# POWER II NOTEBOOK

17/2-19/3

DR. HESHAM HAMDAN
SPRING - 2014

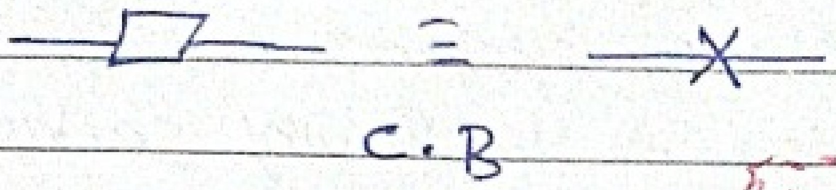
POWER UNIT
ELECTRICAL ENGINEERING

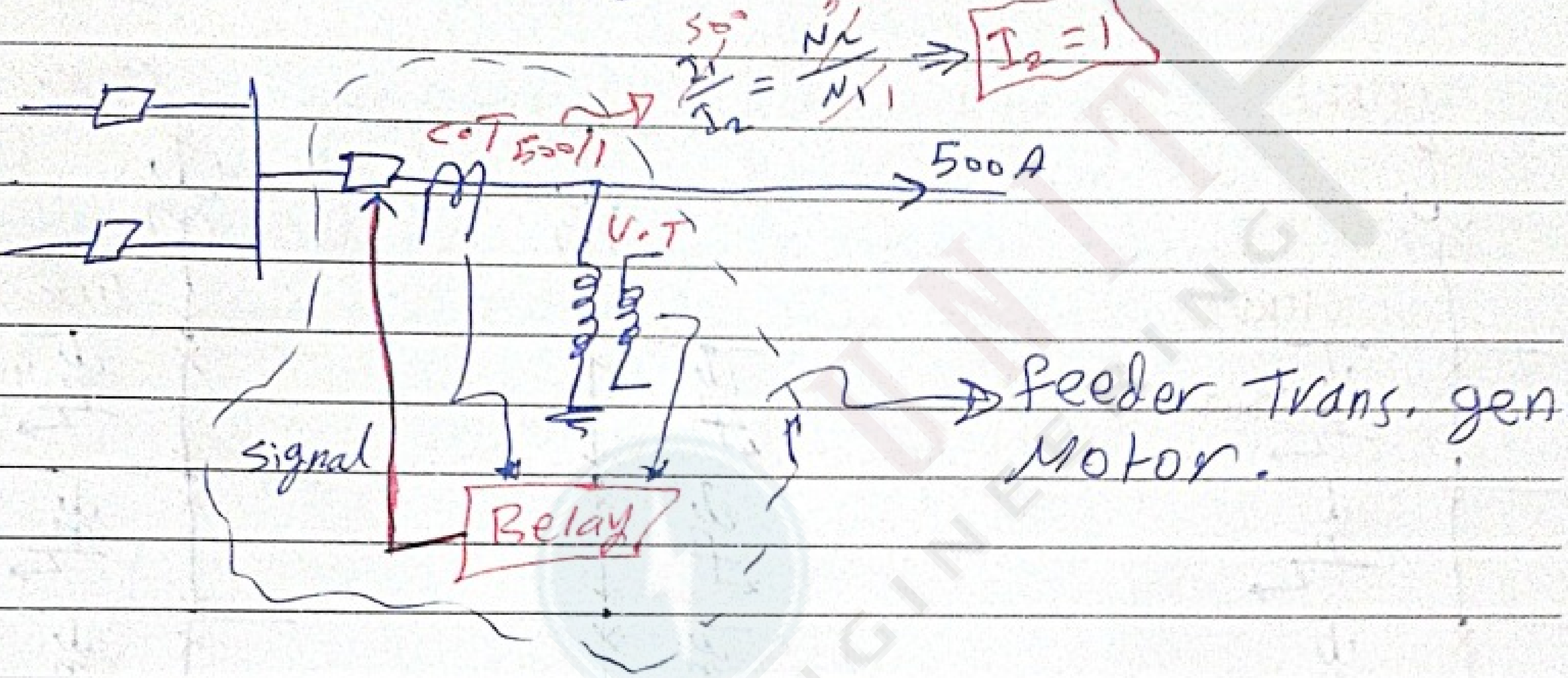
Anas Kat3

# Power (2)

الإثنين 17/2/2014

## * Protection system :-





$\frac{I_1}{I_2} = \frac{N_2}{N_1} \Rightarrow \boxed{I_2 = 1}$

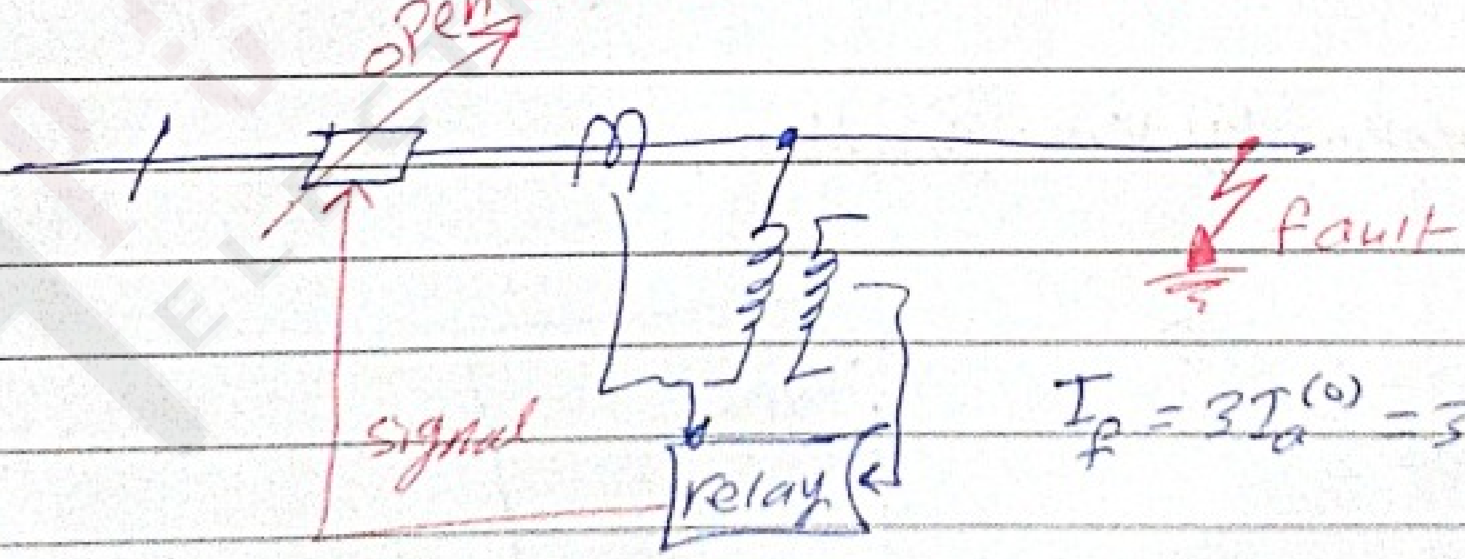
## * Requirements :-

الموثوقية

### 1 Reliability and Testing :-

a- by correct design :-

Ex:- when the fault is happend.



$I_f = 3I_a^{(0)} = 3\times \frac{E}{Z^{(0)} + Z^{(1)} + Z^{(2)} + 3Z_f}$

b- correct installation & Testing

c- proper maintenance.

التمييز الاختيار

### 2 Discrimination «selectivity» :-

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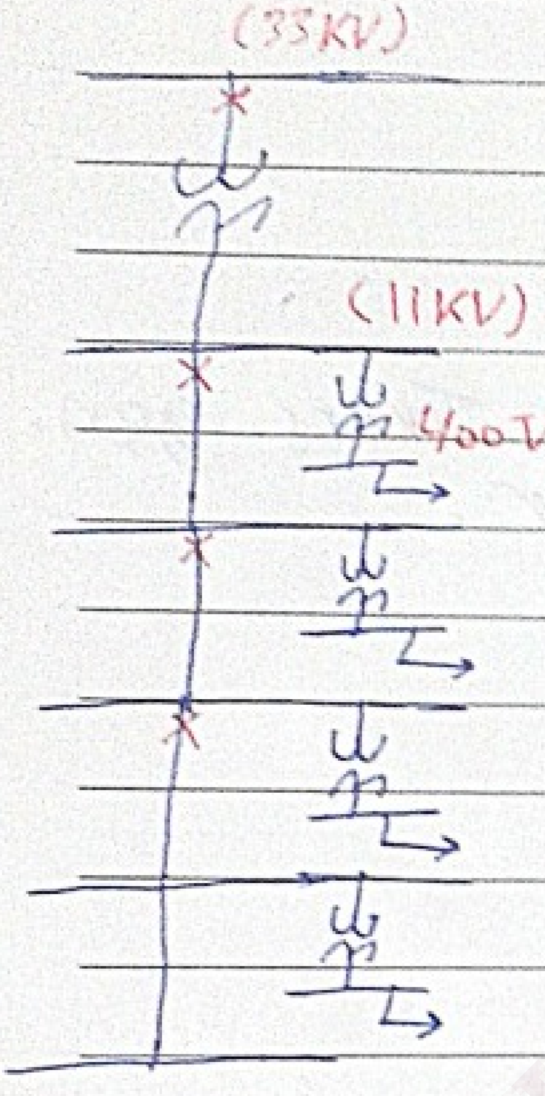
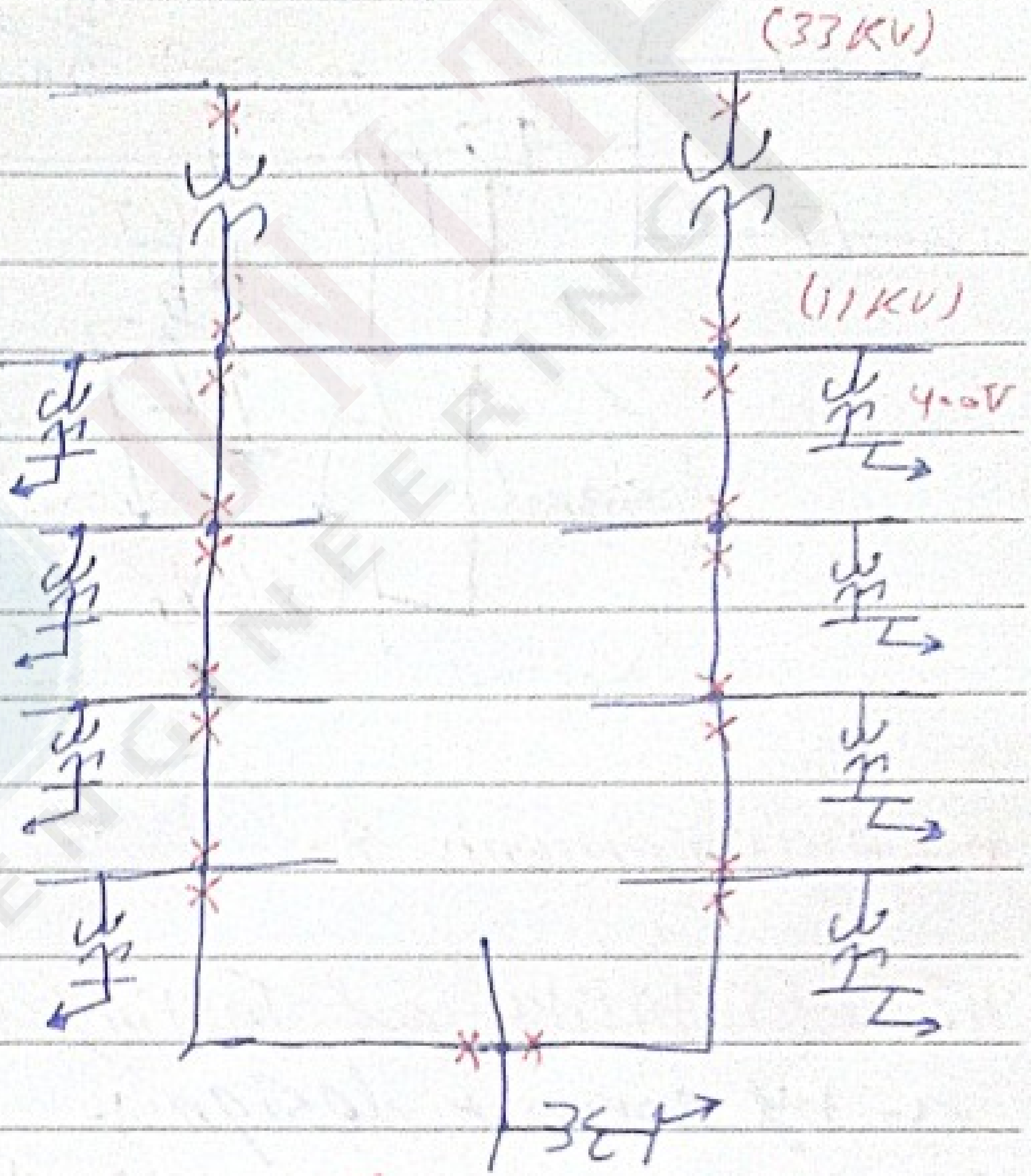
## 2/ Discrimination «Selectivity» :-

quality where by the Protection system is enabled to cause the disconnection «isolation» of the faulty section ONLY

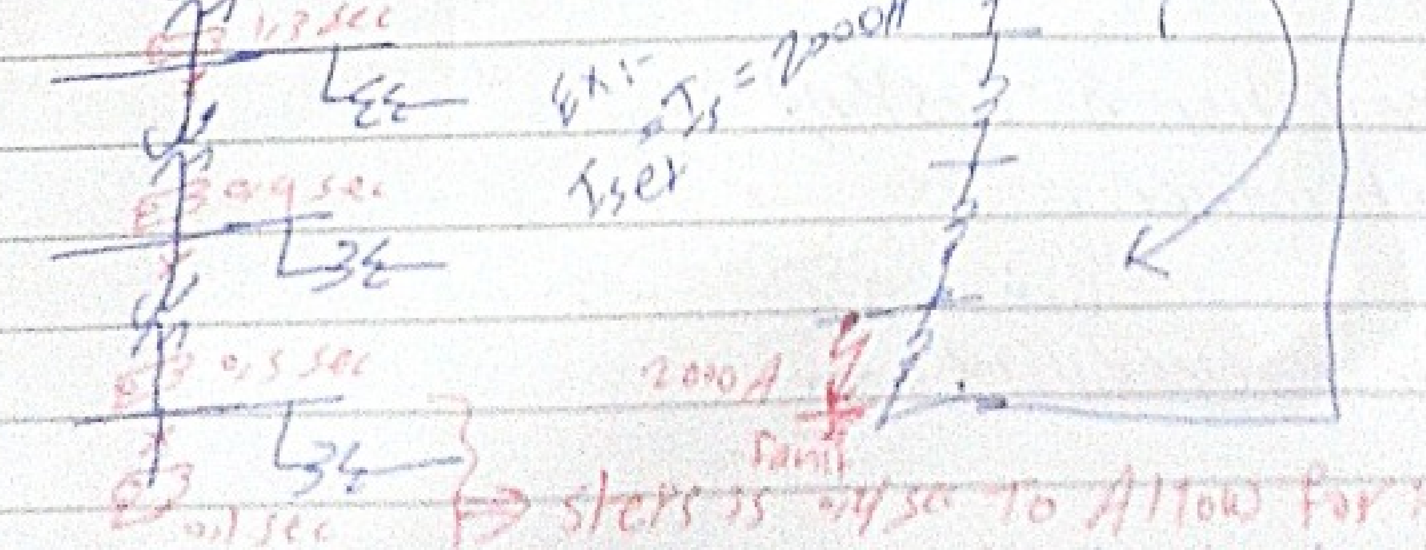


« redial system »



« Ring Main system »

## 2-a Discrimination by time grading :-



⇒ steps is 0.4 sec to Allow for :- ① error ② interruption time of the ...

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*Drawbacks :-

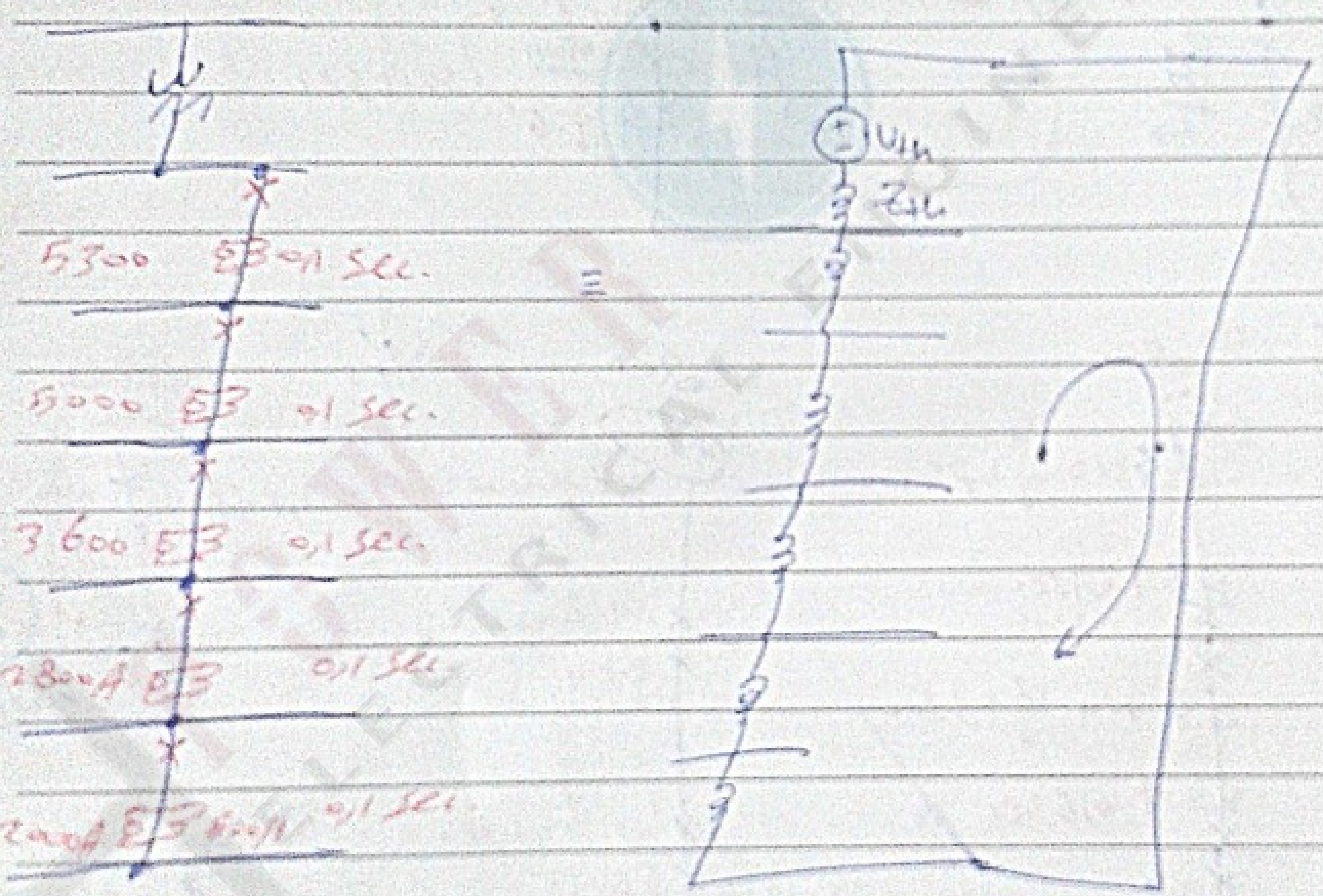
1- for large # of section the fault clearing time may exceed 3 sec. which is the Max. Allowable time duration of the fault.

*Protection system :-

equipment use for detecting & locating the fault and initializing the removal of the faulty section.

2- for faults the source the fault current is the Highest but the fault clearing time is max. Then :-

## 2-b :- Discrimination by current grading :



* Drawbacks :-

1- it can't differentiate between fault on either side of the bar

2- $Z_{th}$ is Not constant ⇒ i.e the calculated fault currents may become less than $I_1$ .

