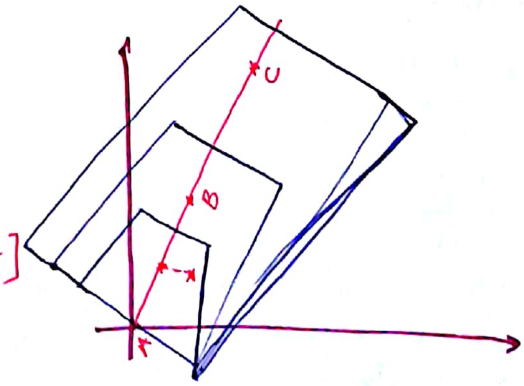
# Stepped distance Relay. (21)



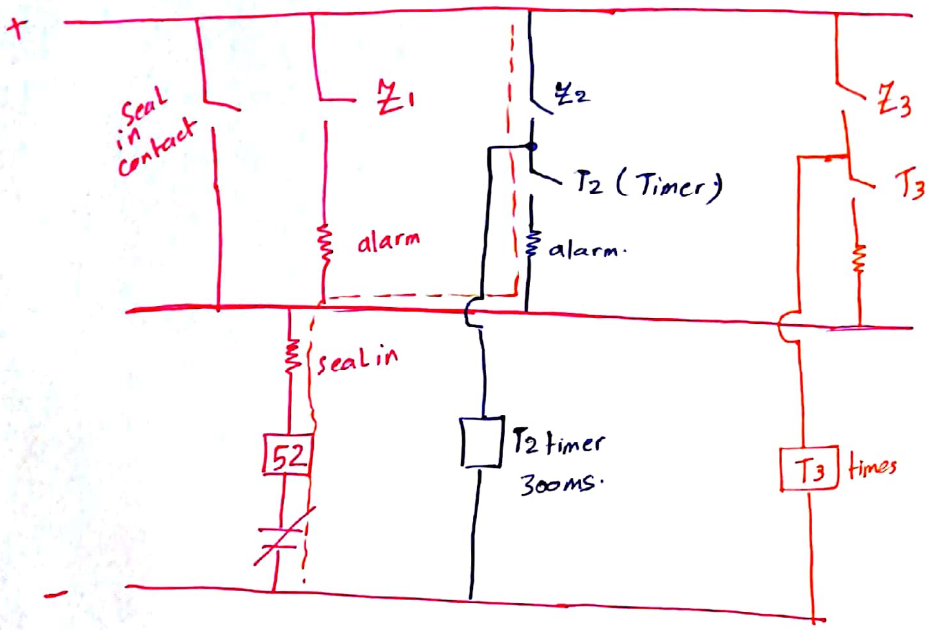



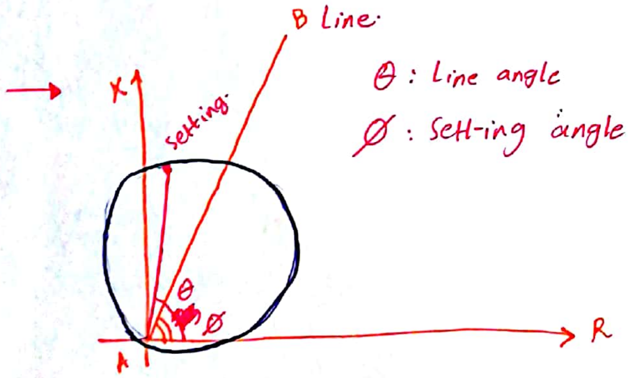

Method 2 to represent relays Zone.

Quadelateral setting.

adv: including Rare. faraway from Load.

# * Distance protection logic

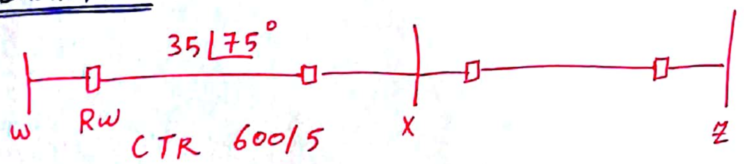



θ : Line angle

∅ : Setting angle.