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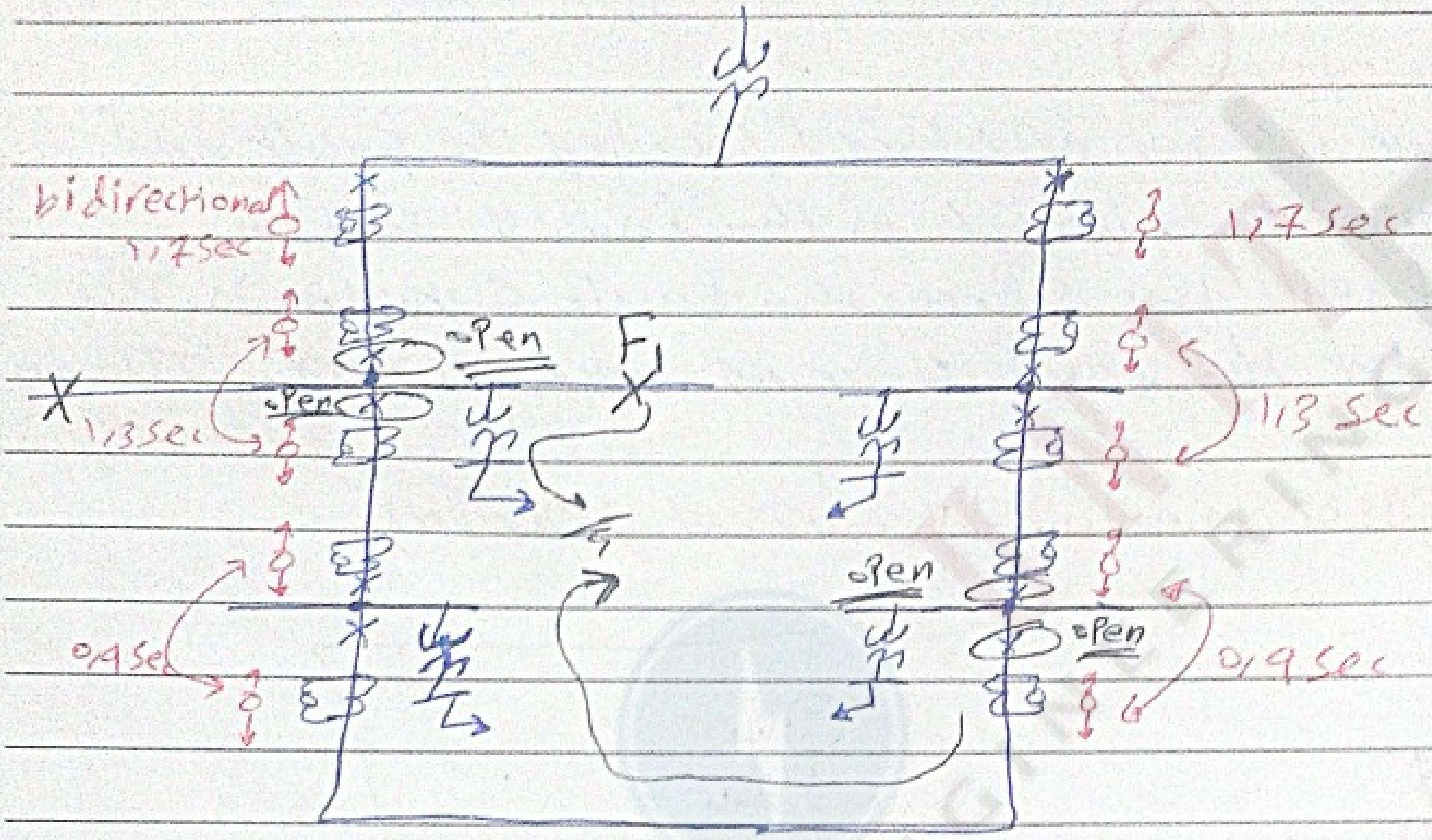
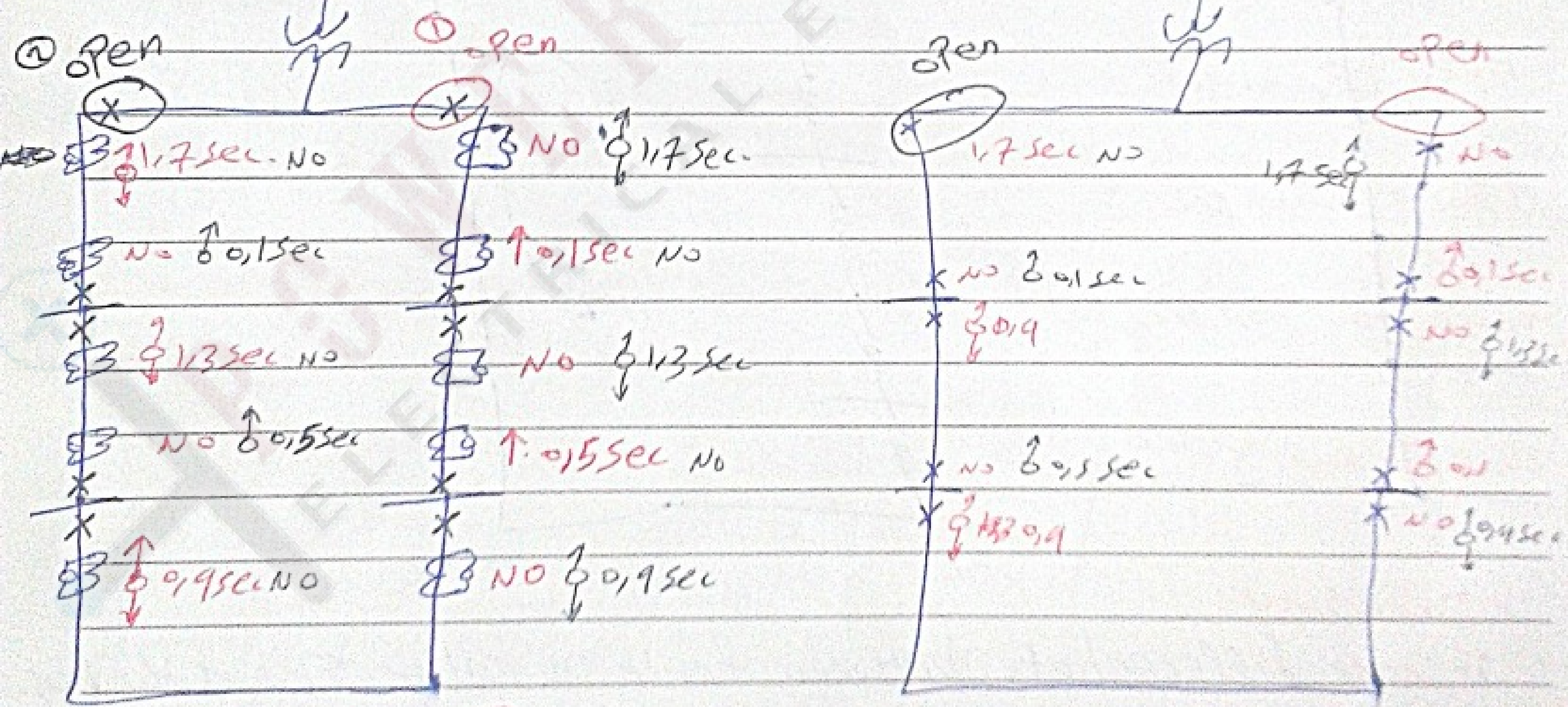
* Discrimination

3-c by Time & direction ⇒ APPLicaple ONLY for Ring system, All relays are set at minimum fault current





4 bus/2 = $\boxed{2}$

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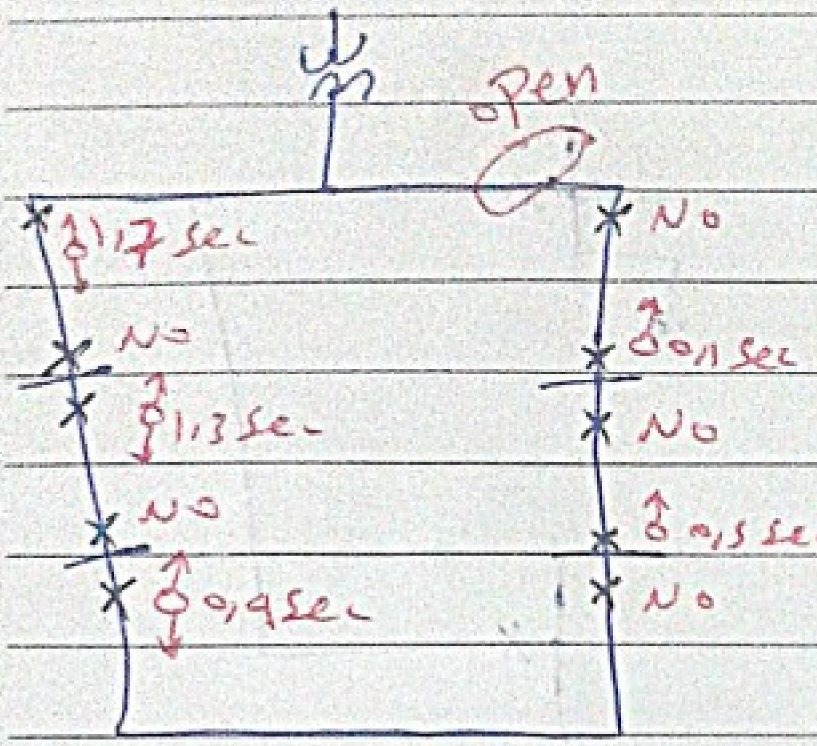
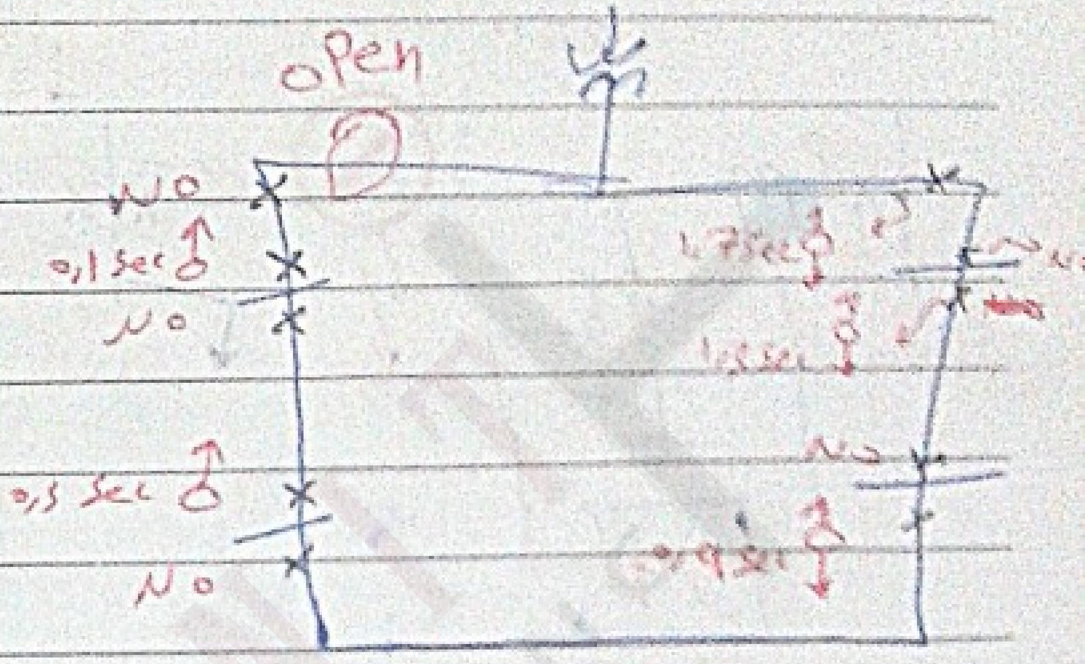
for even # of bus :-



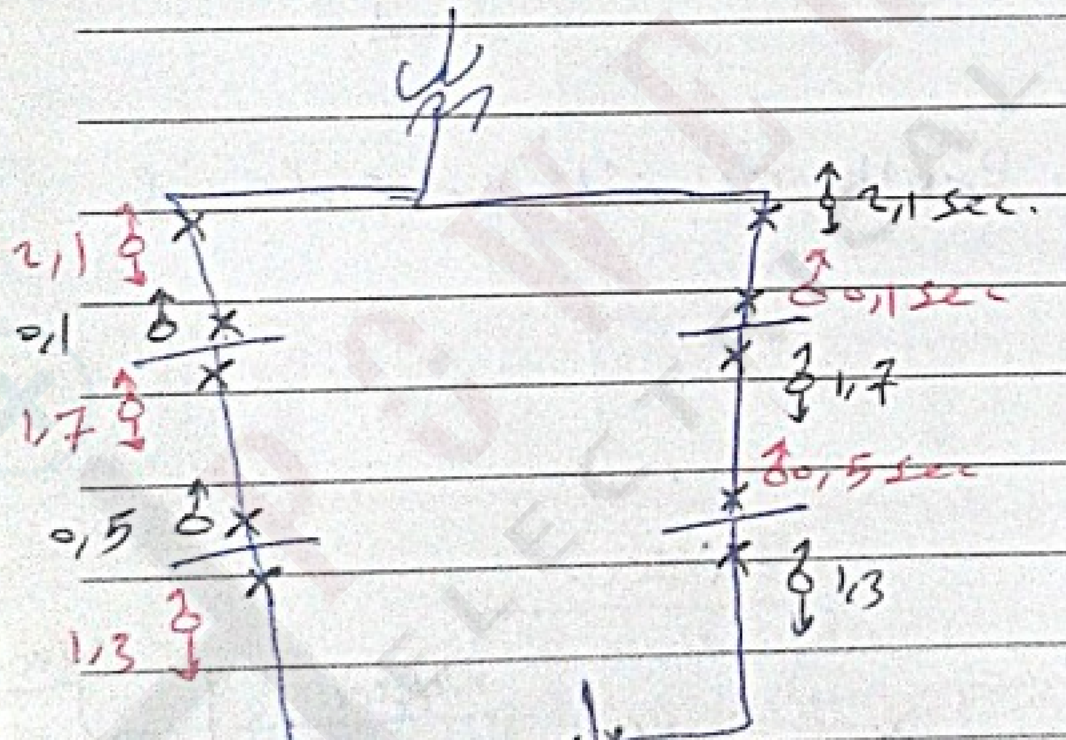
Test (1)



Test (2)

4/2 = 2 then The 1st
2 relay s is directional

For odd # of bus.



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5/2 = 2,5 ⇒ 3 relay is direction

* same Drawbacks as Time grading.

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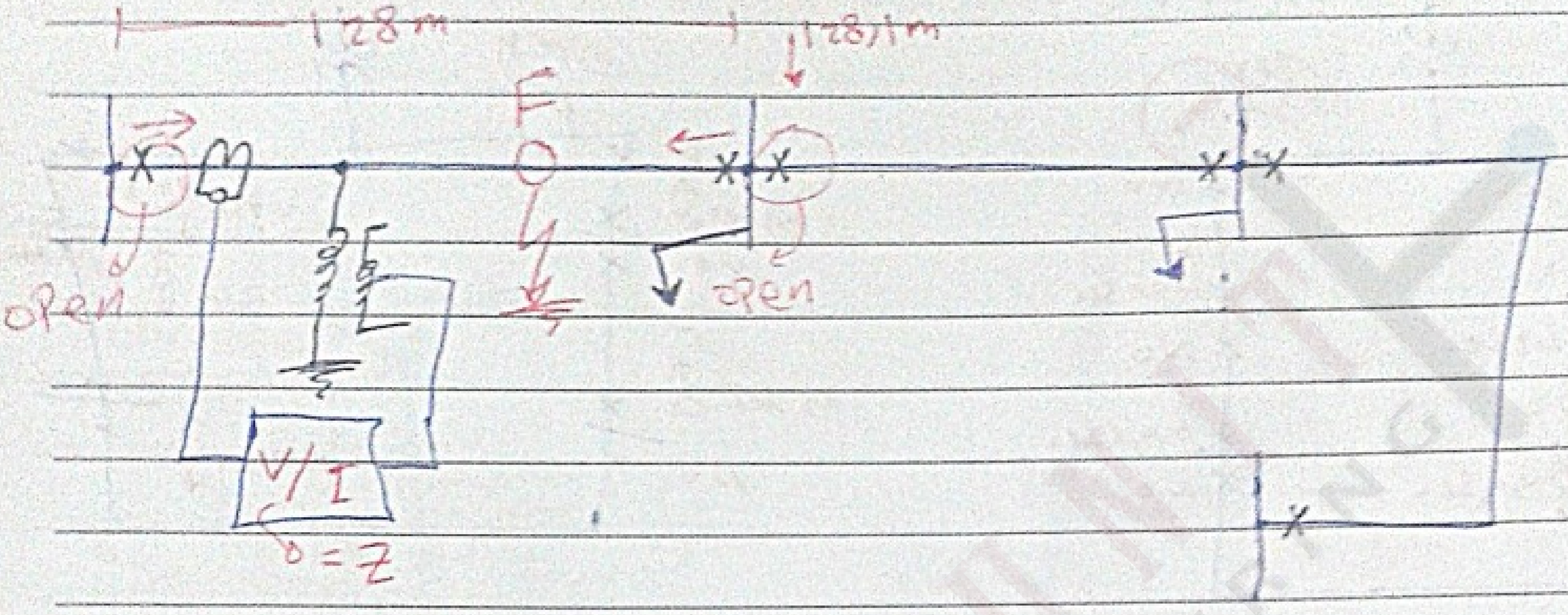
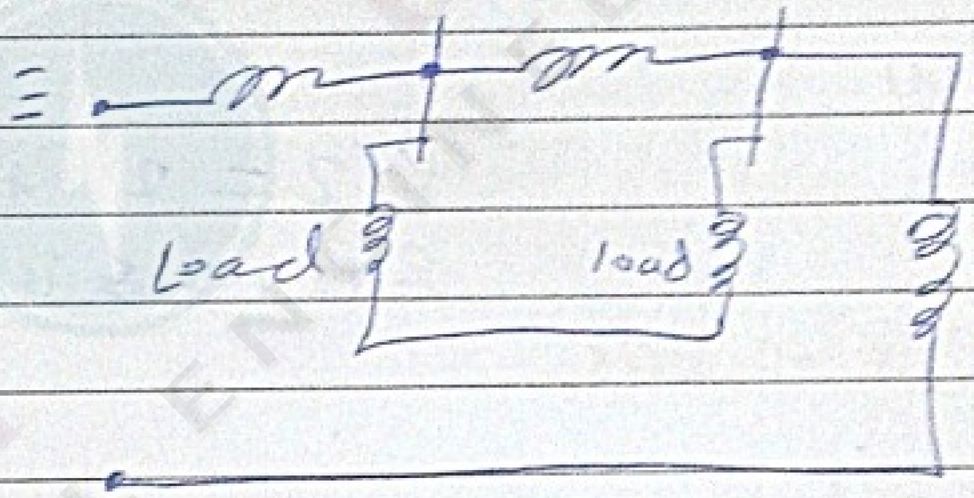
## 3-d by distance «Impedance» Measurement :-

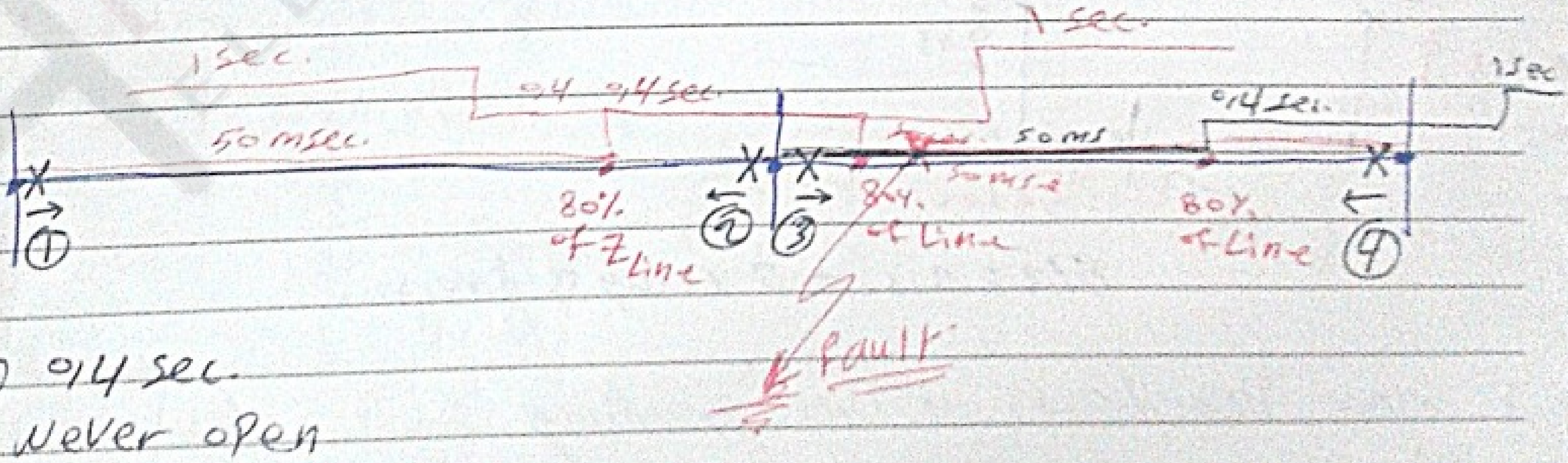




*** Drawbacks :-**

It can't differentiate between faults on either side of the bus.

3-e Distance/Time
current/Time



① 0.4 sec.
② Never open
③ 50msec., it's faster
④ 0.4 sec

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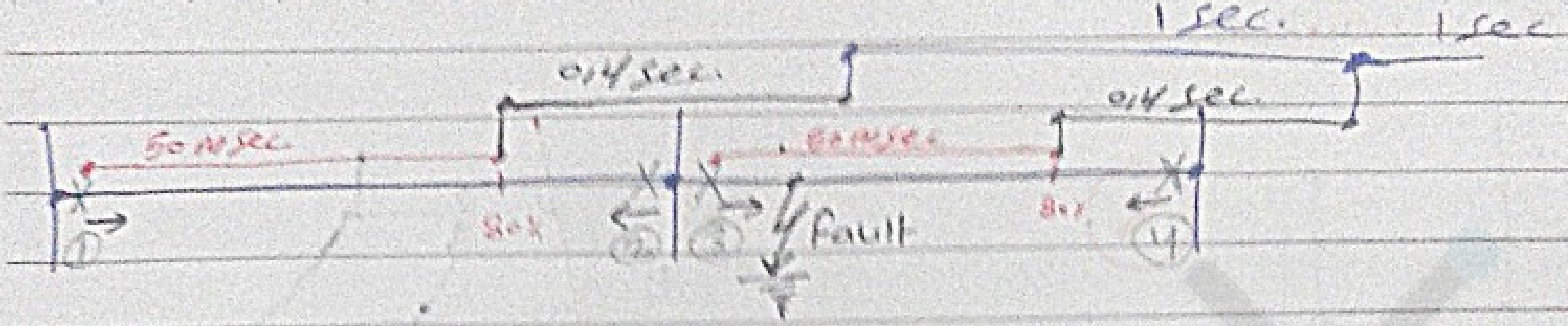
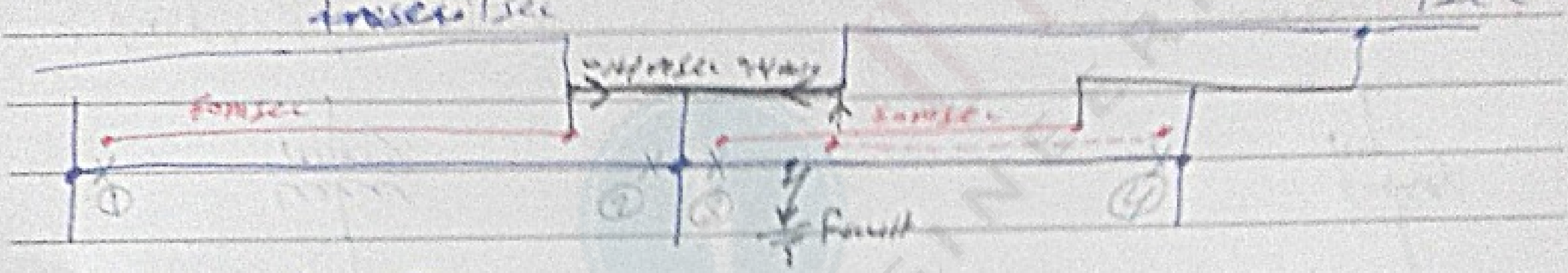
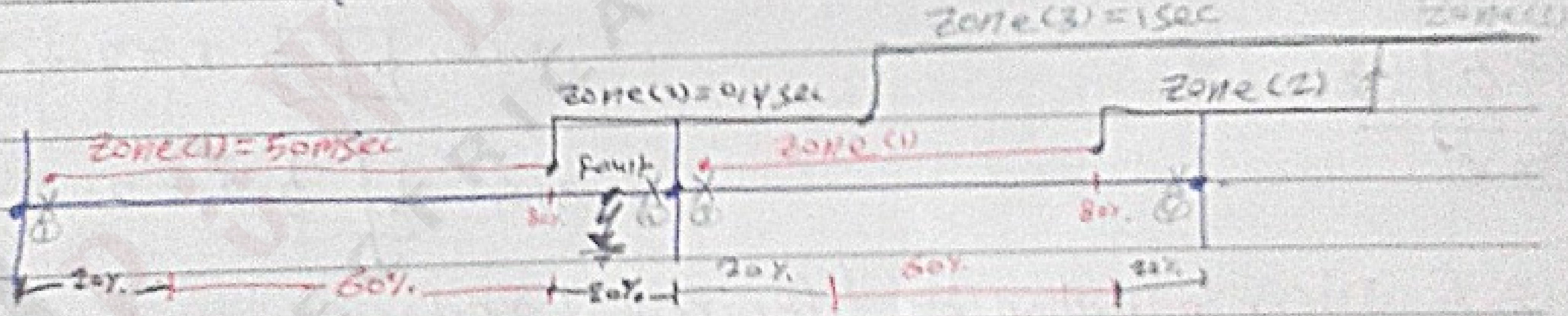


① 0.4 sec.
② Never open
③ 50 msec
④ 0.4 sec.

⇒ ONLY ③ will be open



ONLY ② will be open.



① Relay (2) will send a message for Relay (1) telling that he see the fault in Zone (1).

② Relay (1) realises that the fault in Zone (2) so the time of Zone (2) for Relay (1) will be equal to x 0.2 sec x.

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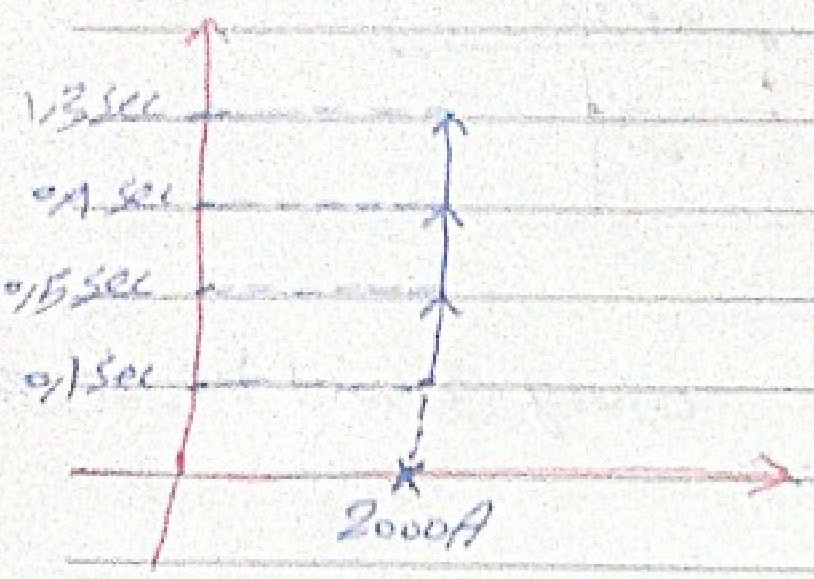
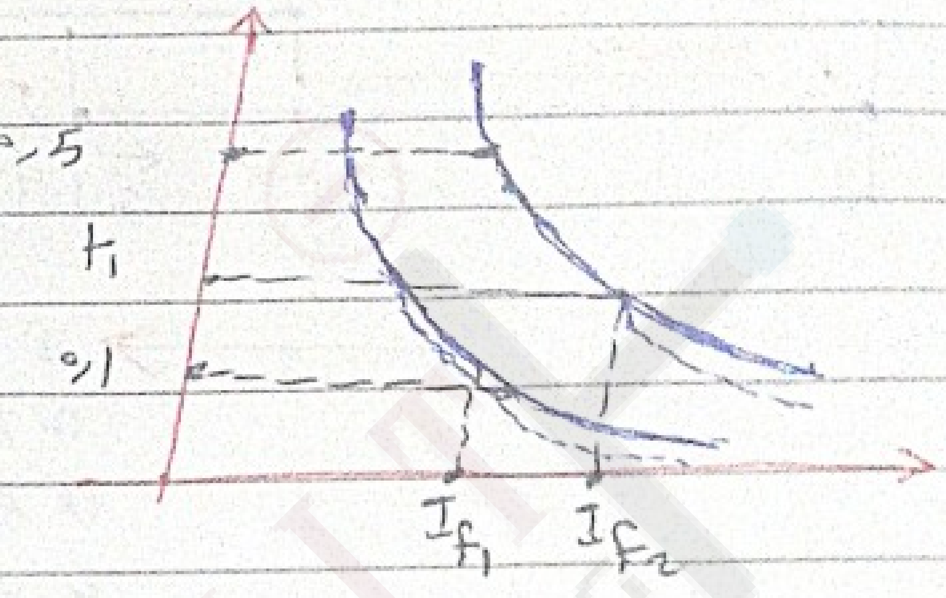
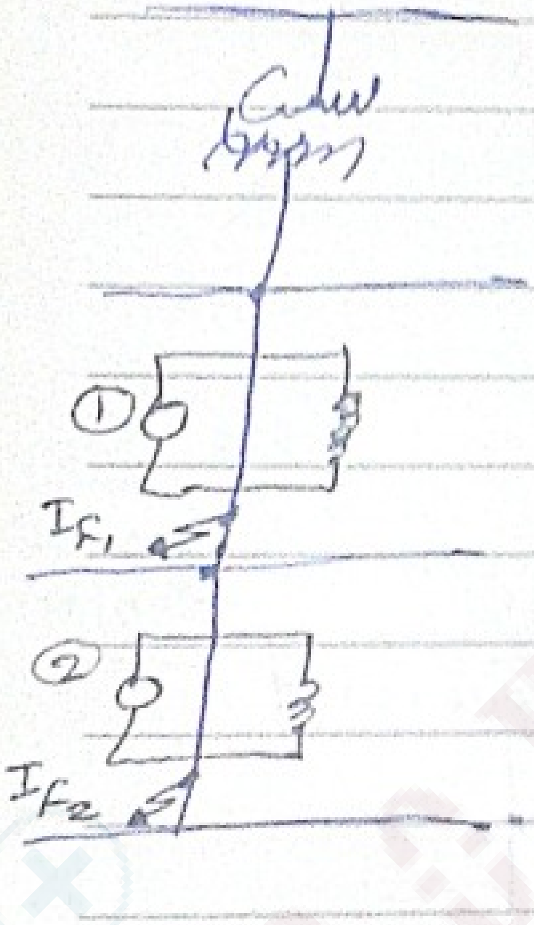
## * Time/current :-

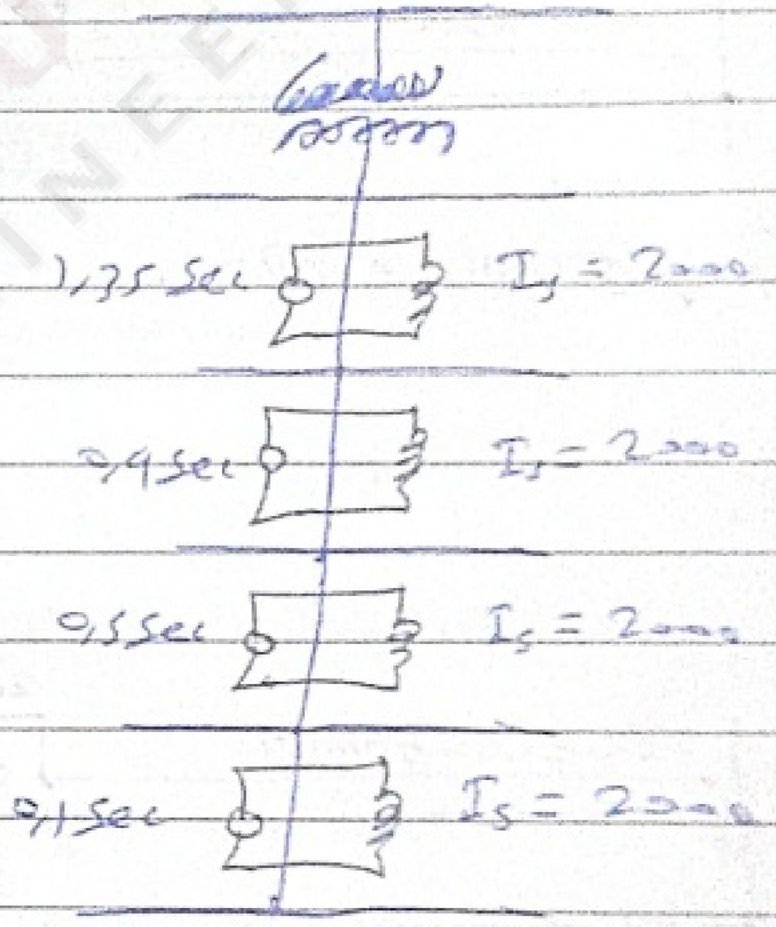




## ⇒ * Time/current

## * Time granding :-

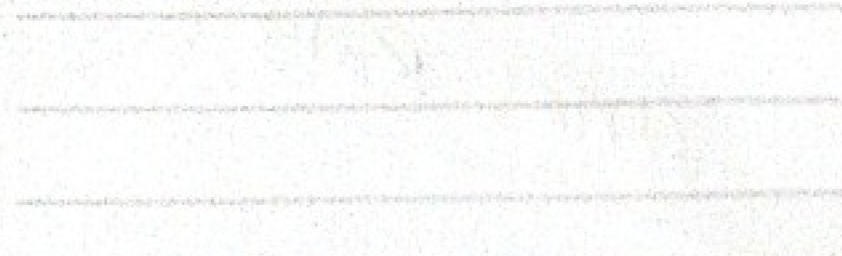




## 2-F Discrimination by diffrerential Protection system « Unit Protection system » :-

① Voltage Balance
② current Balance.

① Voltage Balance :-



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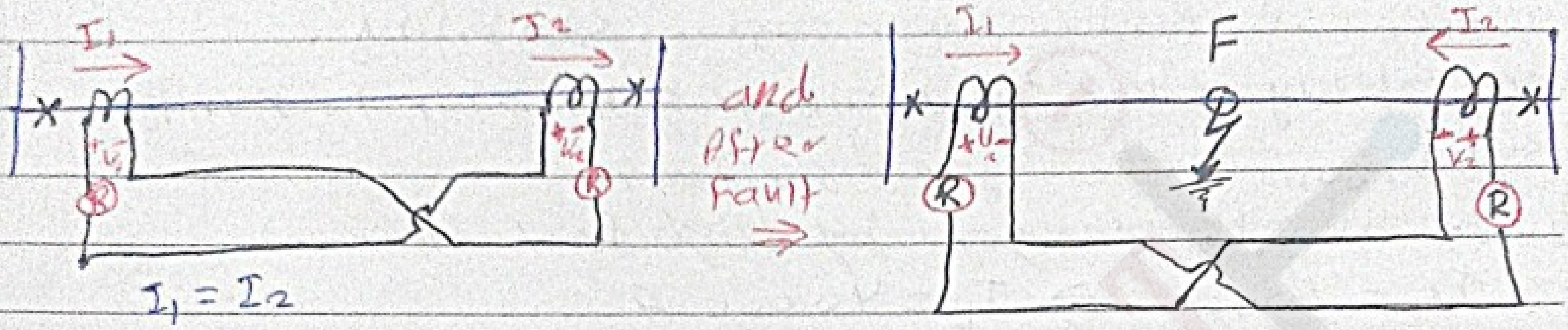
① Voltage Balance :-



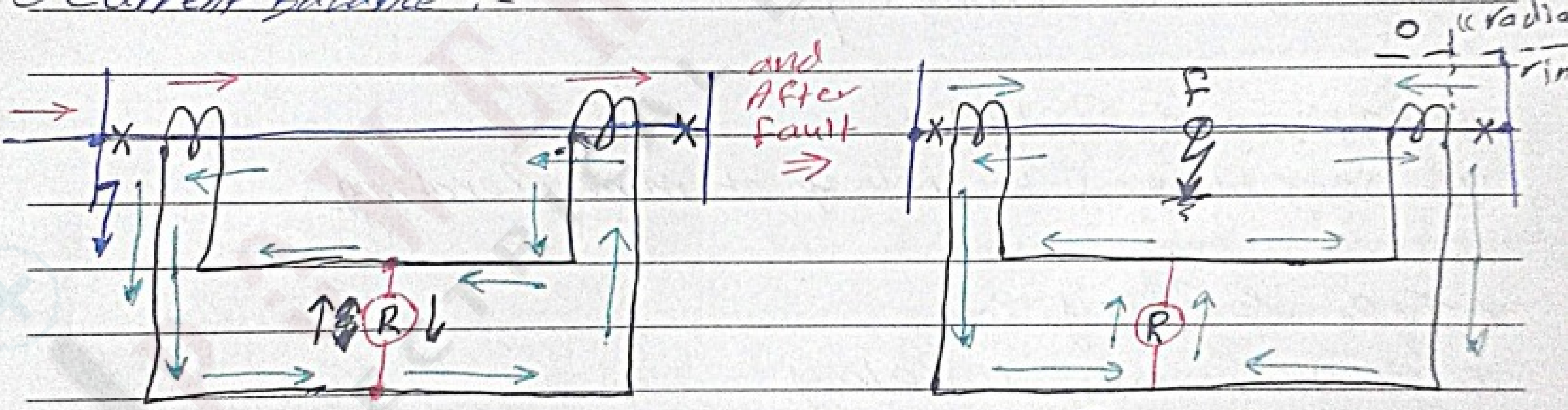
$I_1 = I_2$
and
$V_1 - V_2 = 0$
$\Rightarrow V_1 = V_2$

$I_1 \neq I_2$
$V_1 - V_2 \neq 0$
so the Relayer open
then C.B Isolate the fault

* في الحالة العادية $I_1$ هو نفس الذي يمر في C.T ويساوي $I_2$
* في حالة الـ fault يمر تيار $I_1'$ في الـ fault وبالتالي الجهد بين $V_1$ , $V_2$

⇒ we can use it in Transformer.

② current Balance :-



$I_{Relay} = Zero$

$I_{Relay} \neq 0$
Then the relay open the C.B and Isolate the fault.

## 3-7 Stability of Protection system :-

It's the ability of the Protection system to remain Inner Inert for load and external fault conditions and respond for Internal fault only. ⇒ « Diffrential Protection » هو الـ stabil « يعتبر » *

* معنى الـ « Stability » هو أنه لا يشعر الـ Protection بأي fault خارجي ، لأنه يشعر فقط بالـ fault الذي بداخله .

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## 4- Speed :-

1- effect of speed on power system stability.
the ability of the synchronous generator to run in synchronous following a distribution
2- to avoide dangers by high fast current
$I_L = 500 A \Rightarrow I_f = 40000 A$

⇒ operation in very short time « $\overset{10 msec}{50 msec} \rightarrow 3 sec$ »
because of the Heat effect and stability.
⇒ The ~~Fox~~ function of protection system is to isolate fault from the power system in a very much shorter time.

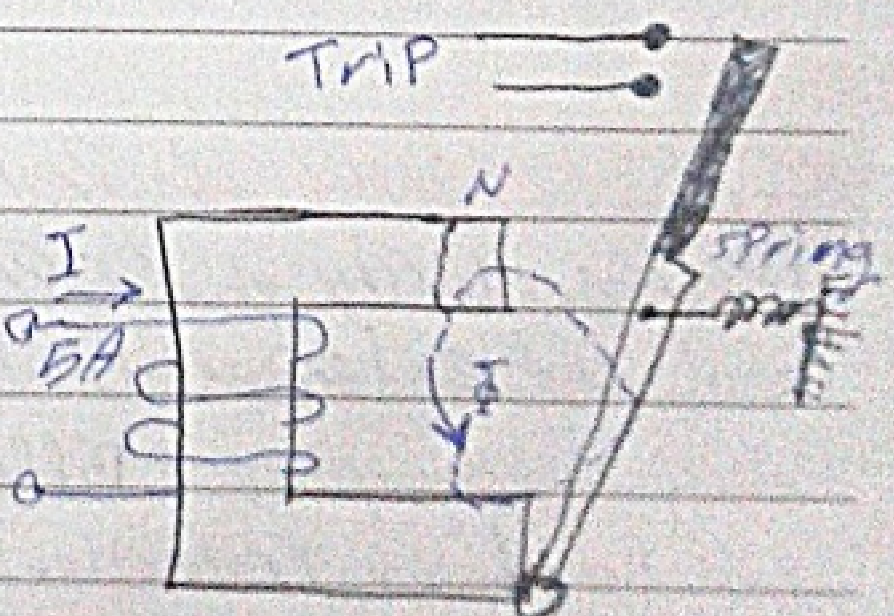
## 5- Sensitivity of a protection system :-

The level of fault current at which a protection takes place « $I_s$ » i.e setting.

* Sensitivity of Relay :-
VA sensitivity of the relay at min. operating.

* Type of Relay :-
① Electro Mechanical Relay
② ~~Static~~ Static Relay
~~① Static Relay~~

① Electro Mechanical Relay :-
over current relay «O/C» Relay
⇐ عند تيار قيمته 5A تعلق ال relay
وإذا قمنا بتقليل ال current لا يرجع إلى حالته
إلا إذا رجع التيار لقيمة معينة وهذا التيار يسمى
~~بـ resetting current~~
بـ resetting current



24/12/2014

[illegible]

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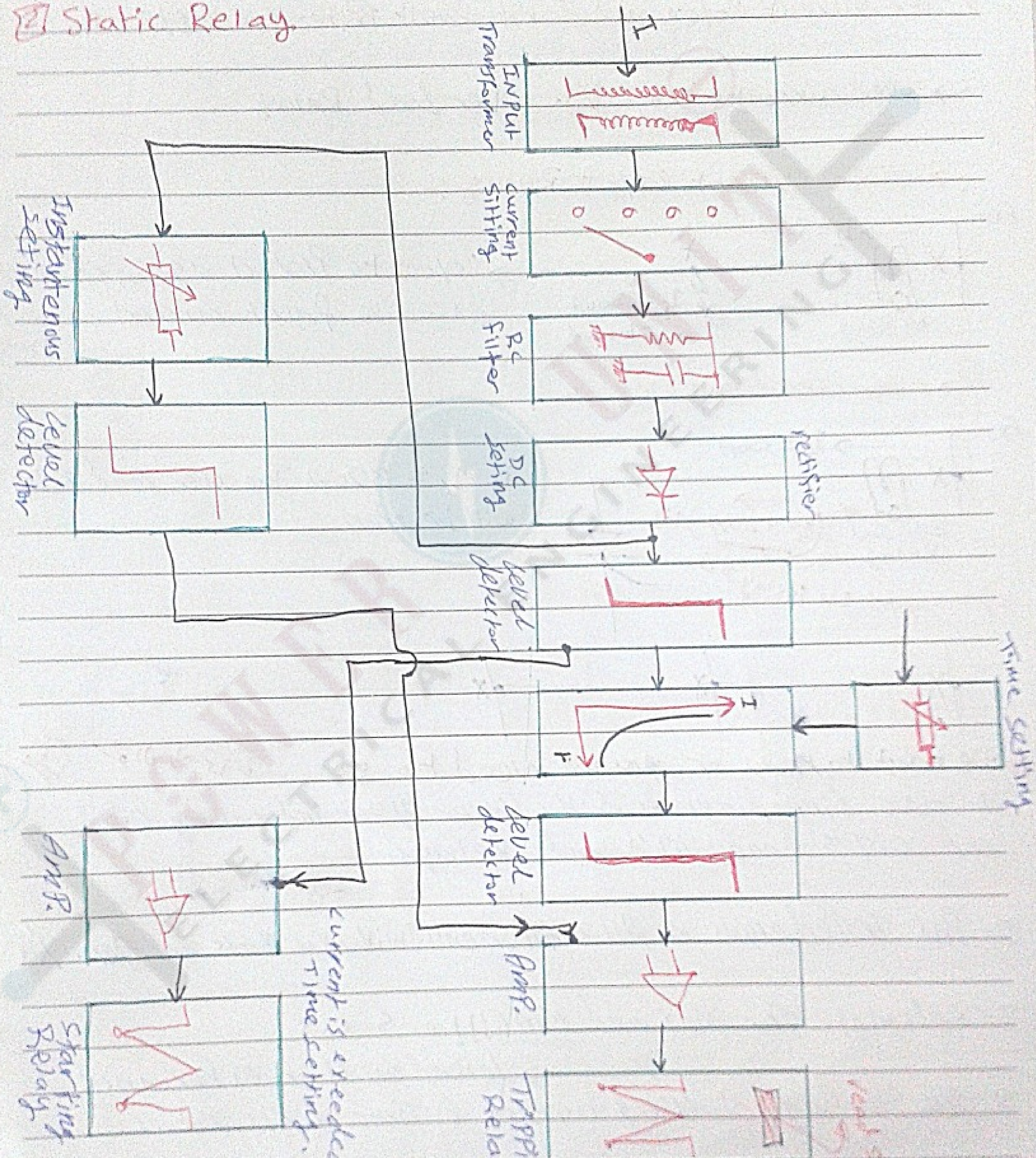
## ☒ Static Relay



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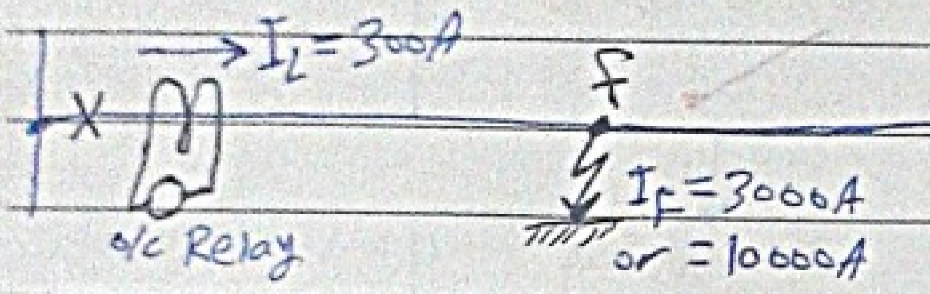
* over current «o/c» and Earth fault Protection «E/f» :-

→ over current «o/c» V.S. over Load Relay.

→ over current «o/c» Relay :-

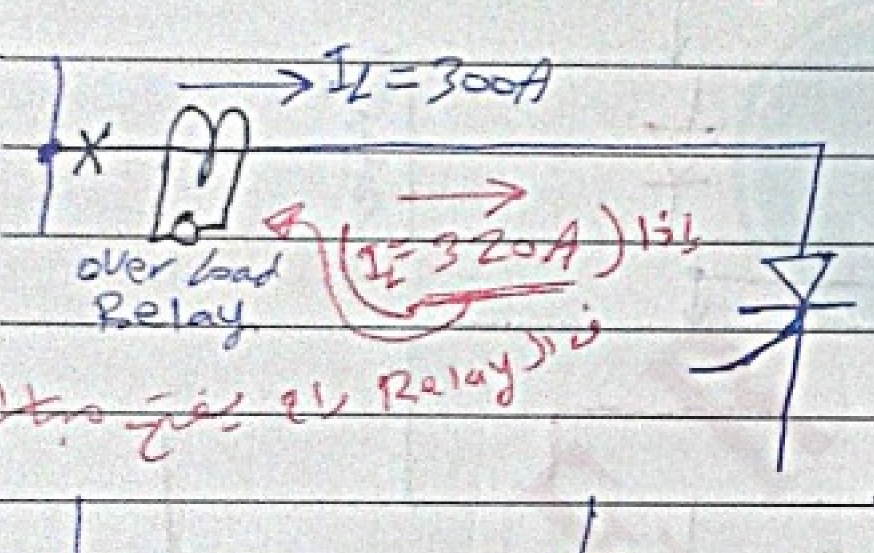
Ex:-



⇒ «o/c» to Protect against excessive fault current.