## Example



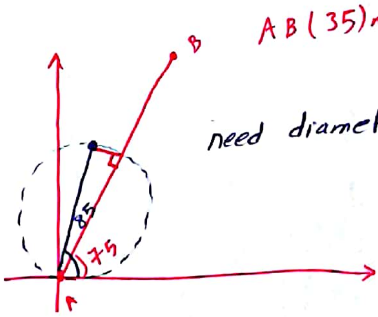

CTR 600/5

VTR 132k/110

1200/1

Find the settings of $Z_1, Z_2, Z_3$ for relay Rw @ Mho relay settings on (sec) of angle 85

AB (35) mile.




need diameter length.

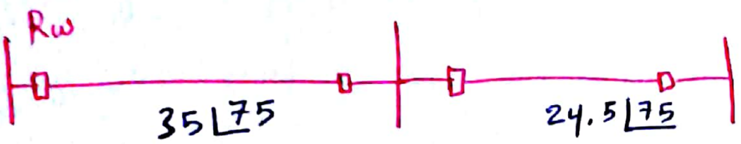
Zone 1 setting

$$\frac{CTR}{VTR} * \frac{35 * 0.8}{\cos(85-75)} = Z_1$$

$$\frac{35 \times 0.8}{\cos(10)} \times \frac{120}{1200} = 3.02\angle 85^\circ \ \Omega \qquad t=0.$$

Zone 2

Lecture #6




$Z_2$

$$Z_1 = \frac{35 \times 0.8}{\cos(85-75)} * 0.1 = 3.02 \angle 85^\circ \quad (t=0)$$

0.1 ↓ $\frac{CTR}{VTR}$

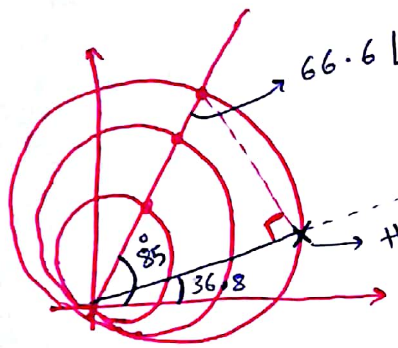
$Z_2 = (1.2 \rightarrow 1.8) Z_L$

$$Z_2 = \frac{35 \times 1.25}{\cos(85-75)} \times 0.1 = 4.44 \angle 85^\circ \quad (t=0.3)$$

$$Z_3 = 35\angle 75 + 1.25 * 24.5 \angle 75 = 6.66 \angle 85^\circ \quad (t=0.6)$$

$$= 65.625 \angle 75$$

66.6∠85 (6.66 × 10 "Refered to primary)




this point should be Calculated (Max Load "Load in system should not exceed this point)

## [Loadability of Distance Relay]

$$Z_L = Z_{diameter} * \cos[85 - [\cos^{-1} pf]]$$

$Z_{diameter}$ = $Z_3$ (primary)

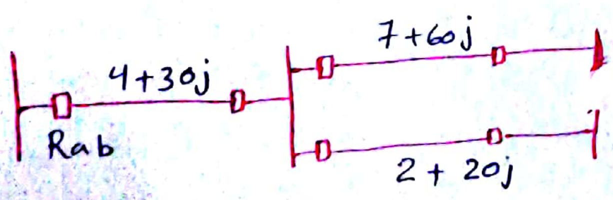
$$= 66.6 \times \cos(85 - 36.9) = 44.5 \angle 36.9$$

$$* \quad S_{max} = \frac{V_{LL}^2}{Z}$$

for a 132 kV system

$$= \frac{(133 \times 10^3)^2}{44.5} = 3.96 \times 10^8 \text{ VA}$$

**Example**: Find settings of Relay Rab ↑ (in primary.) at mho @ 85°



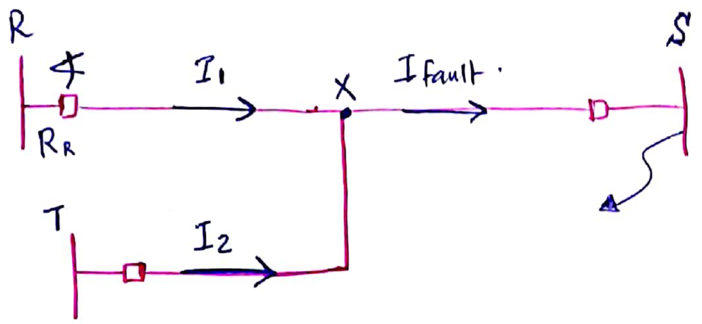

$$Z_1 = \frac{(4+j30) * 0.8}{\cos(85 - \angle T.L)}$$

$$Z_2 = \frac{1.25 * (4+30j)}{\cos(85 - \angle T.L)}$$

$$Z_3 = \frac{[4+j3 + 1.25(7+60j)]}{\cos(85 - \angle Sum)}$$

"Take longest line"

## * Effect of Infeed.




**Case 1)** $I_2 = 0$ CT at T is open. without infeed.

$I_{relay} = I_1' = I_{fault}'$ [Primed quantities are in Secondary]

$V_{relay} = I_1' [Z_{RX}' + Z_{XS}']$

$$Z_{Relay} = \frac{V_{relay}}{I_{relay}} = Z_{RX}' + Z_{XS}' = Z_{RS}'$$ (Relay operate at $Z_2$)

**Case 2)** $I_2 \neq 0$ Considering infeed.

$I_{Relay} = I_1' \neq I_{fault}'$

$V_{Relay} = I_1' * Z_{RX}' + I_{fault}' * Z_{XS}'$

$= I_1' * Z_{RX}' + (I_1' Z_{XS}' + I_2' * Z_{XS}')$ $\quad I_{fault}' = I_1' + I_2'$

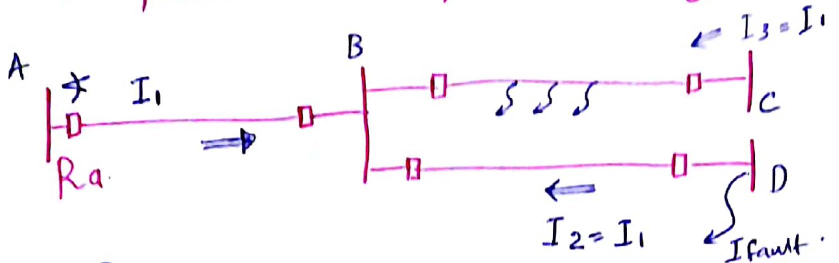
$$Z_{Relay} = \frac{V_{relay}}{I_{relay}} = \frac{I_1' Z_{RX}' + I_1' Z_{XS}' + I_2' Z_{XS}'}{I_1'} = Z_{RX}' + Z_{XS}' + \frac{I_2'}{I_1'} Z_{XS}'$$

$$= Z_{RS}' + \left[\frac{I_2'}{I_1'} Z_{XS}'\right]$$

The relay seen impedence larger than required.

So maybe fault in ~~Z1~~ Zone 1 but Relay See it at Zone 2

→ As previous example Considering infeed




**Case ①**

**No infeed.**

$Z_{AB} = 4 + j30$

$Z_{BC} = 7 + j60$

$Z_{BD} = 2 + j20$

$Z_{AC} = 11 + 90j$

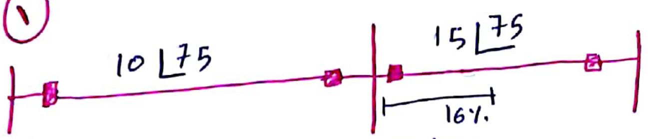
$Z_{AD} = 6 + j50$

Zones : (No Fault) (Comparing with and without infeed)

$Z_1$ no change! ($Z_{AB\,APP} = Z_{AB}$)

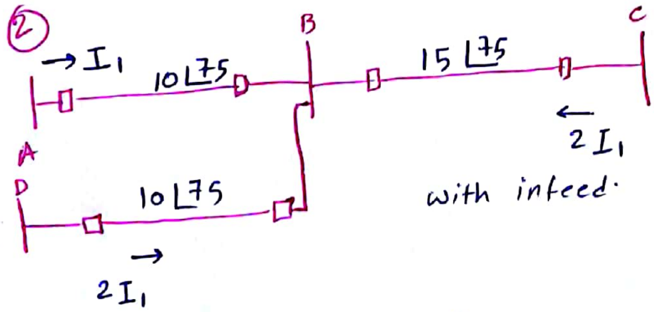
$Z_2$ : will cover less distance. from the remote Line.