→ over Load ~~or~~ Relay :-

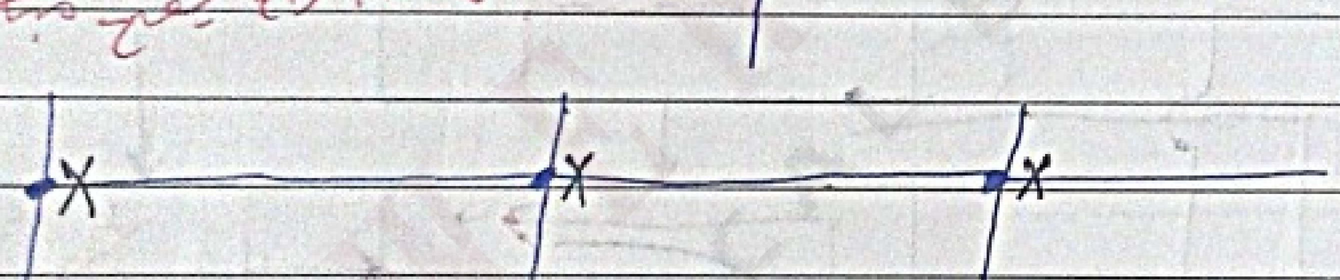
Ex:-



اذا ($I_L = 320A$)

لن يفتح ال Relay مباشرة

if $I_L = 320A$ The over Load Relay will be open



* we must to Know or ~~you~~ we Need to :- سؤال امتحان مهم //

1- oNe Line diagram of the Power system indicating C.B's and C.T's and V.T's and Relays

2- P.u Impedances of All components «with the Base and Gen. $X_d'$

3- calculate The Max and Min «!!!». S.C.C
↳ depend on your experiance.

4- The Starting / Stalling current & Time of All Motors.

5- Max. Load current.

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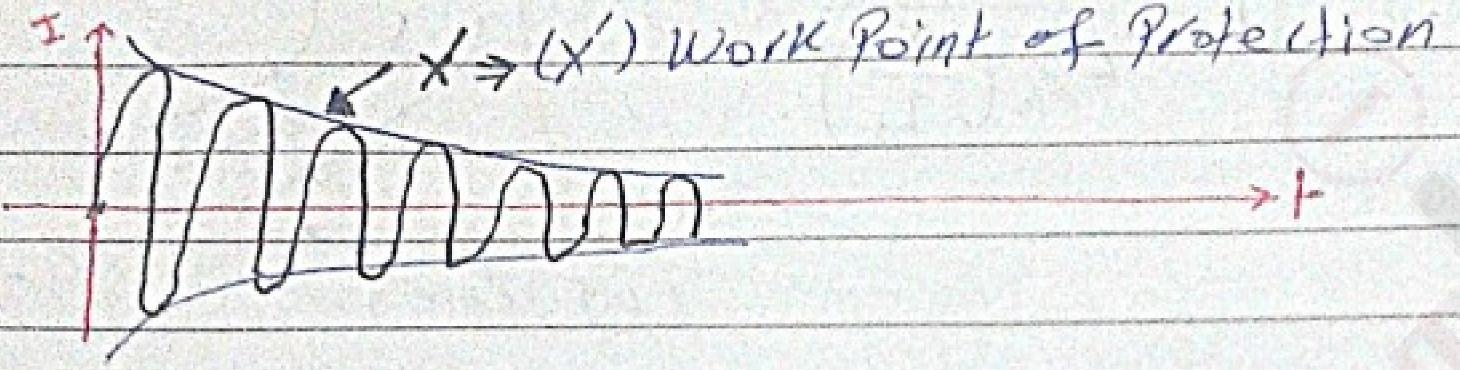
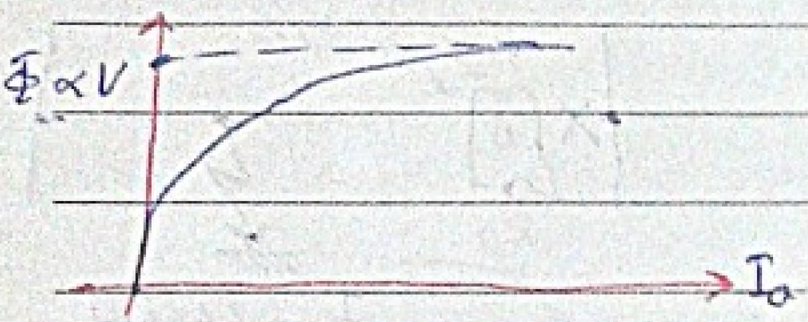
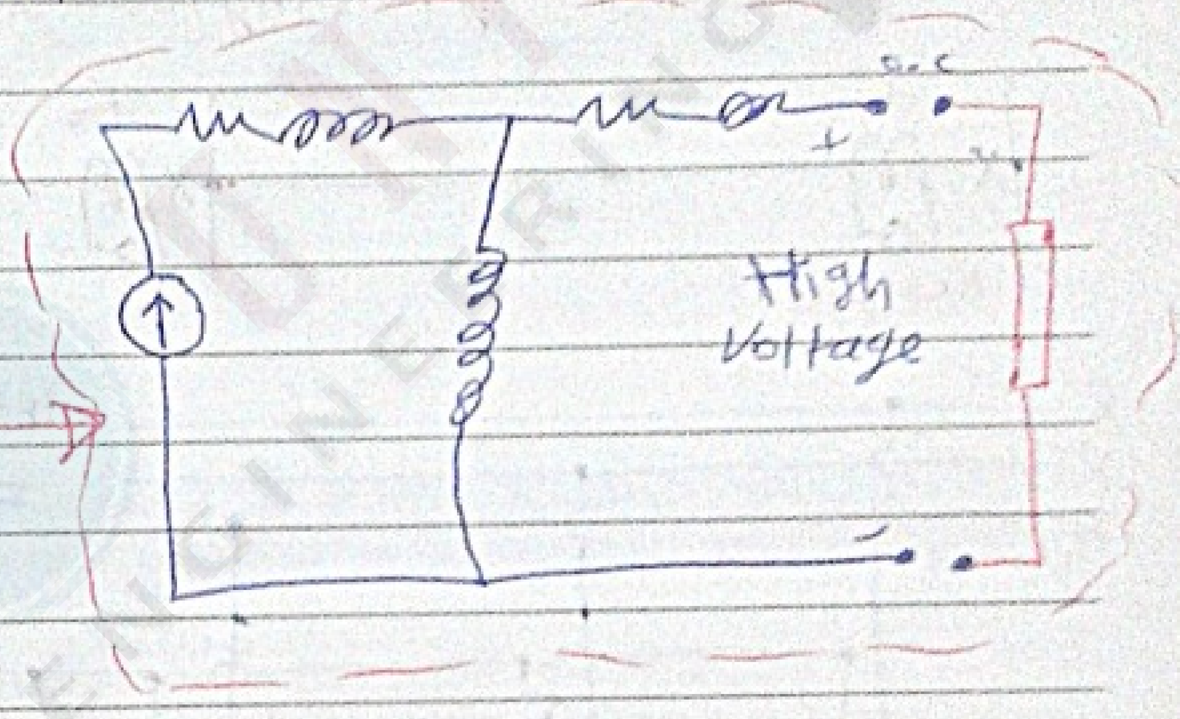
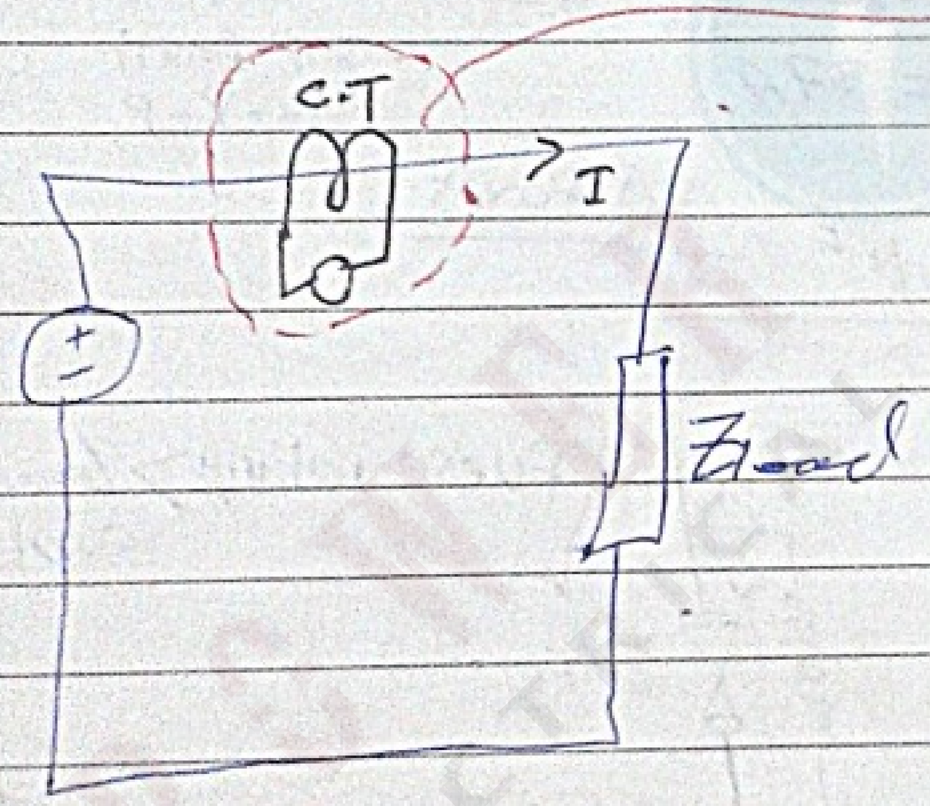
6- Decrement curves of All generation.



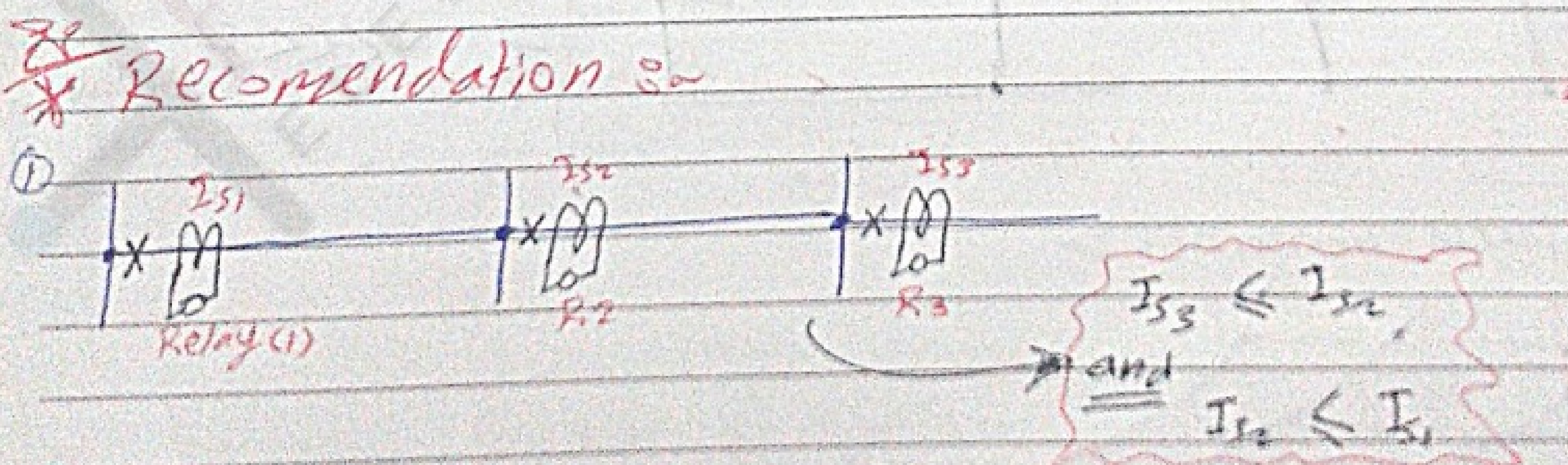
7- Performance curve of All C.T's







* Recomendation :-



أبعد واحد لازم يكون أقل $(I_s)$ وأقرب واحد لازم يكون أكبر $(I_s)$

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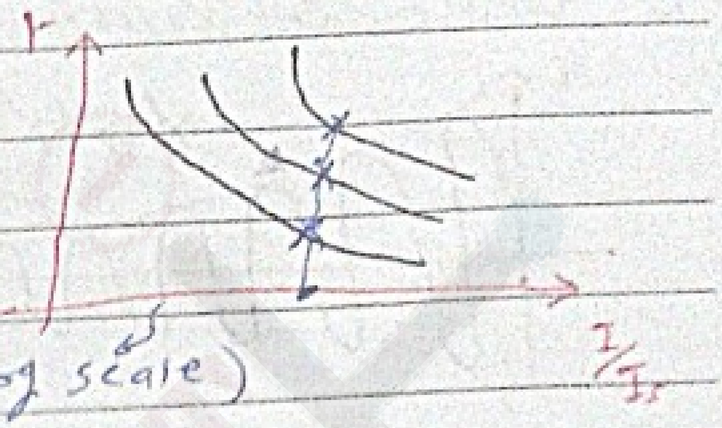
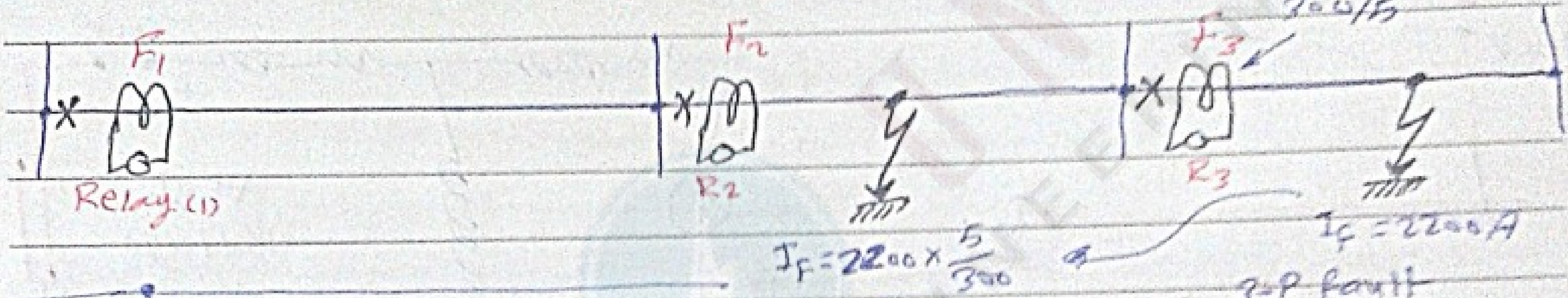
② I/t characteristic of All relays should be the same.

$$t = \frac{13,5}{\left(\frac{I}{I_s}\right)-1}$$ OR $$\boxed{t = \frac{3}{\log_{10}\left(\frac{I}{I_s}\right)}}$$ ※

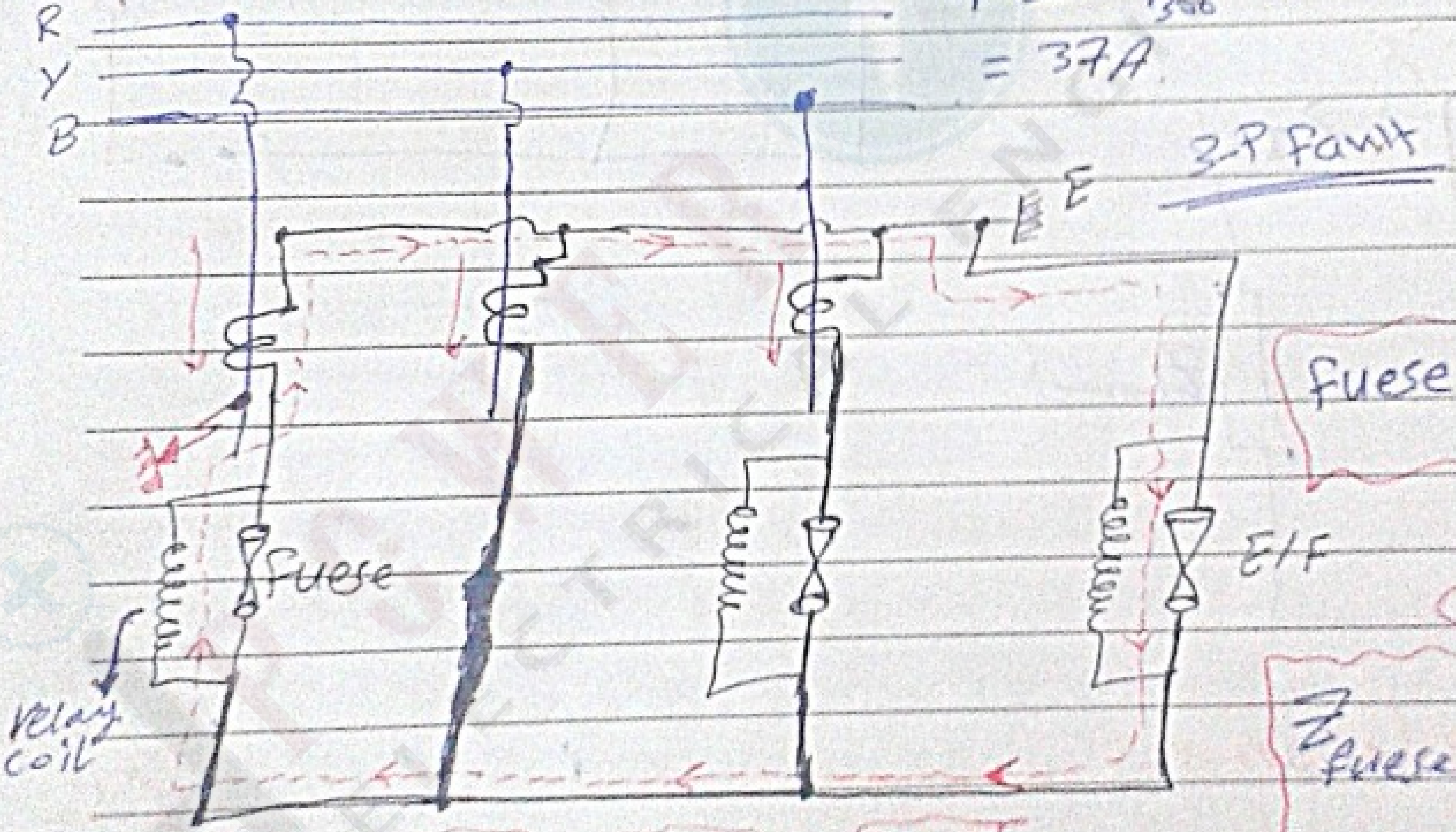


## * Time/current grading using fuese.



$I_F = 2200 \times \frac{5}{300}$

$= 37A$



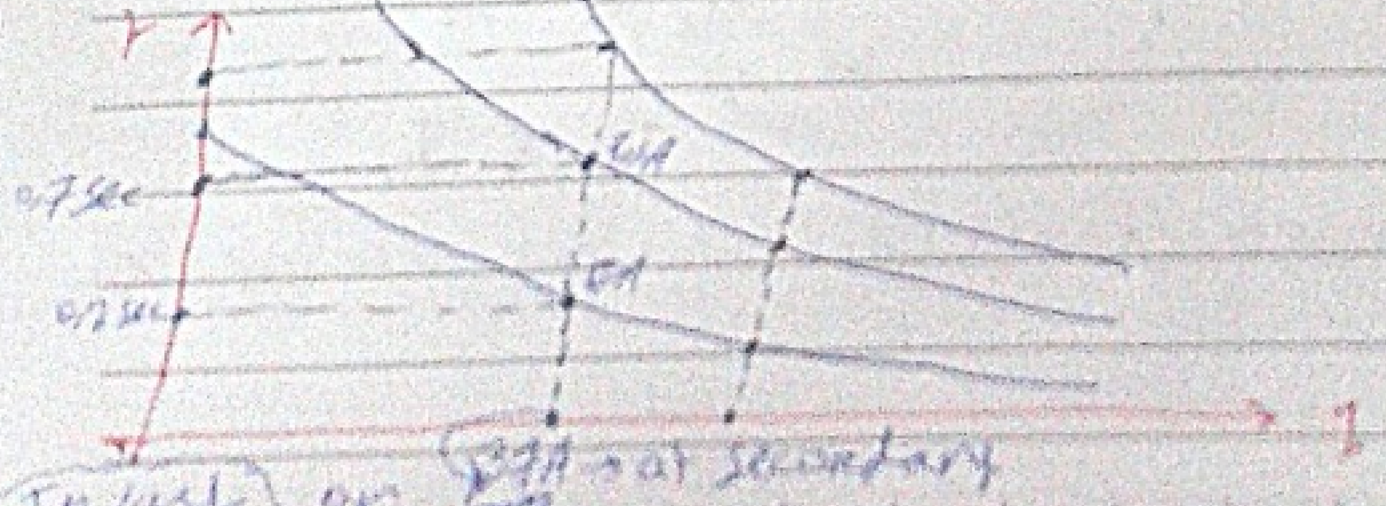
RY-B or R-Y or Y-B or B-R

fuese rating > load current

3Z

$Z_{fuese} \lll Z_{Relays\ coil}$

→ fuese charcteristic :-



(37A → at secondary

In (us)t or

RY

2200A → at Primary

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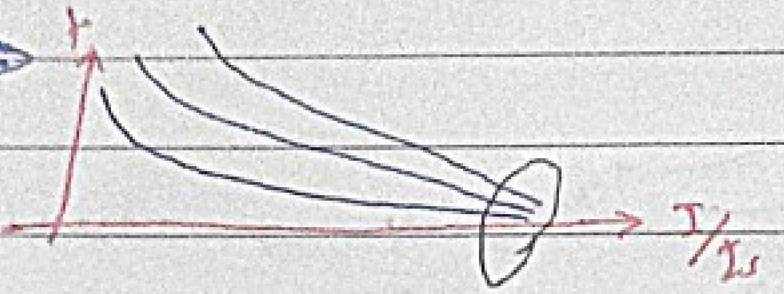
* Drawbacks :-

① The discrimination Period ((0.4 or 0.5 sec)) can't be optained at high s.c.c. ⇒

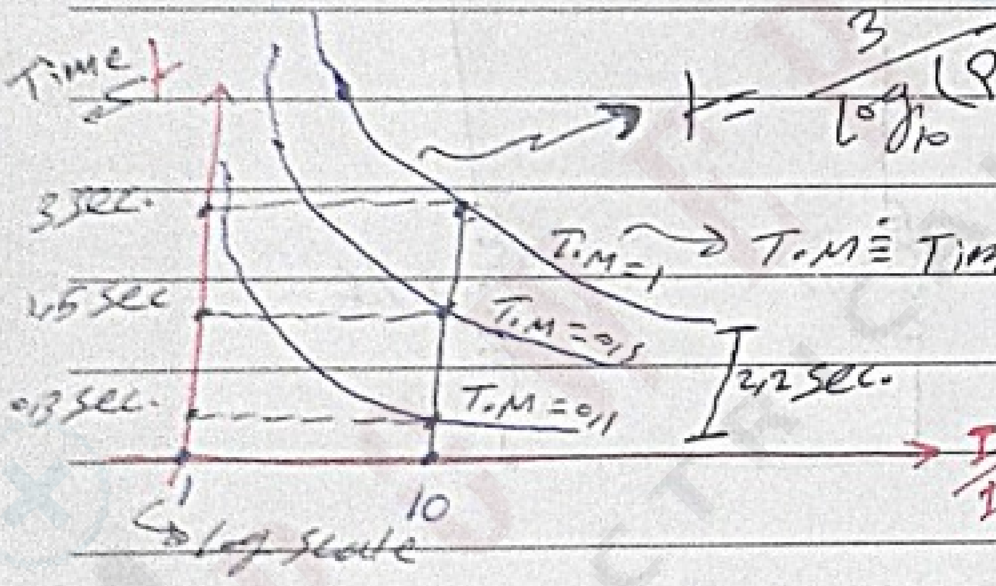


② change in I-t fuse characteristic due to through fault current and ageing ((شيخ))

③ Two conflicting requirement

$$Z_{fuse} \ll Z_{relay}$$

$Z_{Relay}$ small enough to avoid C.T saturation



$\rightsquigarrow t = \frac{3}{\log_{10}(P.S.M)}$

T.M → T.M ≡ Time Multiplier $= \frac{3}{\log_{10}(P.S.M)}$

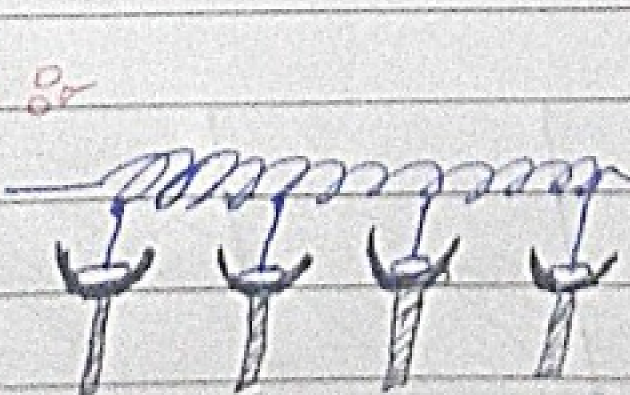
$\underline{P.S.M} = \frac{I}{I_s}$ I → Actual fault current, $I_s$ → setting

P.S.M → Plug setting multiplier.