①




Zone2 ⇒ $Z_2 = 12.5 \angle 75$ "with out infeed"

②




with infeed.

$$Z_{AC\,app} = \frac{I_1 * Z_{AB} + 3I_1 Z_{BC}}{I_1} = Z_{AB} + 3Z_{BC}$$

$Z_{AC\,app} = 10\angle 75 + 45\angle 75 = 60\angle 75$

$Z_{BC\,app} = 45\angle 75$ (5.5% instead of 16%.)

**Case②**

**Consider infeed.**

$Z_{AB} = 4 + j30$

$Z_{BD\,app} = 4 + j40$

~~$Z_{AD} = Z_{AB} + \frac{I_x}{I_1} Z_{BD}$~~ =1

$$Z_{AD\,app} = \frac{V_{relay}}{I_{relay}} = \frac{(I_1 Z_{AB}) + [(I_1 + I_3)(Z_{BD})]}{I_1}$$

$= Z_{AB} + 2Z_{BD}$

$\boxed{Z_{AD\,app} = 8 + j70}$

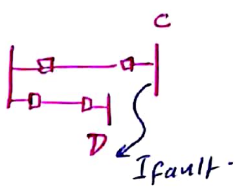
$Z_{BD\,app} = Z_{AD\,app} - Z_{AB\,app}$

$= 4 + 40j$

$$Z_{AC\,app} = \frac{V_{relay}}{I_{relay}} = \frac{Z_{AB} I_1 + (I_1 + I_2) Z_{BC}}{I_1}$$

$= Z_{AB} + 2Z_{BC}$

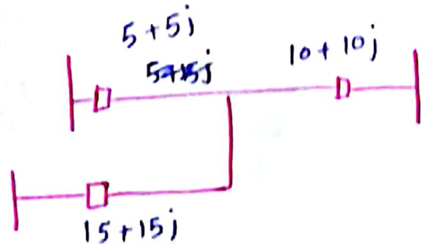
$\boxed{Z_{AC\,app} = 18 + j150}$




$Z_{BC\,app} = 18 + 150j - 4 - 30j$

$\boxed{Z_{BC\,app} = 14 + 120j}$

→

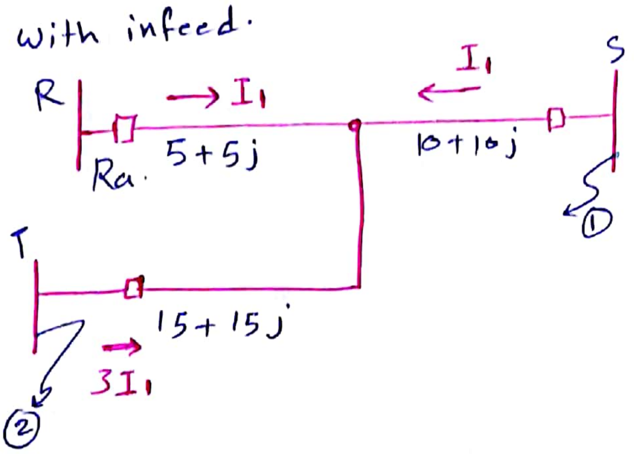



$[5+5j + 10+10j]$

Zone 1 should underreach. → $Z_1 = 0.8\,[15+15j]$ — neglect infeed.

Zone 2, 3 should overreach.

with infeed.




**Find $Z_1$ Considering Infeed.**

to calculate $Z_1$

Assume $I_{fault\,1}$ ⇒ calculate Z

then assume $I_{fault\,2}$ ⇒ calculate Z.

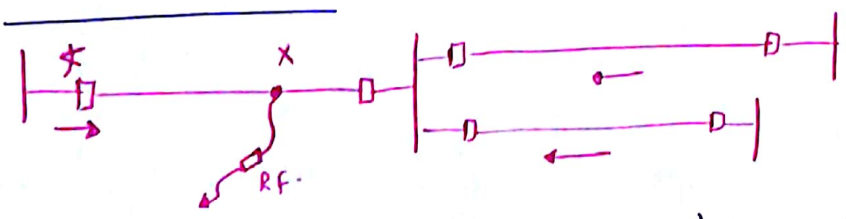
take smallest Z.

$$Z_{RS\,app} = \frac{(5+5j)I_1 + (10+10j)\,4I_1}{I_1} = 45+45j$$

$$Z_{RT\,App} = \frac{V_{Relay}}{I_{Relay}} = \frac{I_1(5+j5) + 2I_1(15+15j)}{T_1} = 35+j35$$

Shortest!


$$\text{Zone 1} = \frac{0.8 * (35+j35)}{\cos(\text{Mho} - \angle T.L)} \times \frac{CTR}{VTR}$$



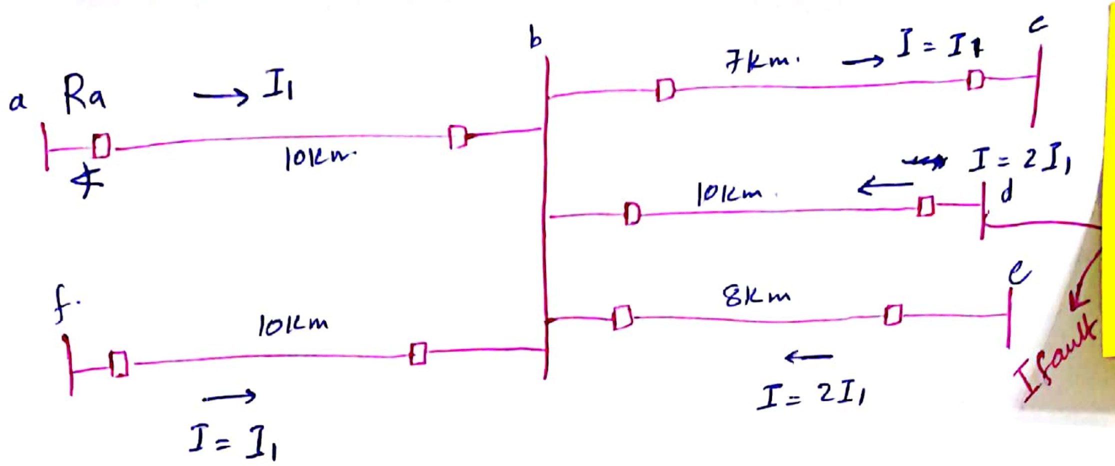

$$Z_{Relay} = \frac{V_{Relay}}{I_{Relay}} = \frac{(Z_{AX} + Z_f)I_1 + (Z_f * I_2) + (Z_f * I_3)}{I_1}$$

(Zone 1 will changed with RF.)

④

Scanned by CamScanner

lecture #7



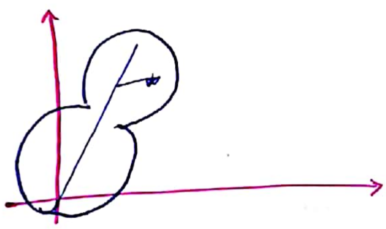

$$Z_3 = Z_{ab} + 2Z_{bd} + 3Z_{be} + 2Z_{fB}.$$

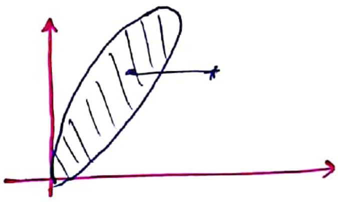
Zone 3 would be larger than required.

So ① maybe we don't use Zone 3.

② Use communication wire between Relays.