P.S ≡ Plug setting ⇒ $I_s$

T.M ⇒ change the scale.

* → Plug setting :-



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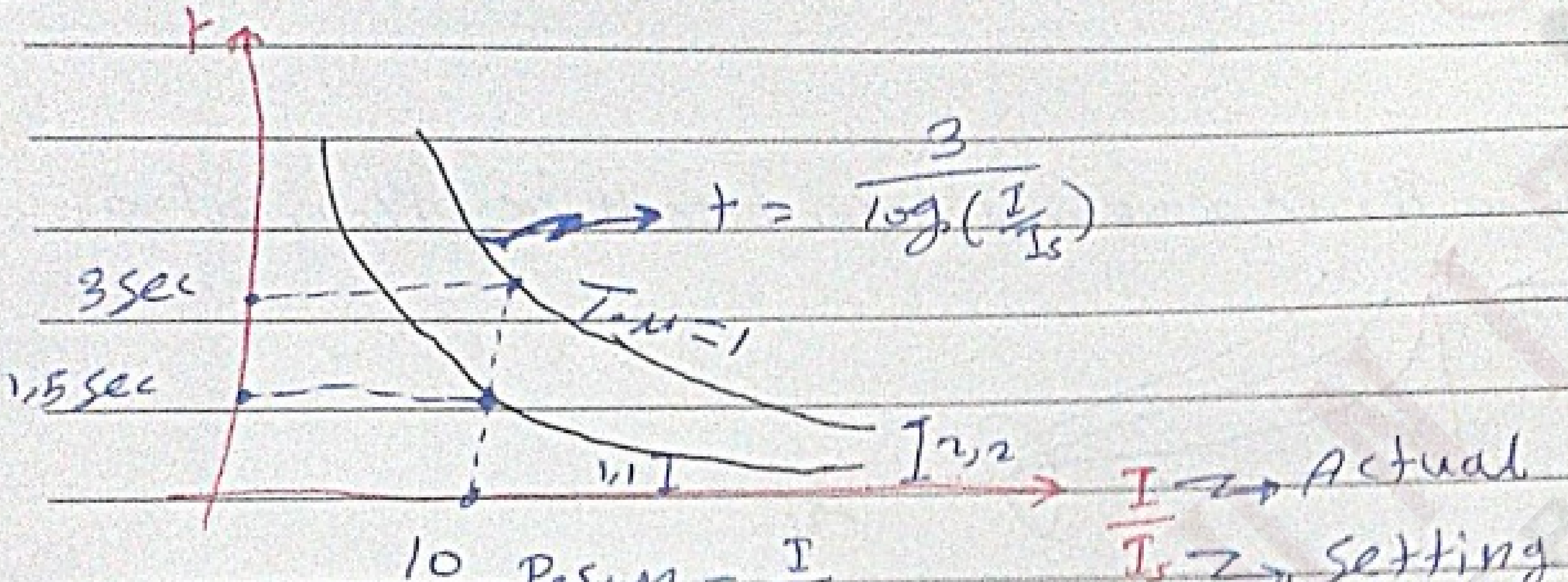
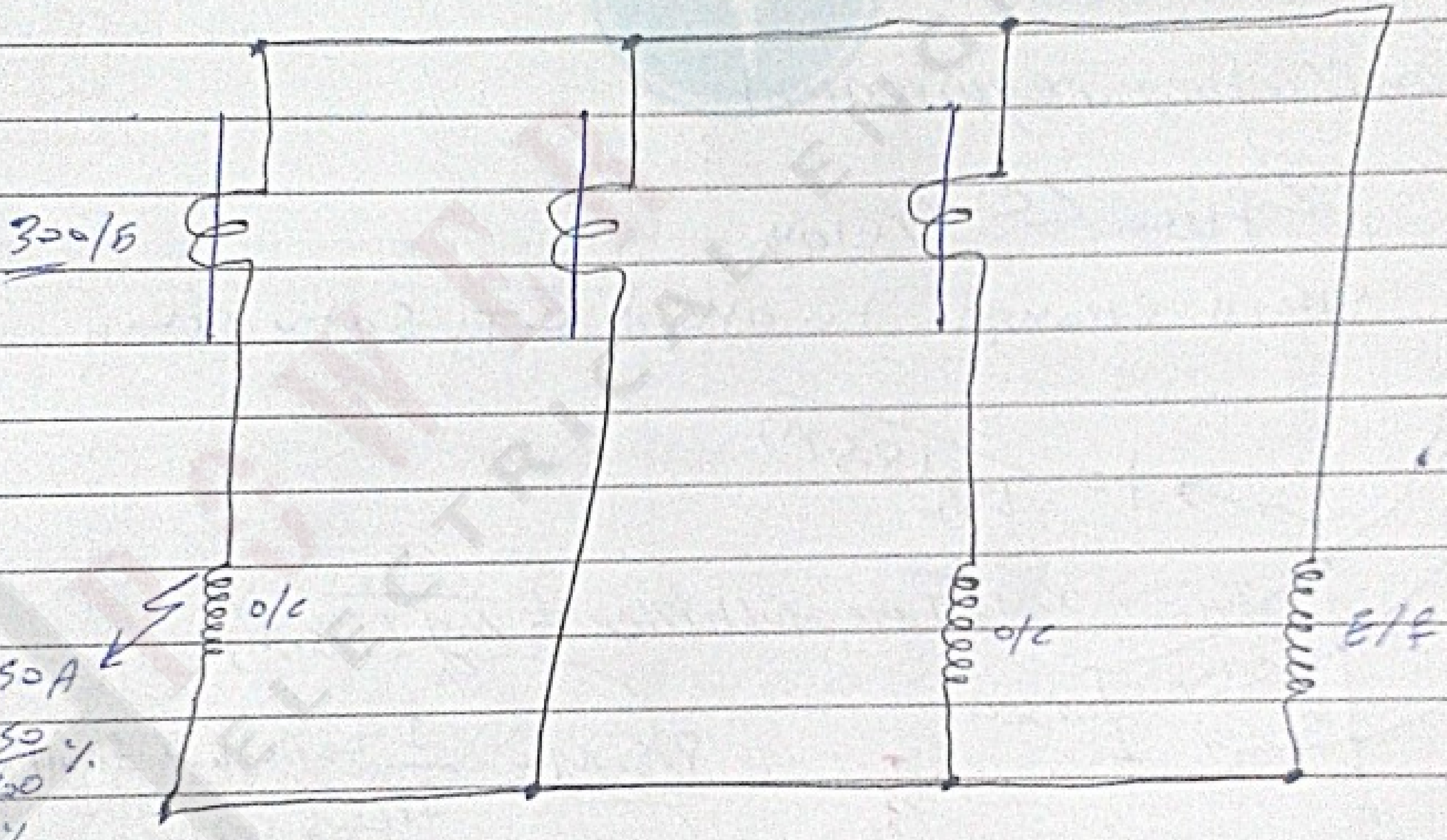


$P.S.M = \frac{I}{I_s}$ → Plug setting Multiplier



$I_s = 150A$

$= \frac{150}{300}\%$

$= 50\%$

Plug setting

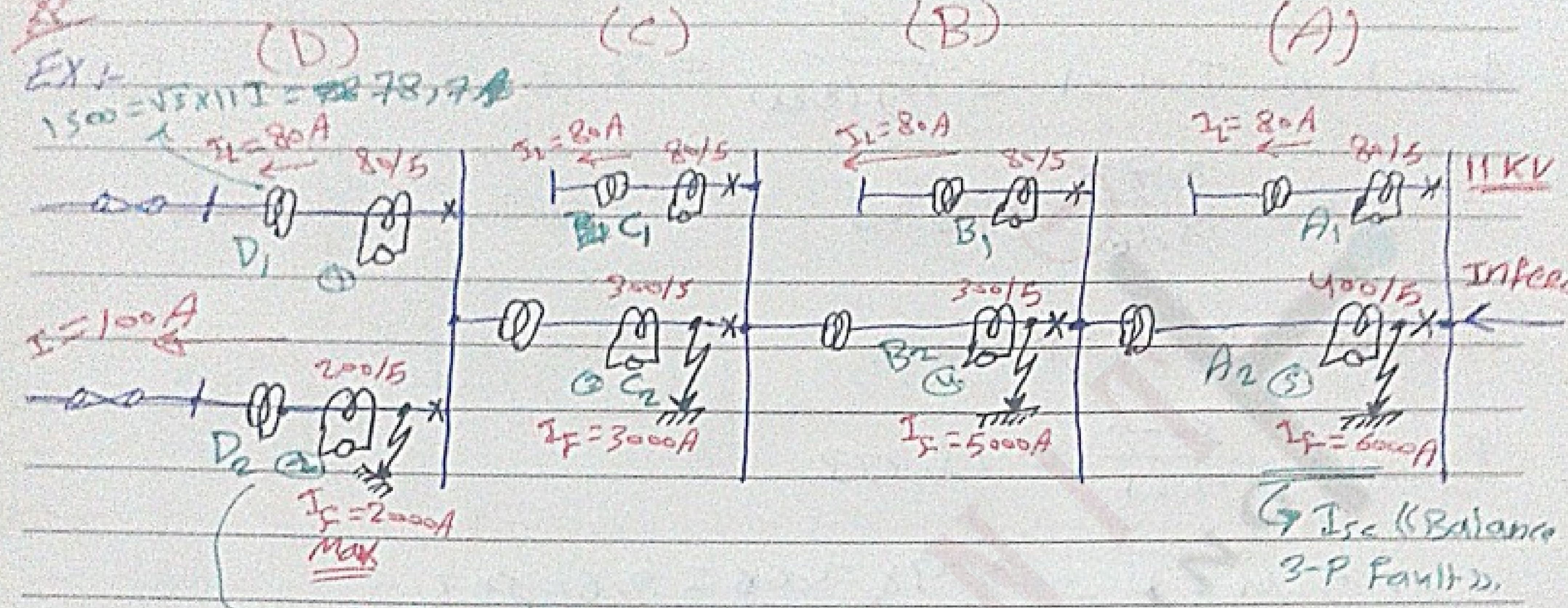
→ o/c Range « 50% → 200% »

with STEP ((25%)) EX [50 → 75 → 100 → ... → 200]

EX/

الإثنين 3/3

EX :-



→ 2000KVA ⇒ 2000 = √3 × 11 I = 105

→ at $D_2$ :-

P.S = 50% = 100A

T.M = 0,1

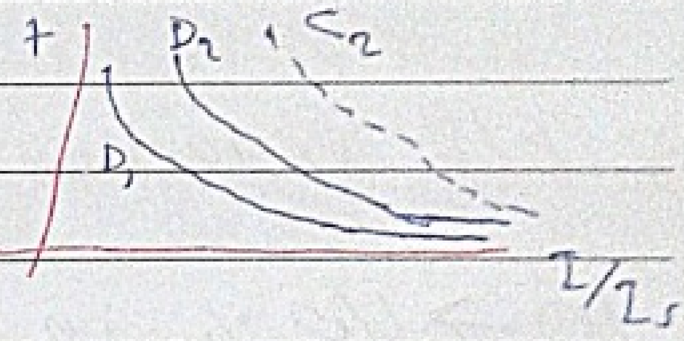
at $D_1$, $C_1$, $B_1$, $A_1$ the same :-

P.S = 100% = 80A

T.M = 0,1

Note:-

T.M Range ((0 → 1)) in steps ((0,1)).



→ at $C_2$ :-

for a fault at $D_2$ ⇒ $C_2$ ~~stad~~ should operate at (($t_{D_2}$ + 0,5 sec))

⇒ $I_f$ = 2000A

$\frac{I}{I_s}$ = 20 , t at T.M = 1 = $\frac{3}{\log(20)}$ ≈ 2,2 sec.

t at T.M = 0,1 = 0,22 sec. ⇒ t = $\frac{3}{\log(P.S.M)}$ at T.M = 1 P.S.M > 20

= 2,2 sec for P.S.M ≥ 20

→ for a fault at $D_2$ :-

P.S = 75% = 225 A and P.S.M = $\frac{2000}{225}$ = 8,88

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~~t~~ t at T.M = 1 $= \frac{3}{\log(8.88)} = 3.16$

$\therefore$ T.M $= \frac{0.72}{3.16} = 0.23$

→ for a fault at $C_2$ :

P.S.M $= \frac{3000}{225} = 13.333$

t at T.M = 1 $= 0.23 \times \underline{2.68} = 0.61$ sec

↳ t at T.M = 1 $= \frac{3}{\log(13.33)} = 2.66$

at $B_2$ :

for a fault at $C_2$ it should operate at $t = 0.61 + 0.5 = 1.1$ sec

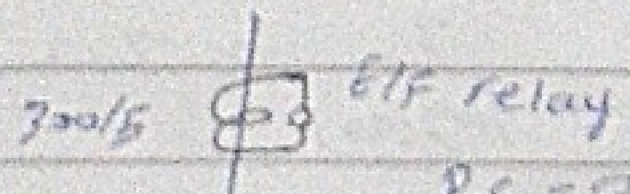
P.S = 100% = 300 A

* E/F Protection :

10 → 40 % in 10% steps for transf. circuit

20 → 80 % in 10% steps for feeder circuit

* VA consumption of an E/F ~~Relay~~ Relay is quoted at the setting.



P.S = 20%

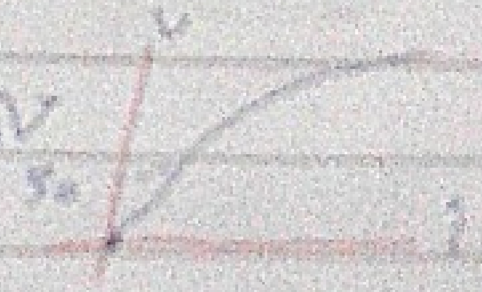
1A sec

300 → 5

(20%) 300 → x = 1A

⇒ $I^2 Z = 3 \Rightarrow V = 3V$

but if $I_f = 6000A \Rightarrow 10^2 Z = 300$ VA ⇒ V = 30V



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but at [illegible] P.S = 40%

$I_s = 120A \Rightarrow I_{sec} = 2A$

$2^2 \cdot Z = 3 \Rightarrow Z = \frac{3}{4}$ if $I = 600 \Rightarrow I_{sec} = 10$

$\Rightarrow 10 \times \frac{3}{4} = 7.5V$

$\Rightarrow \boxed{V = 7.5V}$

*for successful operation of « E/F » Protection system :-

1- Limit E/F current
2- Use Special C.T's
3- High C.T ratio.

* * *

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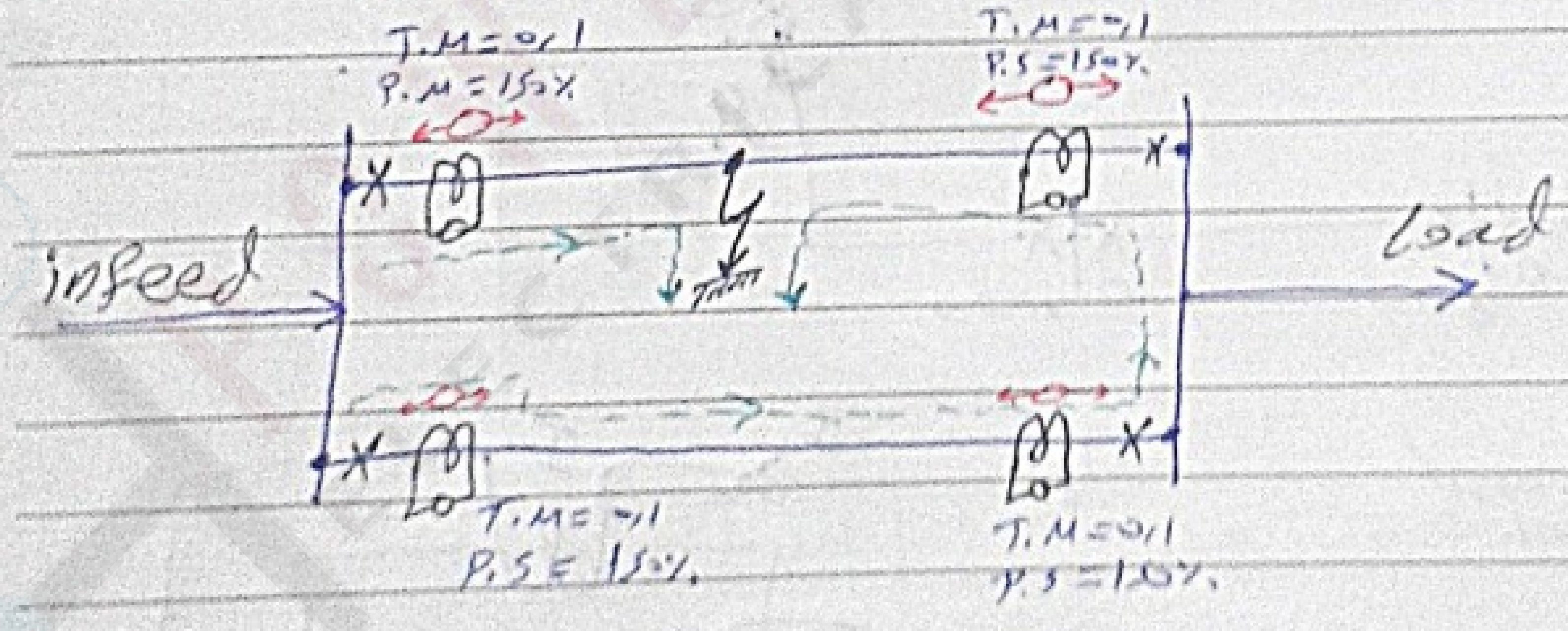
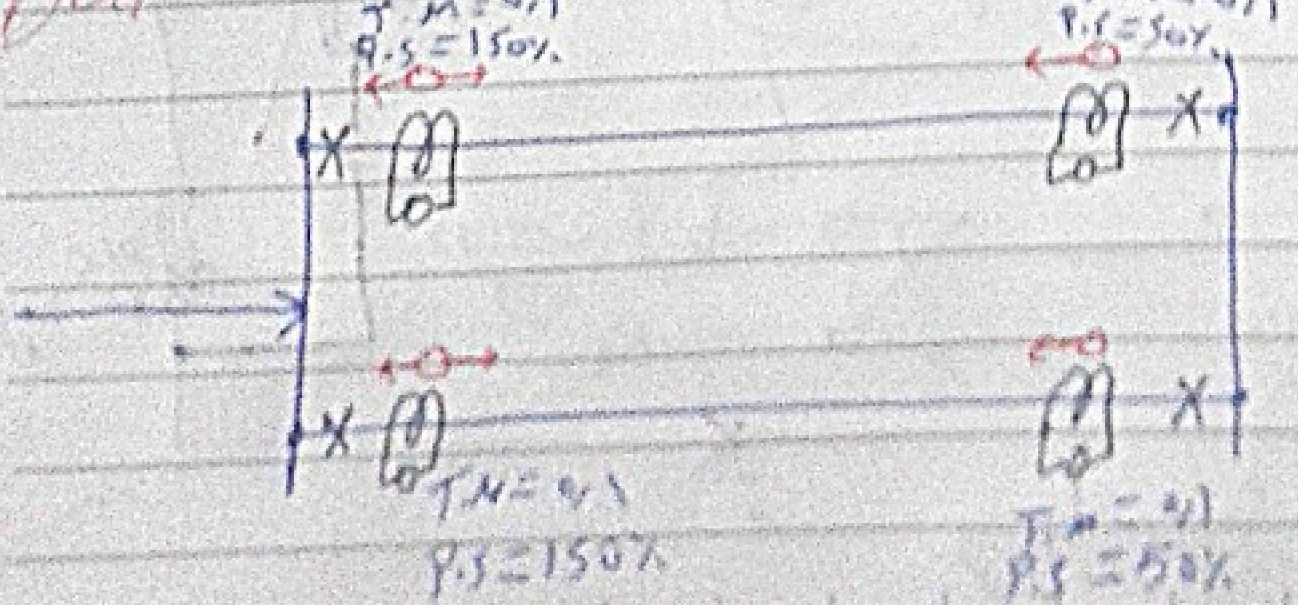
## Direction O/C and E/F Relays :-