## Other shapes of Distance Relay.





## Fault resistance.

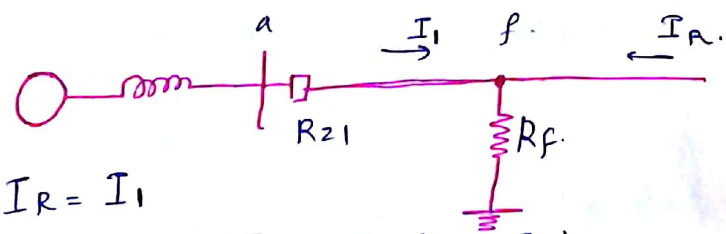
→ Fault maybe with resistance (Arc)

→ Imprical formula for $R_{fault}$

$$R_{arc} = \frac{76\, V^2}{S_{sc}}$$

$V$ → voltage in kV

$S_{sc}$ → short ckt capacity in kVA.




$I_R = I_1$

$E_R = Z_{af} * I_1 + R_f\,(I_1 + I_2)$

$Z_R = Z_{af} + R_f + \frac{I_2}{I_1} R_f.$

# → Pilot protection.

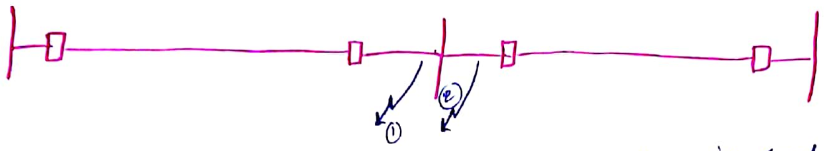
Pilot : protection scheme based on Communication.

Goal : to protect the whole line instantaneously.. (main Protection)

Cannot be done Using 50, 51, 67, 21 !!

→ Communication may present a solution.

Microwave عنا استخدم
Connection.
But disadvantage.
① Line of sight
② Needed too much repeaters for long T.L
③ take care about mountains, Building...

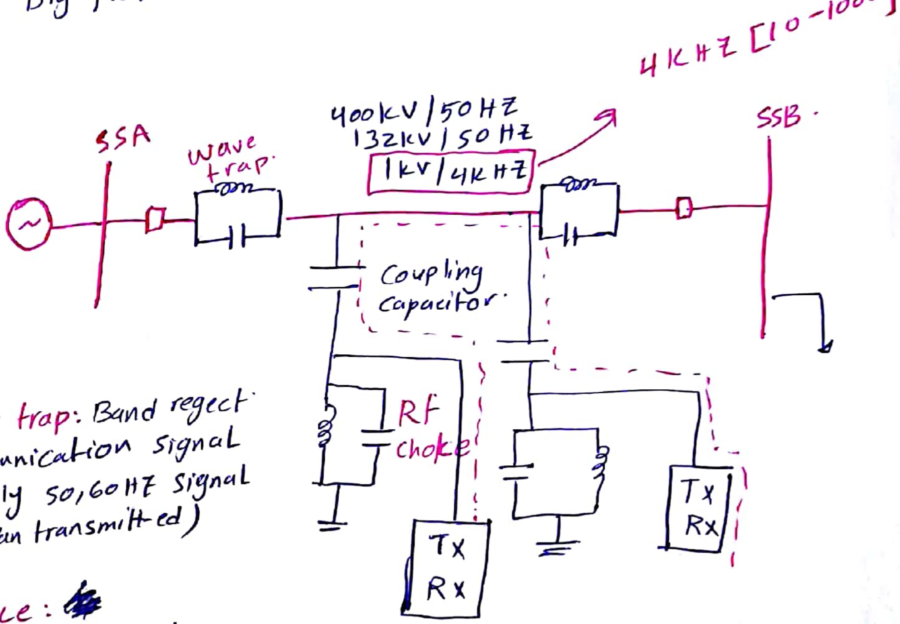



- we have Big problem in such these fault !!

* Communication wire.

PLC : power line Carrier

①




Wave trap: Band reject communication signal
→ (only 50, 60HZ signal can transmitted)

RF choke :
Communication signal shouldn't transmitted to earth.
RF choke can stopped it.