but



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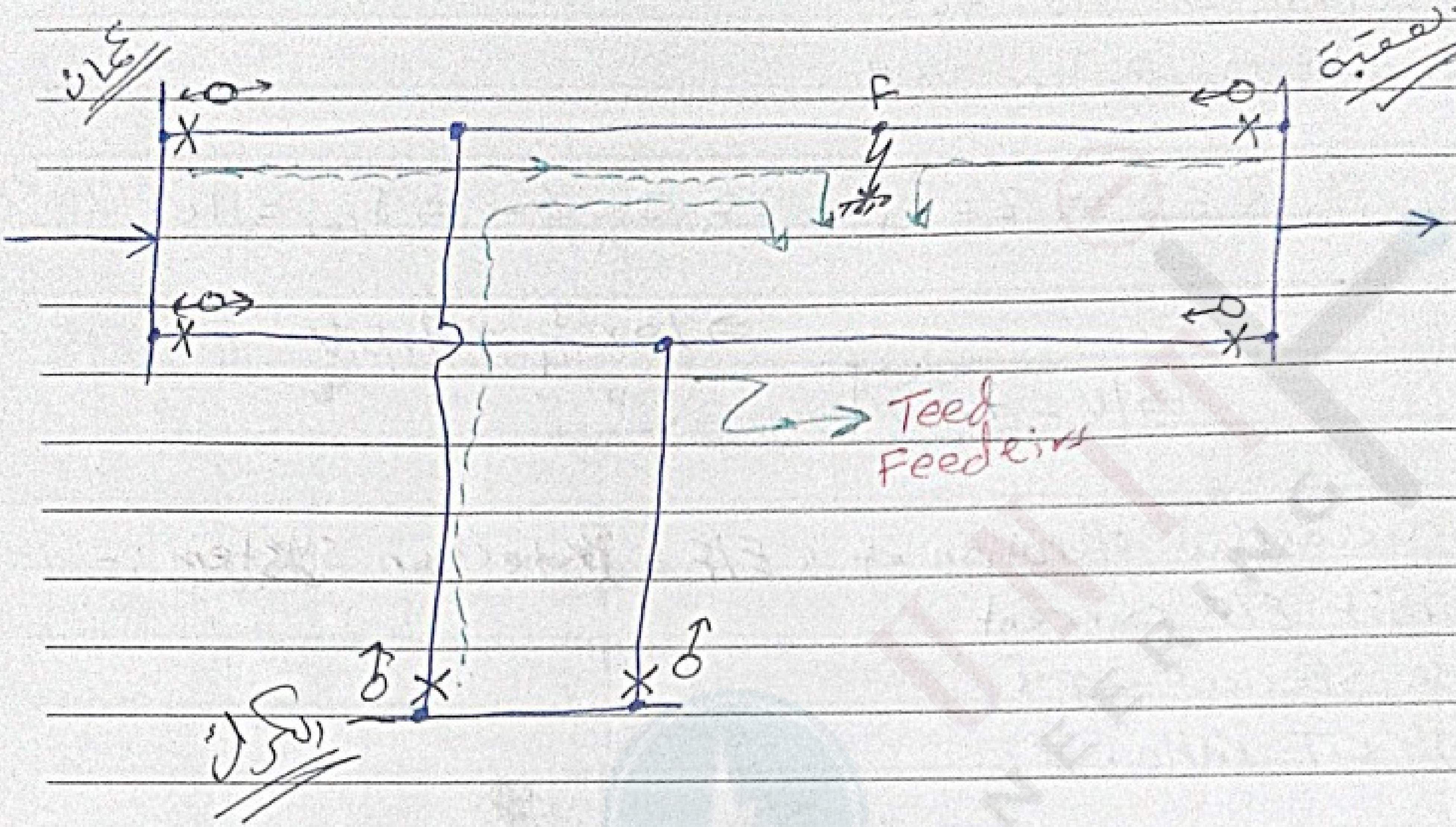

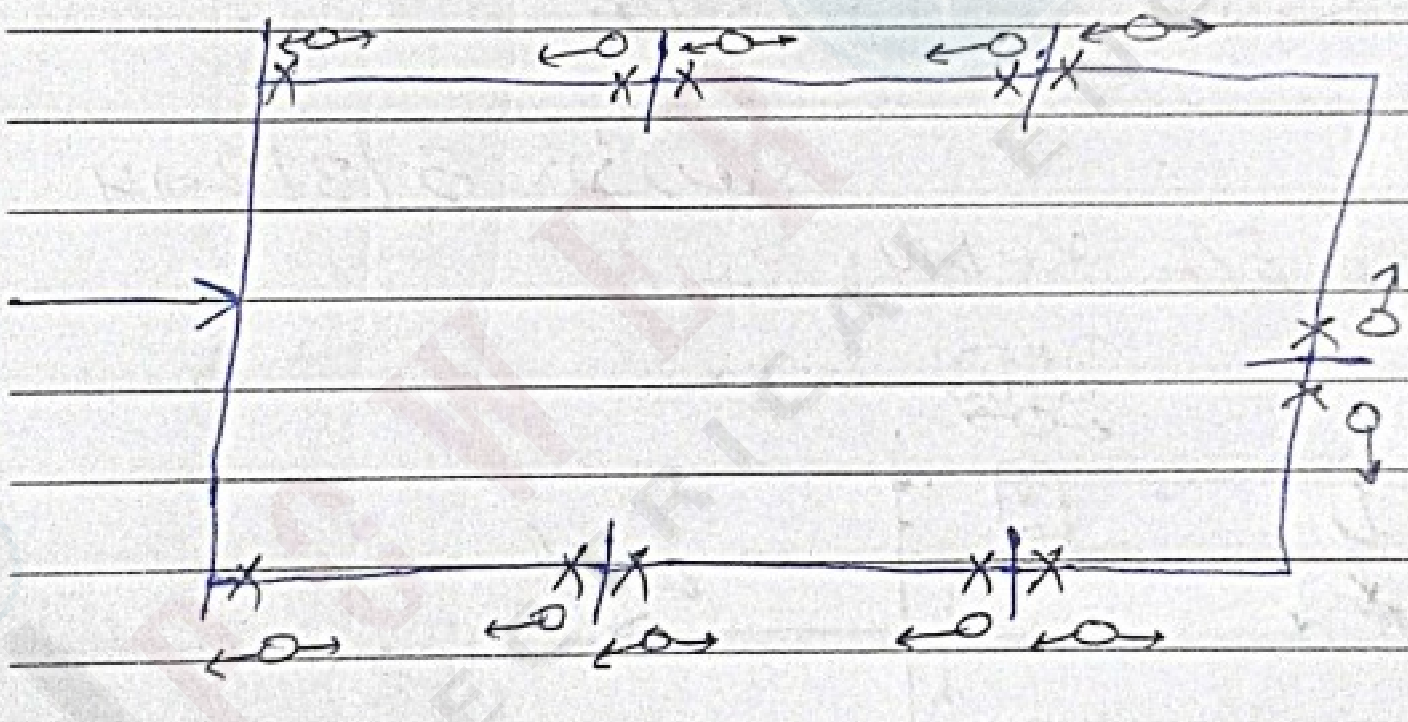

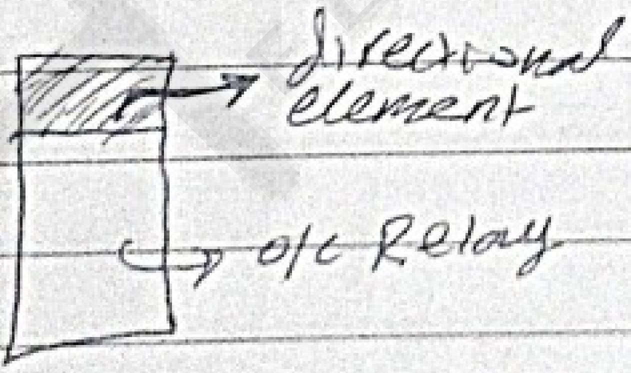

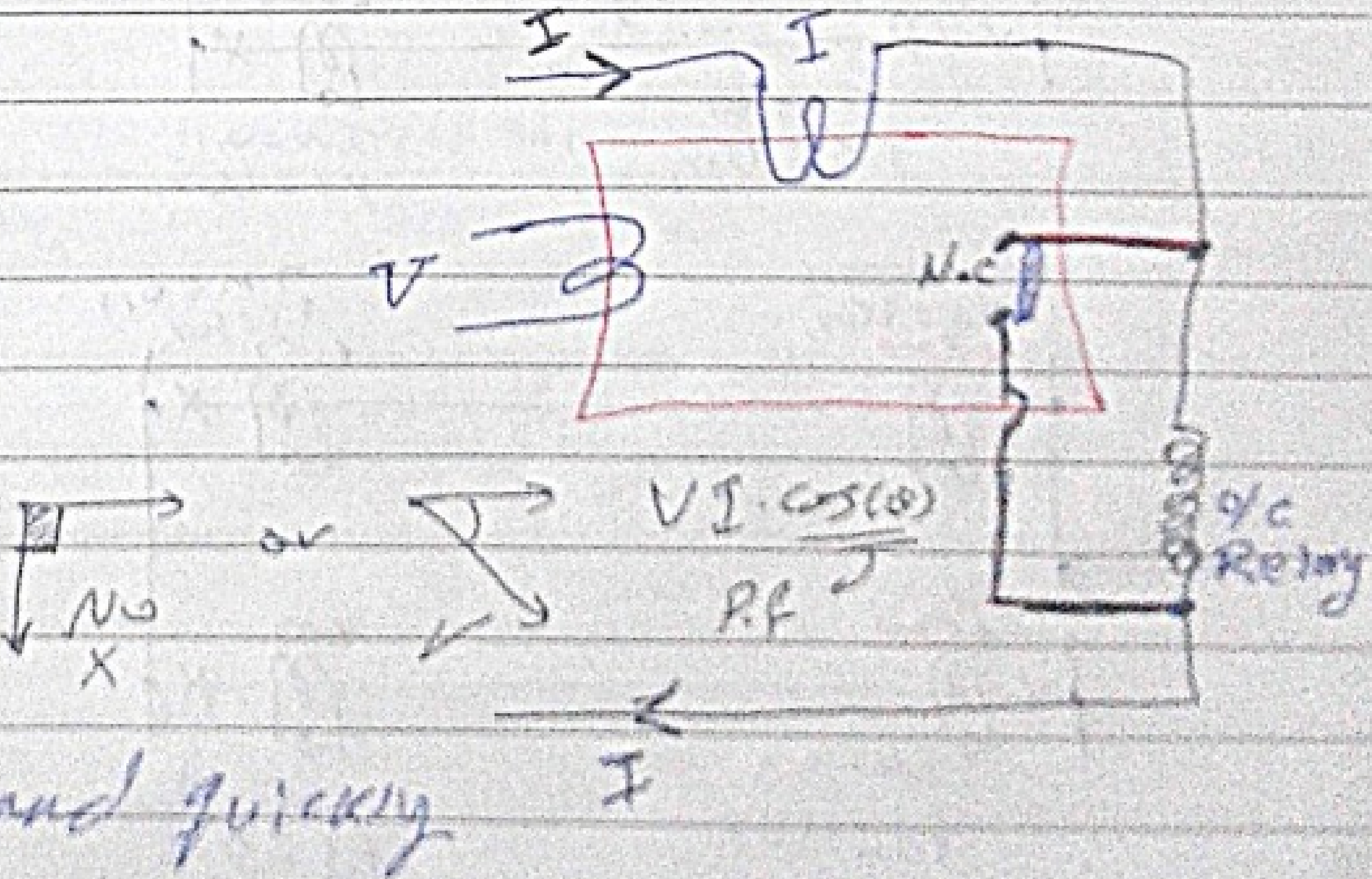

decisively and quickly

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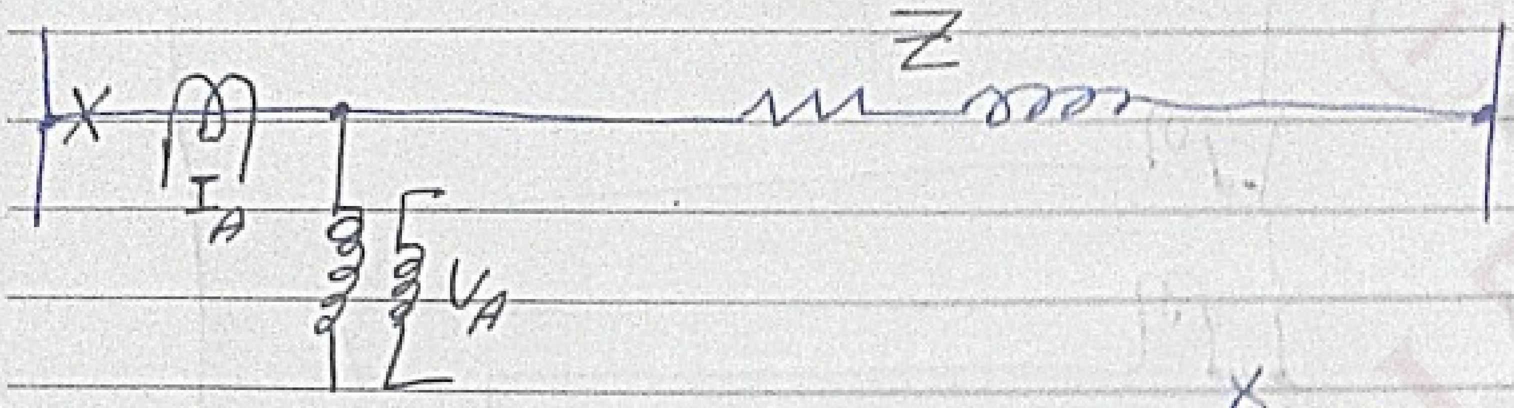
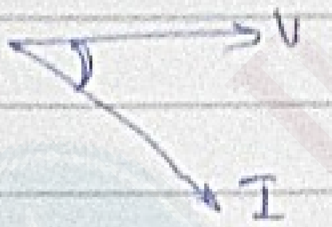
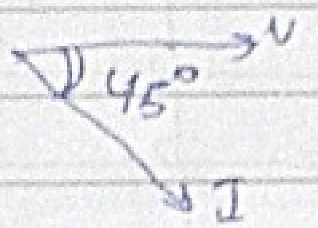
→ O.H. Line :-



In O.H.L ⇒ $\frac{X}{R} \simeq 3 \to 7$



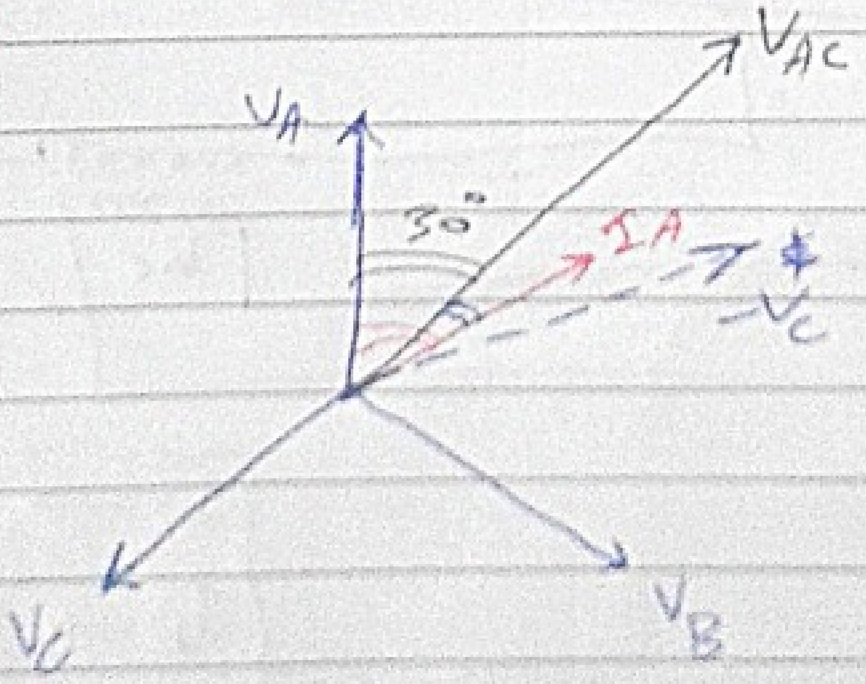
but for cable ⇒ $Z_{cable} = \frac{X}{R} \approx 1 \to 3$ ; if $\frac{X}{R} = 1$

→


→ 30° connection

→ 90° connection

## 1 30° connection



بدل ما أعطي الـ Relay ($V_A$) بصير أعطيه ($V_{AC}$) ⇐ تسمى الـ Pol

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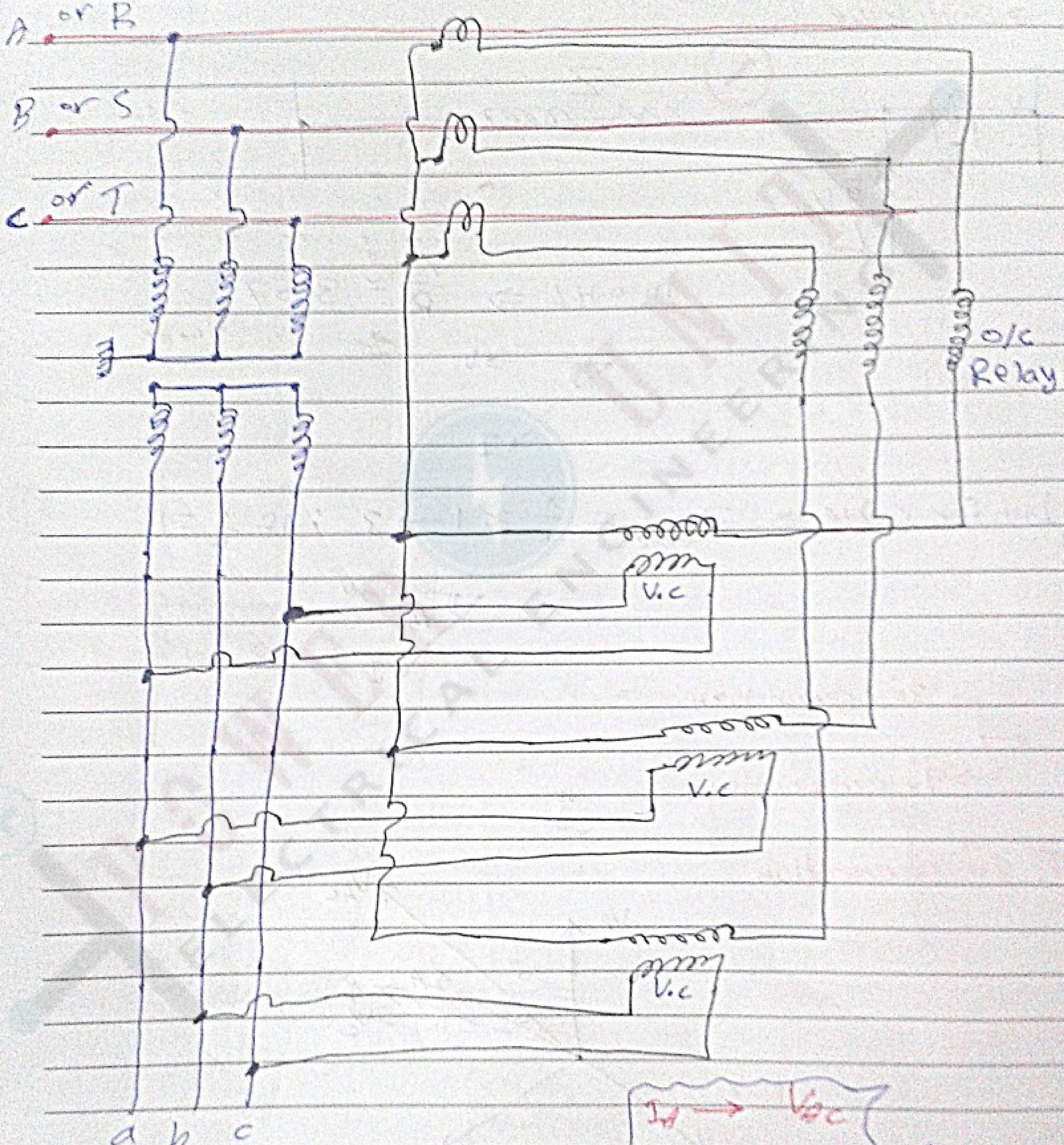

$I_A \rightarrow V_{BC}$

$I_B \rightarrow V_{BA}$

$I_C \rightarrow V_{CB}$

$30^\circ \Rightarrow$ used usually In cable design

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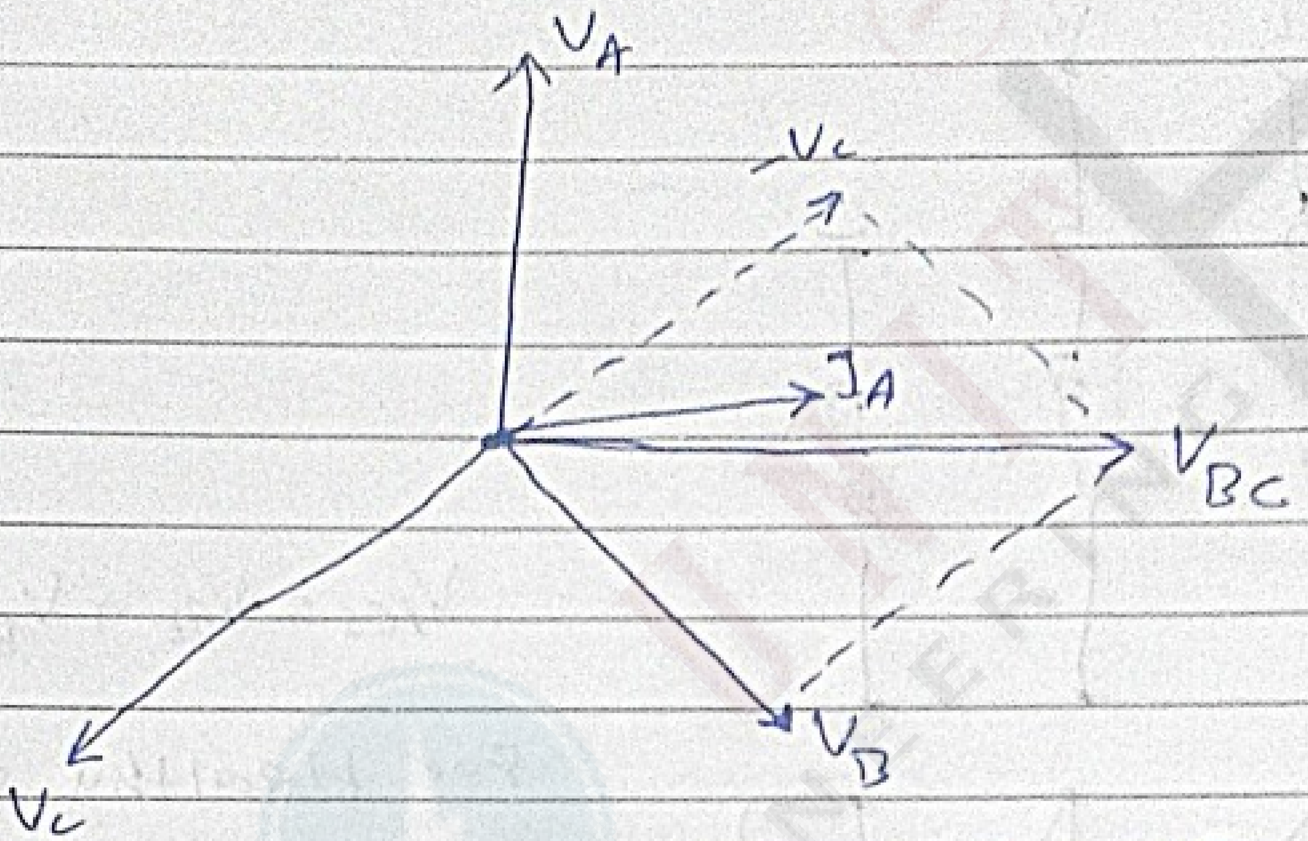
## ② 90° connection:-

used usually in O.H.Line

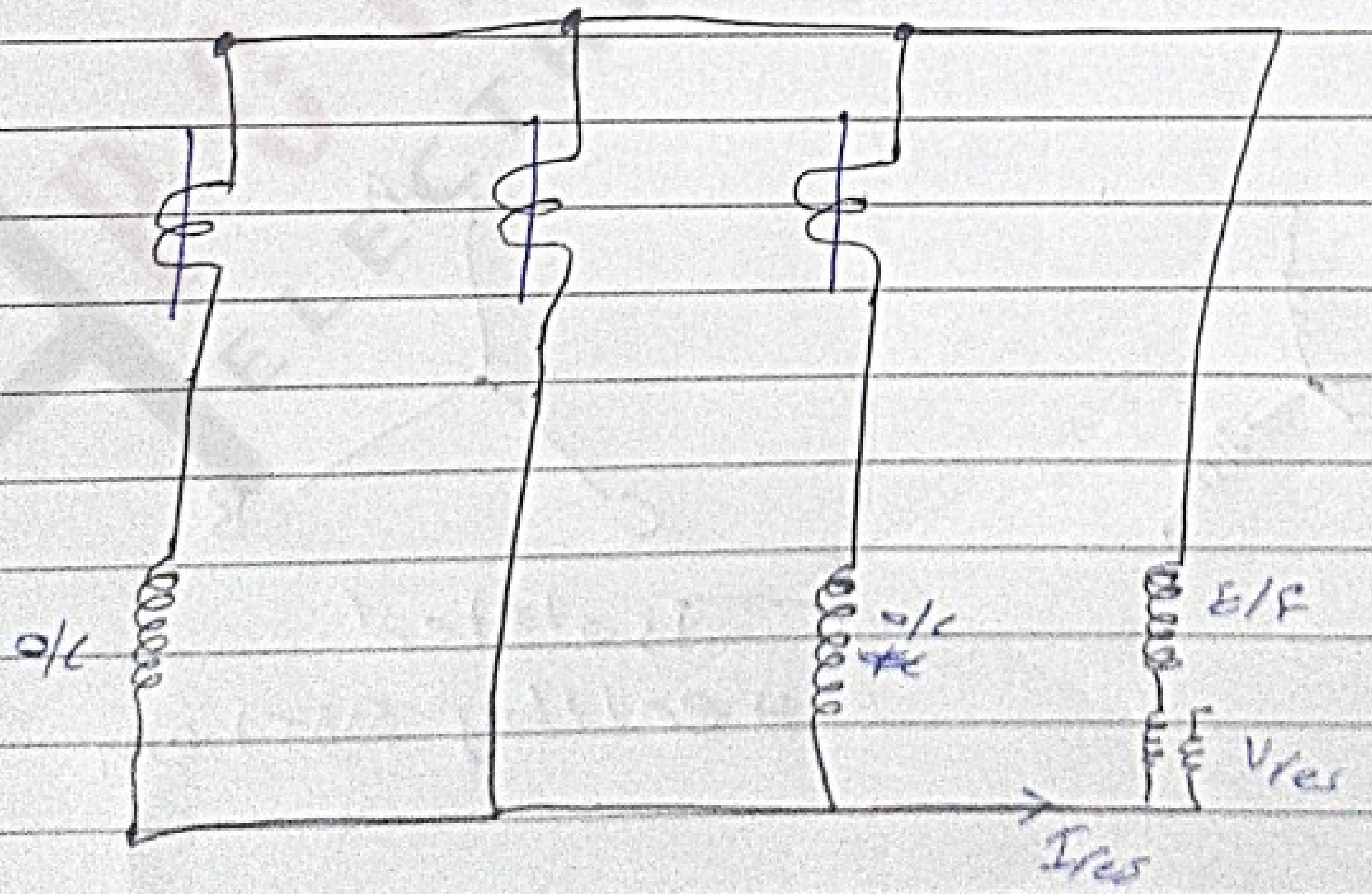


$I_A \rightarrow V_{BC}$

$I_B \rightarrow V_{CA}$

$I_C \rightarrow V_{AB}$

## * E/F Protection:-



directional E/F

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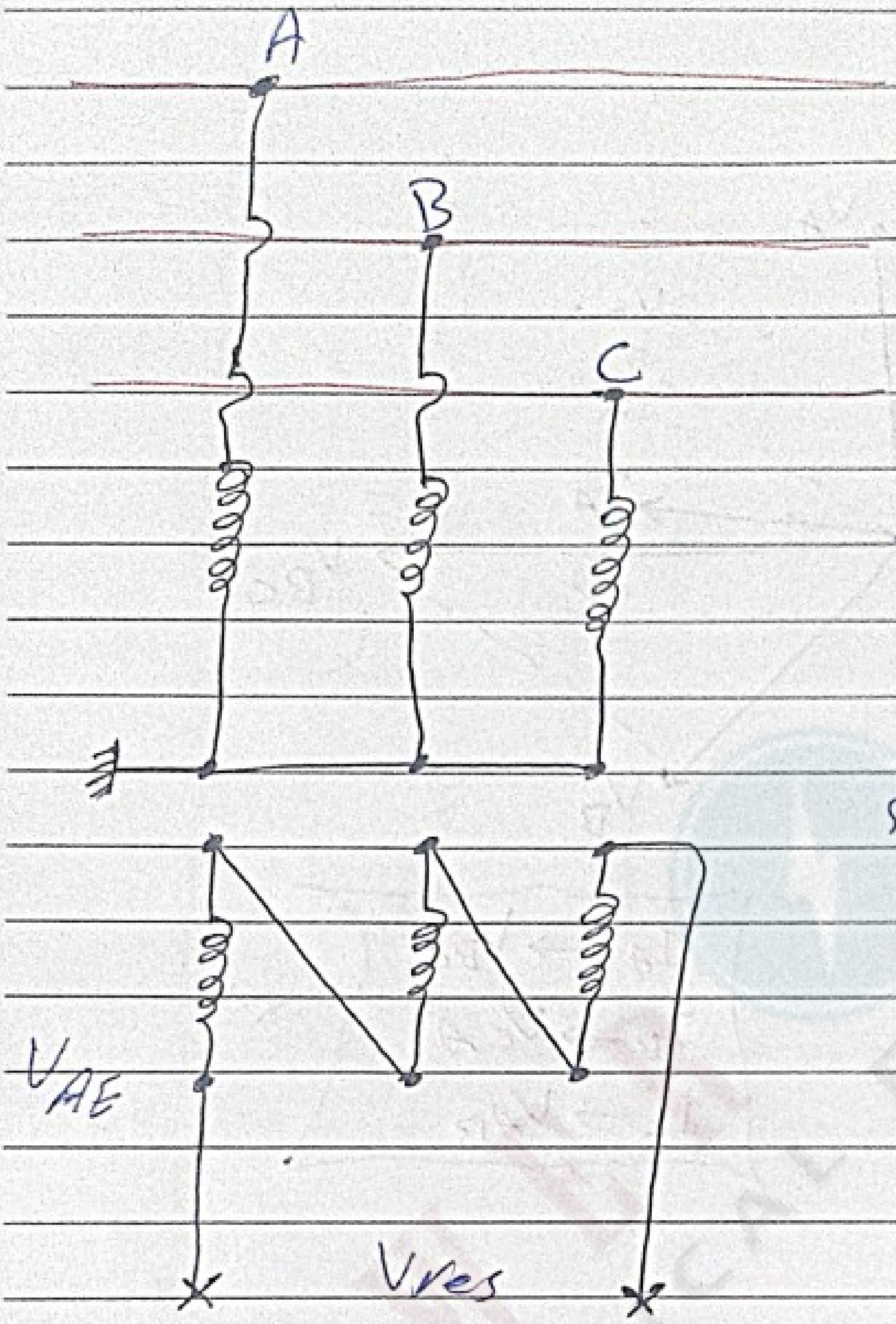
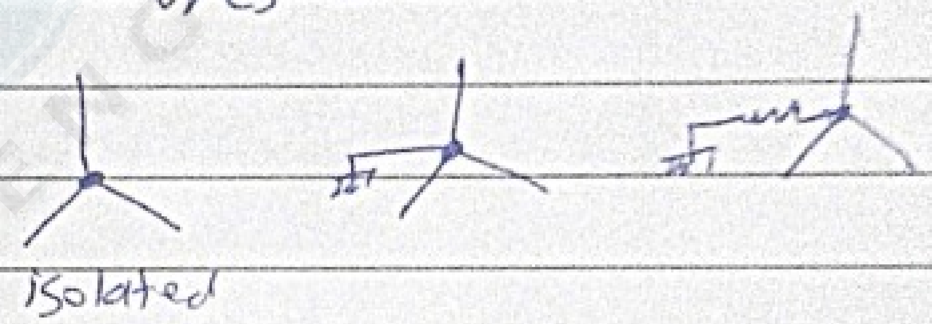
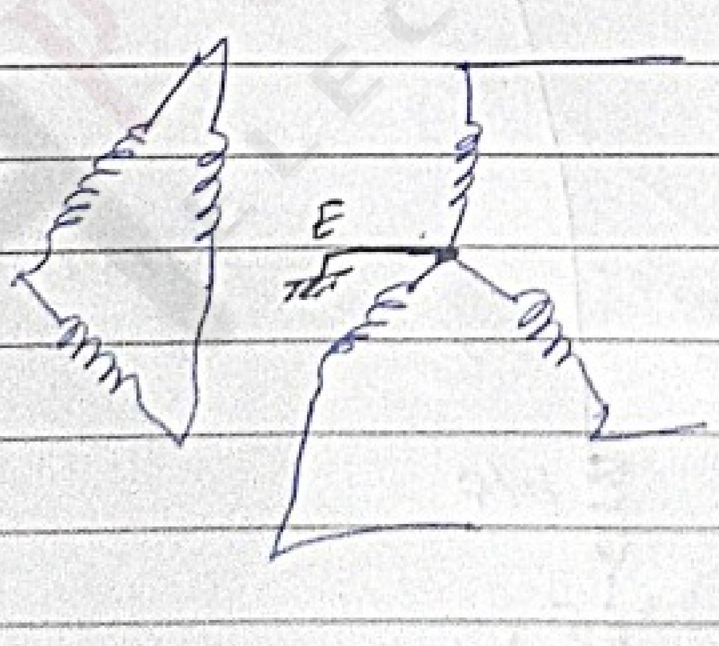


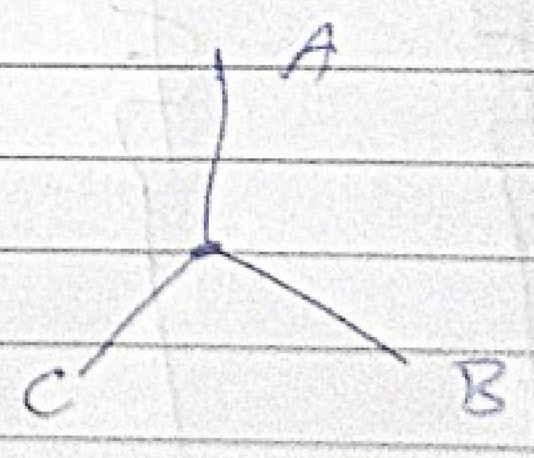
$V_{res} = V_{AE} + V_{BE} + V_{CE}$

for Healthy system

$V_{res} = 0$







Isolated

Healthy system

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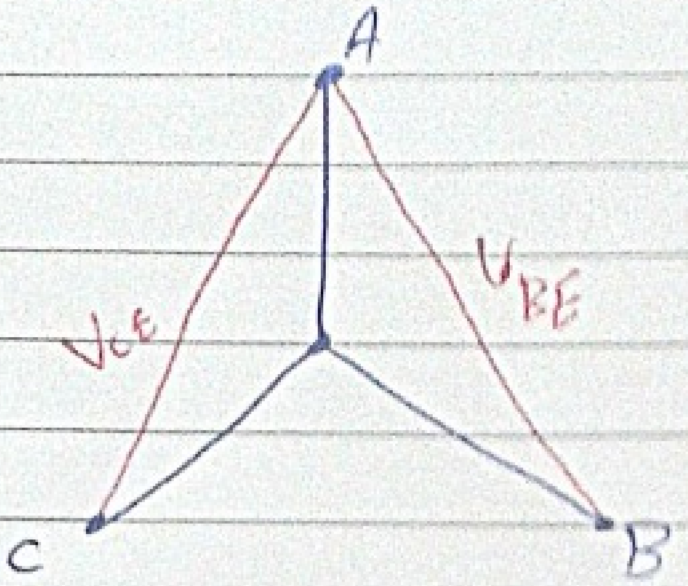
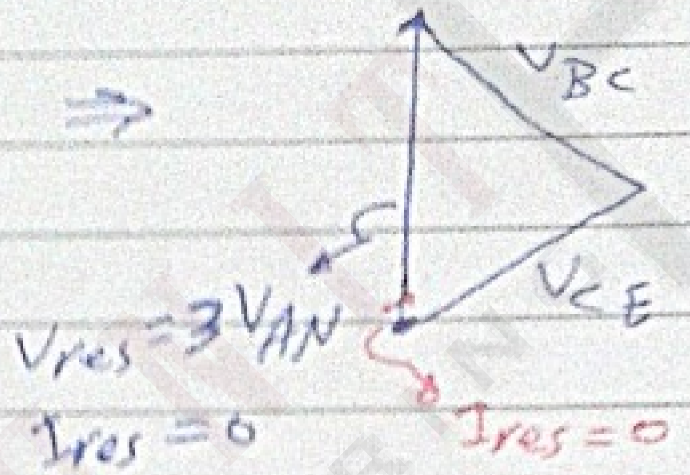
①

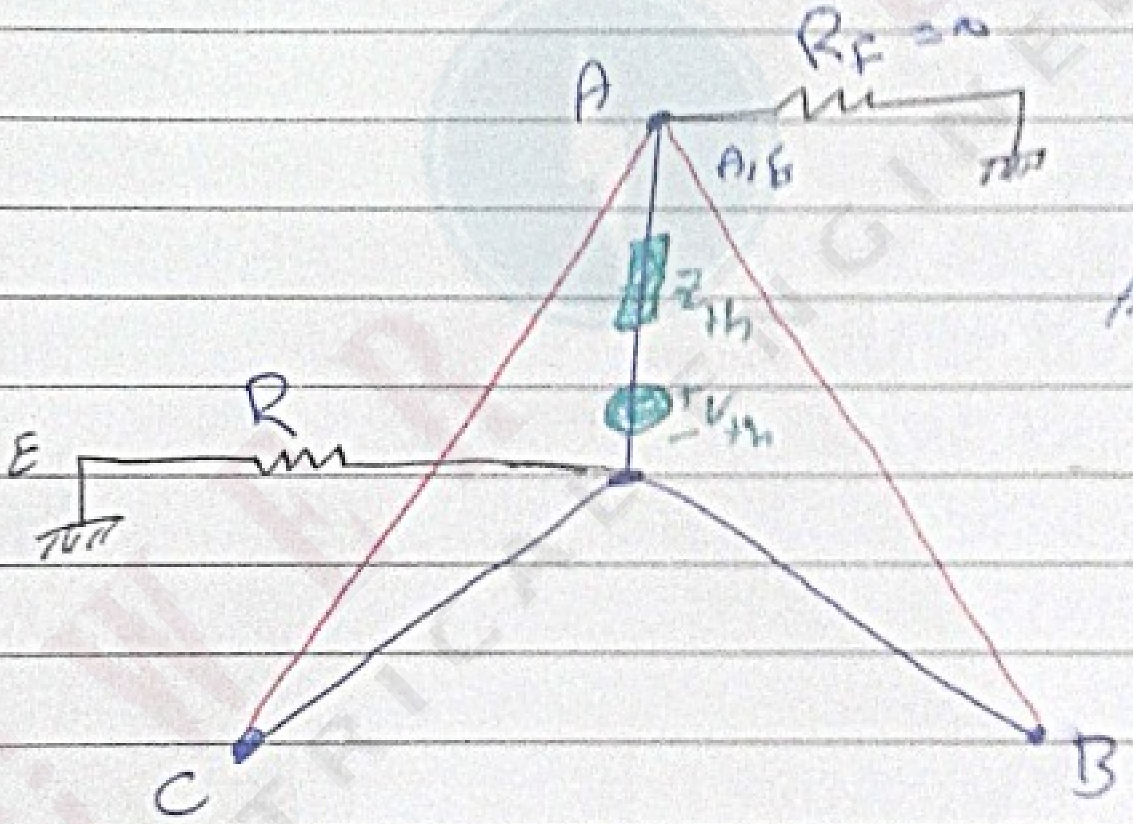


$V_{AE} = Zero$

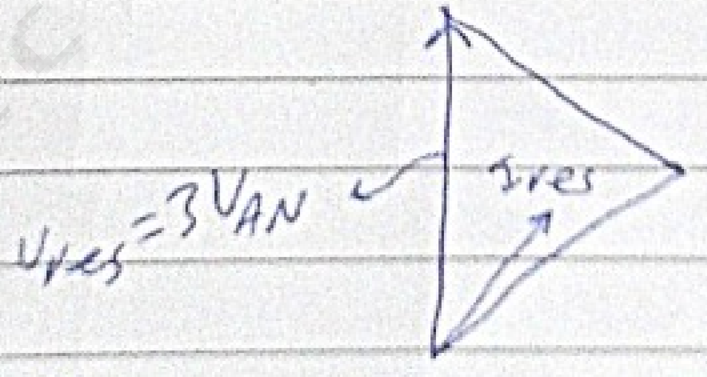
⇒



②



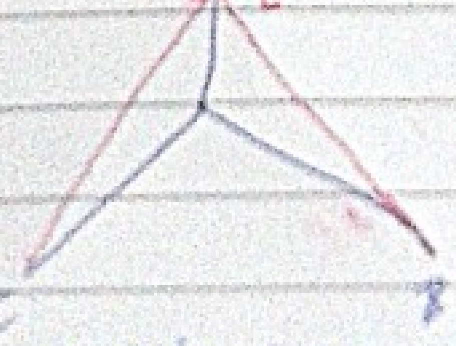
$A - E \Rightarrow R_f = 0$



$R \gg Z_{th}$

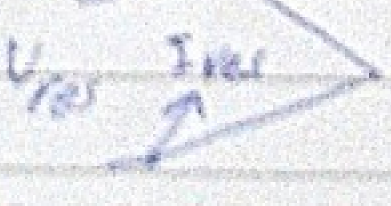
if $R_f = Value \uparrow$

⇒



I depend on $R_F$

علاقة عكسية



if $R_f$ = High Value ⇒

$R_f \uparrow \downarrow I$

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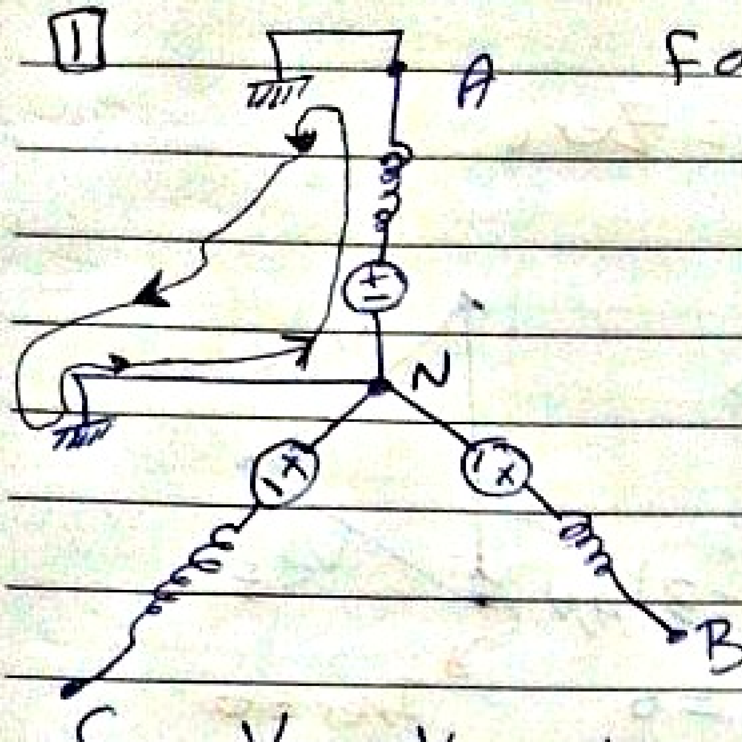
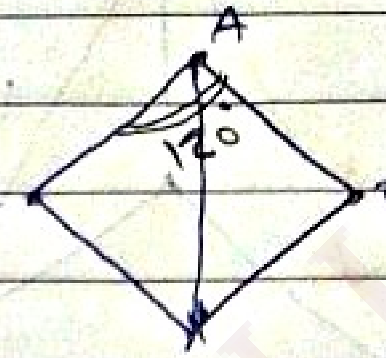
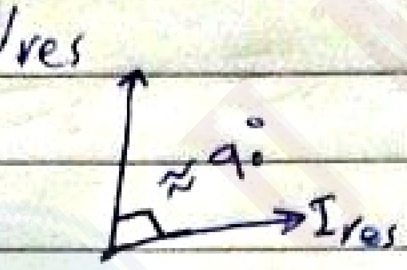
## 1 fault through $R_f = Zero$



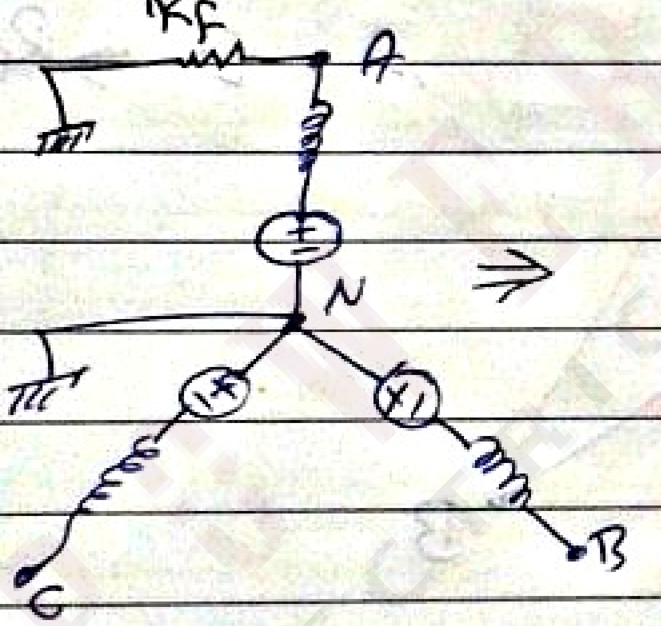
$V_{AE} + V_{BE} + V_{CE}$



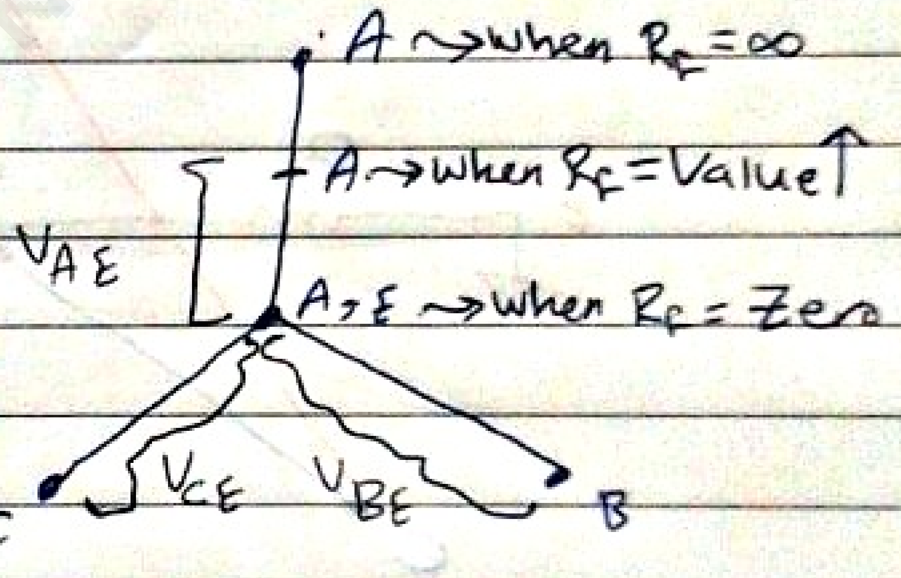


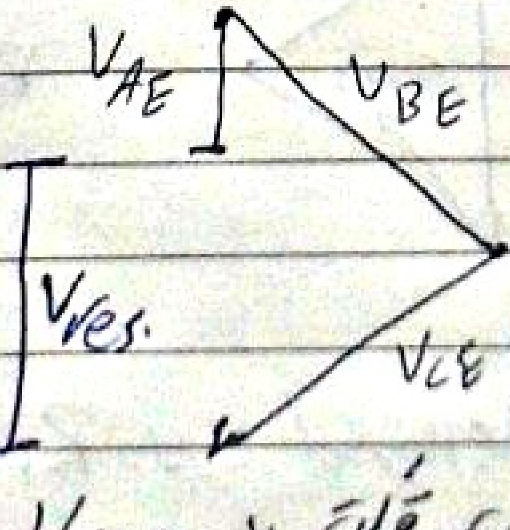
⇒ it's Not working Quickly and Not Reliabile.