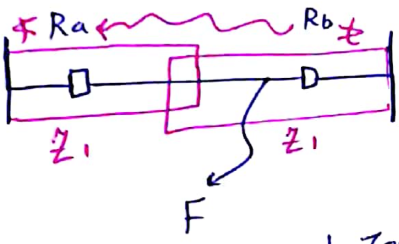
Coupling Capacitor : Low power high frequency with High power low freq system.
allow connection between.

*!! warning.
If fault will occur in my line → Communication will lost.

Solution
Tripping scheme
Blocking scheme.

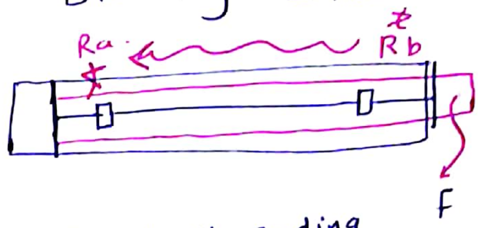
Using Blocking scheme in PLC.

## Tripping scheme




F in Zone 1 Rb and Zone 2 Ra.
need communication connection.
in order to detect the fault inst. from Ra.

## Blocking Scheme.

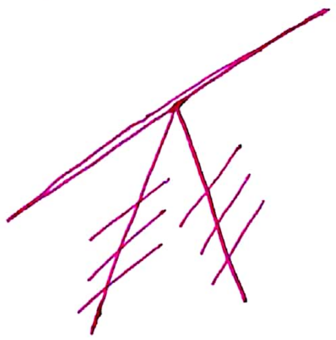



Rb should sending signal to Ra in order to not detect this fault. (not our. Area)

Using one zone in order to protect whole line.

Using in PLC

## ② Optical fiber.



Unlimitted Bandwidth.

very far distances.

## ③ Microwave [150 M – 20 GHZ]

→ Attenuation and distortion.
  ↳ due to channel and propogation.
  ↳ due to terrain, Building.

→ Fading.

→ Earth curvature. [repeaters is the solution]

→ line of sight.

## ④ Pilot wires.

twisted pair and Coaxial Cable.
[very small distance, limited Band width.]

→ Use of Communication Channels.

Tripping

Ra → Rb [trip]

Blocking.

Ra → Rb [No trip]

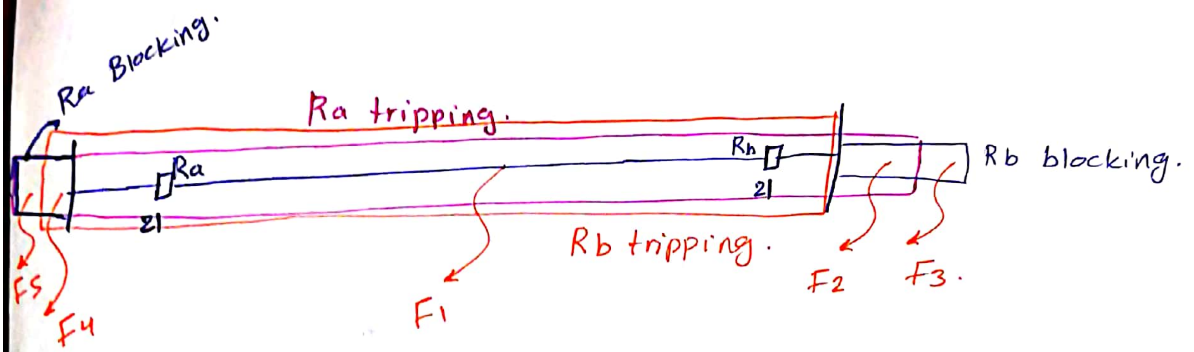
PLC.

Other communication channels.

→ Blocking signal : a signal if received will block CB from tripping.

## Blocking schemes.

① Directional Comparison Blocking.




F1 → Ra trip, Rb trip. ⇒ trip.

F2 → Ra trip, Rb Block ⇒ No trip.

↳ Rb send signal to Ra inorder to not trip this fault.

F3 → Ra out of Zone, Rb Block. → No Trip.

F4 → Rb trip, Ra Block → No Trip.

F5 → Rb out of Zone, Ra Block → No trip.