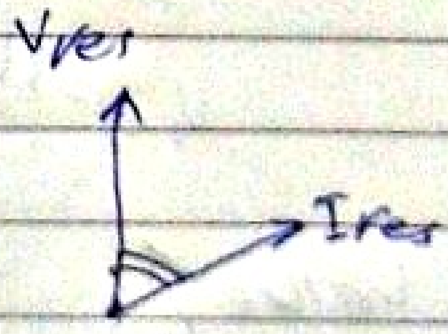
## 2



⇒







لا علاقة بتحسين الـ (P.f) بين طاقة الـ Vres و طاقة الـ Ires

⇐ لا الـ الغلط ممكن يشتغل ~~[illegible]~~ لـ ٥ لأن قيمة Vres و Ires قليلة فمش شغال

لا يكون أجل الـ compensation .

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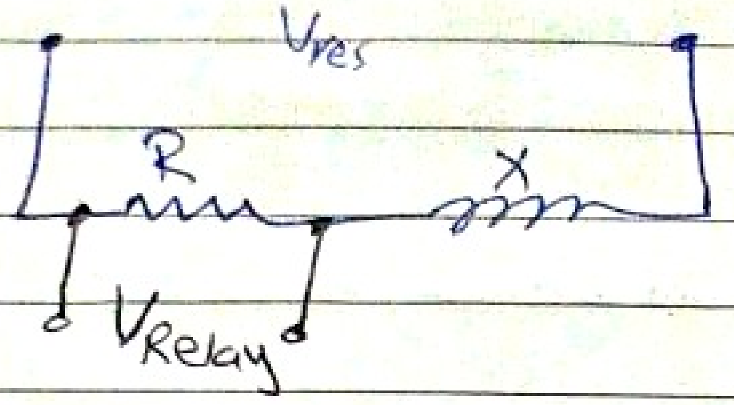
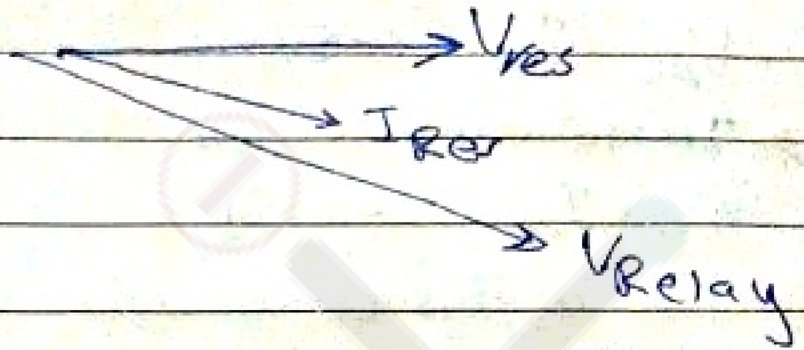
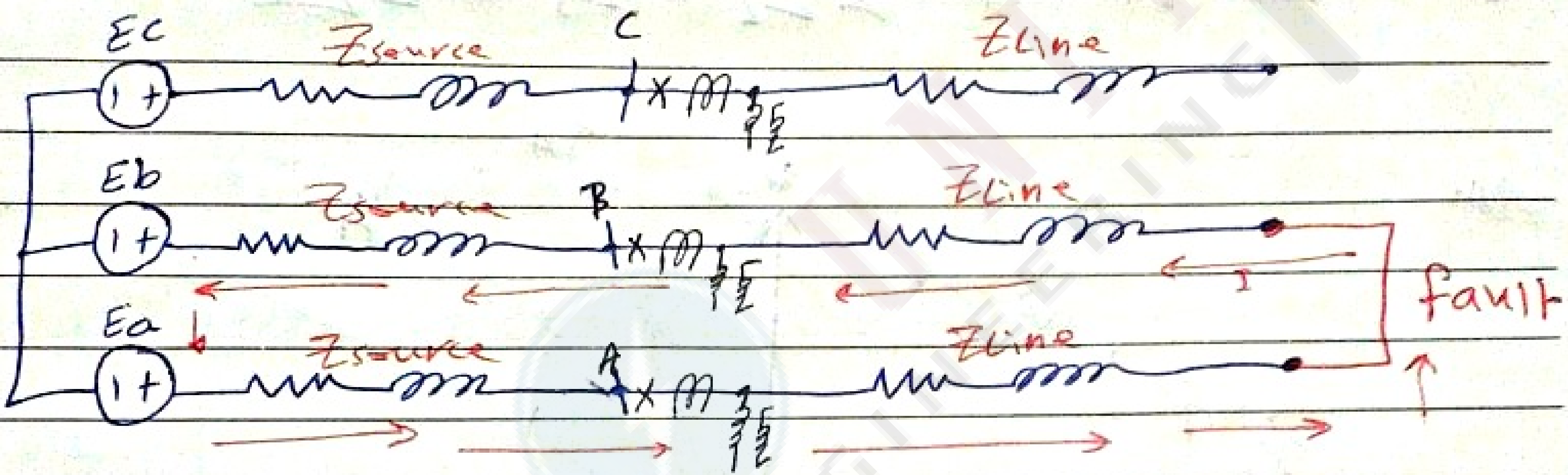
⇒ compensation :-





* هذا النظام موجود في ال above و 132 KV

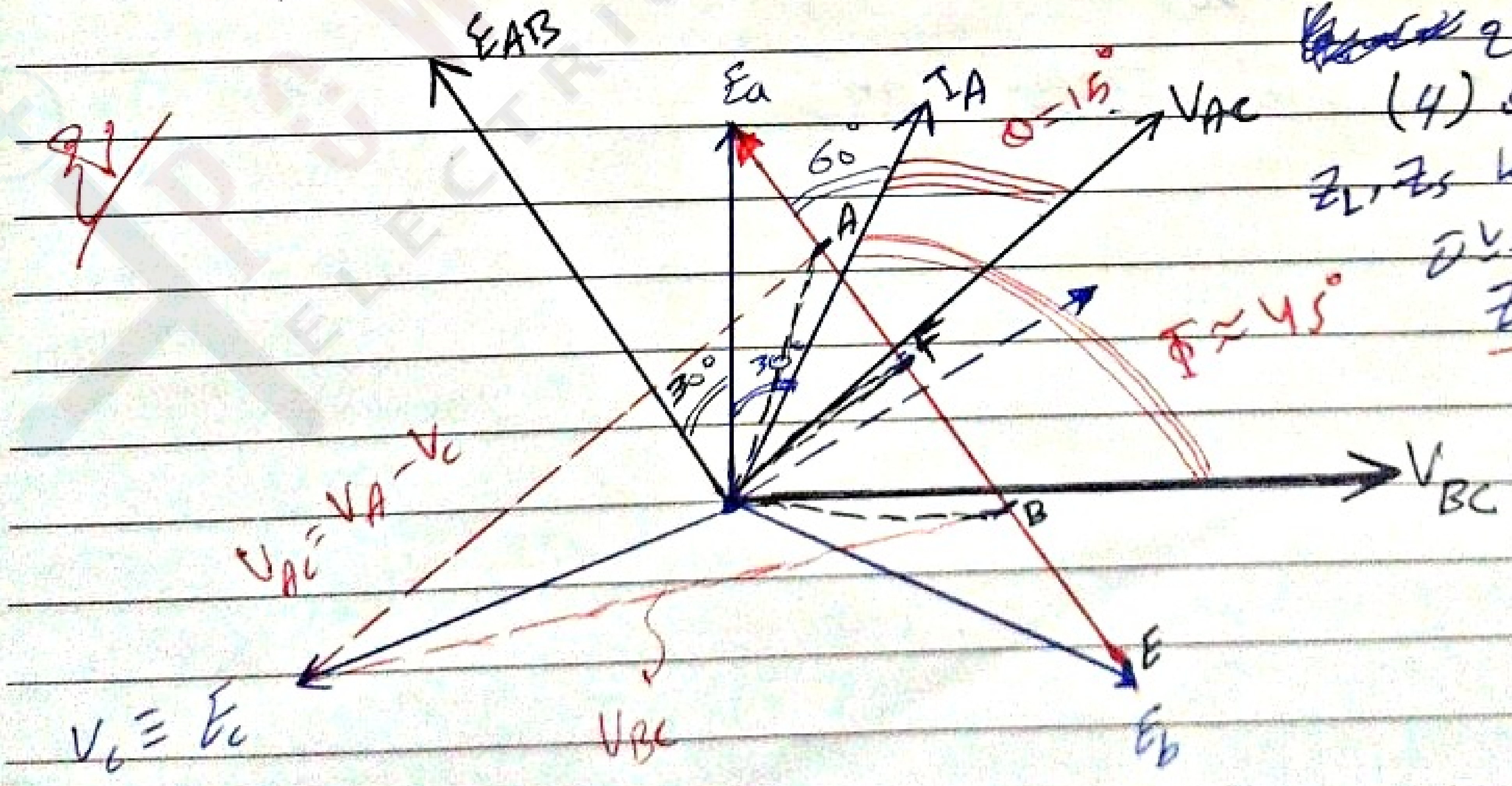
EX :-



* if $Z_{line} = Z_{source} = Z\angle 60$

solution by direc. o/c Protection. but what the best connection

30° or 90° ???!



~~[illegible]~~ 90 لـ ($V_{AB}$)

تستعملها في (4)

$Z_L, Z_s$ لما ان

متساوية

أو

$Z_L = Z_s$

→ In 30° connection :-

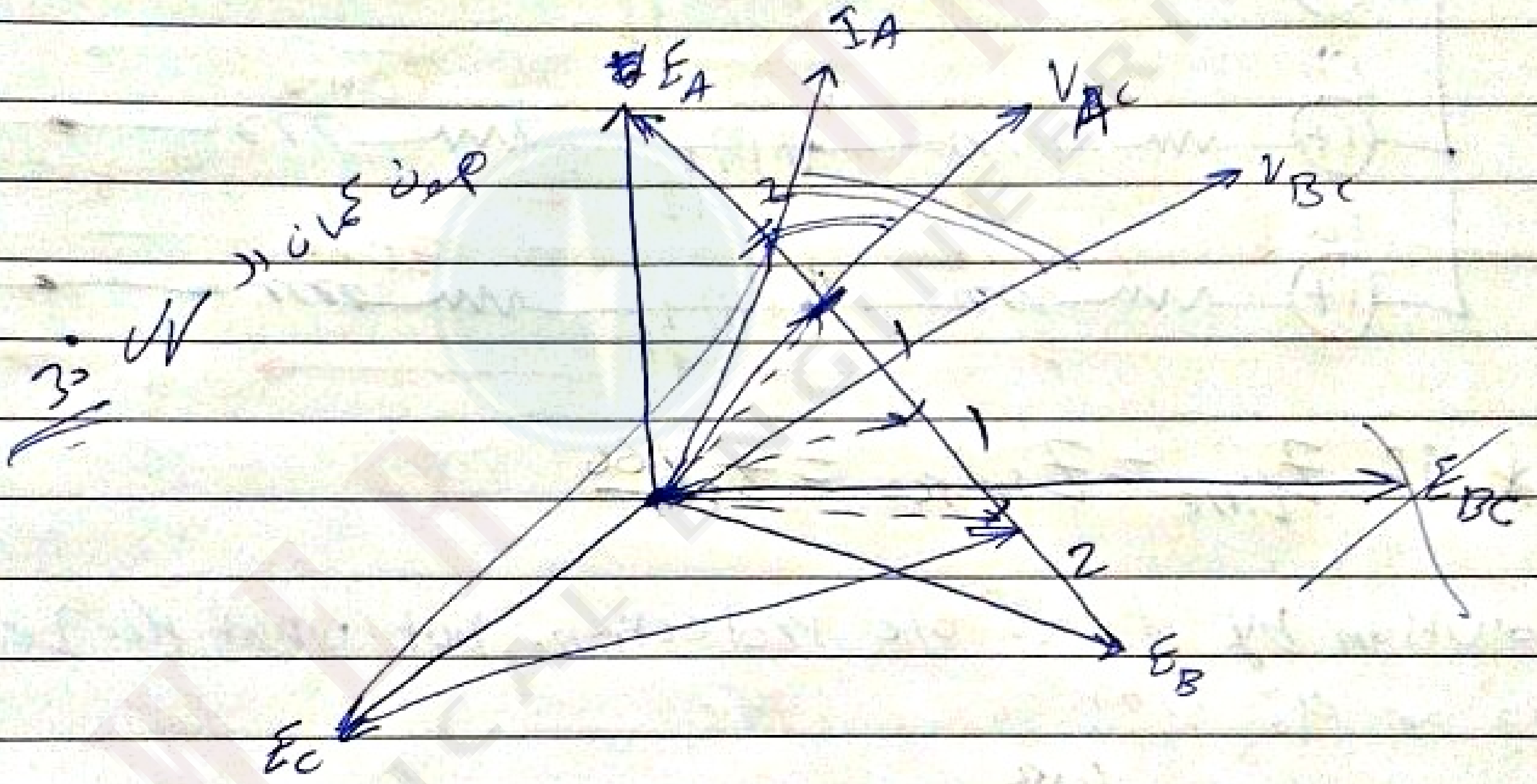
$V_{AC} \cdot I_A \cdot \cos(\theta)$

→ In 90° connection

$V_{BC} \cdot I_A \cdot \cos(\Phi)$

⇒ So in this case the 30° connection is beter than 90°

Q:- in last Ex if $2 Z_L = Z_s = Z \angle 60°$



Q. $4 Z_L = Z_s = Z \angle 60$ ??

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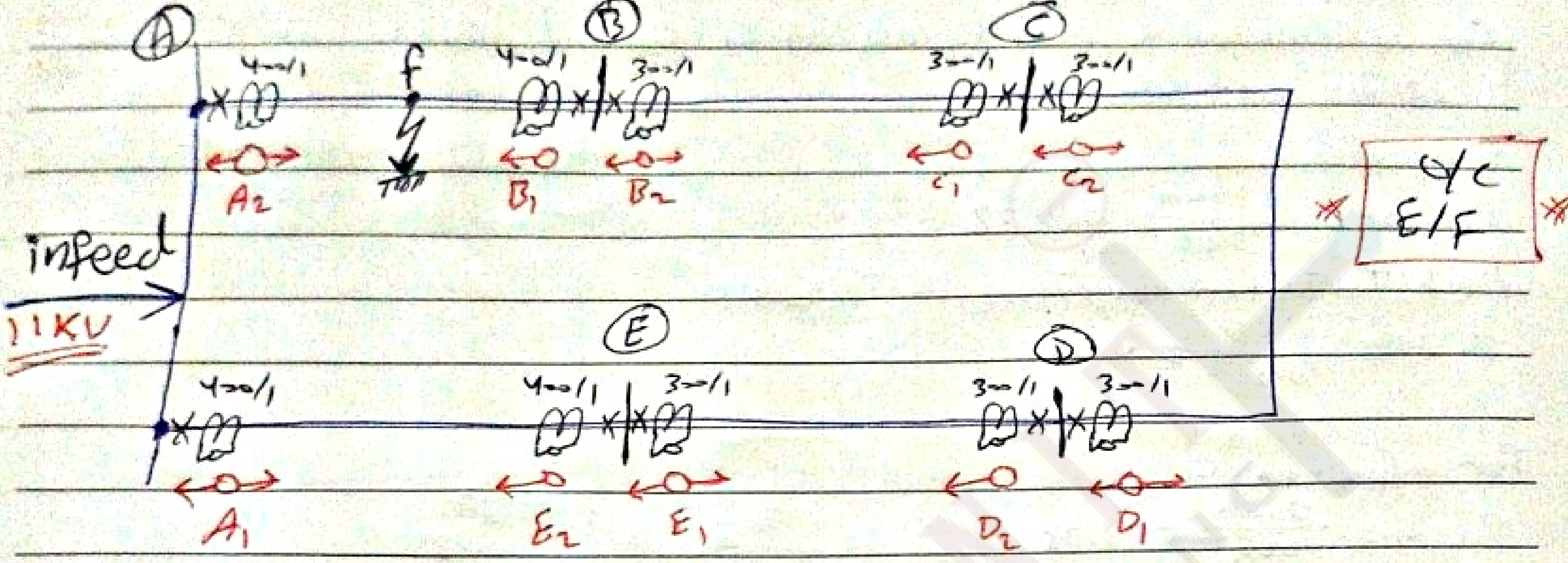

→ MAX 3-Φ fault current

عن طريق

VIA A→E . (A2 open) :-

~~faultcurren~~

fault current at B = 2000A
" " at C = 3000A
" " at D = 5000A
" " at E = 8000A
" " at A = 12000A

} at 3-P Balance fault.

① O/C Relay :-

Via A-E

at B1 :-

P.S = 50%

T.M = 0,05

$P.S.M = \frac{2000}{0,5 \times 400} = 10$

$t \text{ at } T.M = 1 = \frac{3}{\log(10)} = 3 \text{ sec}$

t at T.M = 0,05 = 0,15 sec.

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at $C_1$

for a fault at $B_1$ the Relay at $C_1$ should operate at $\boxed{t = 0,15 + 0,5}$

$\Rightarrow t = 0,65$ sec.

P.S = 75 %

$P.S.M = \frac{3000}{225} = 8,88$

$t$ at $T.M = 1 = \frac{3}{\log(8,88)} = 3,16$ sec

$T.M = \frac{0,65}{3,16} = 0,21$

for a fault at $C_1$

$P.S.M = \frac{3000}{225} = 13,33$

$\hookrightarrow 300 \times 0,75$

$t$ at $T.M = 0,21 = 0,56$ sec

كمل كالتالي

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② E/F Relay :-

Earth fault current is limited to 1000A

(( 20% → 80% in 10% steps )) ☆

↳ saturation!!

at $B_1$ :-

P.S = 30%

T.M = 0,01 !! but (( Practicability !!! )).

$P.S.M = \frac{1000}{120} = 8,333$

$t$ at $T.M = 1 = \frac{3}{\log(8,333)} = 3,2$ sec.

$t$ at $T.M = 0,01 = 0,32$ sec.

at $C_1$ :-

for a fault at $B_1$ it should operate at $\boxed{t = 0,32 + 0,5 \text{ sec}} \Rightarrow \boxed{t = 0,82 \text{ sec}}$

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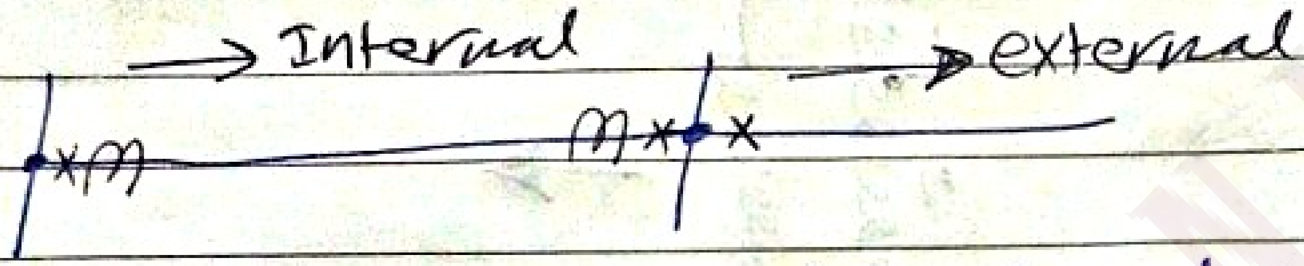
P.S = 40%.

P.S.M = $\frac{1000}{120}$ = 8,333

t at T.M = 1 = 3,2 sec.

T.M = $\frac{0,532}{3,2}$ = 0,17 .



diff.

1- Reliability ✓✓ ← depend on design & Maintenanc. and installation.

2- Discrimintation ✓✓

3- Stability ✓✓

4- sensitivity → Max

5- Speed.

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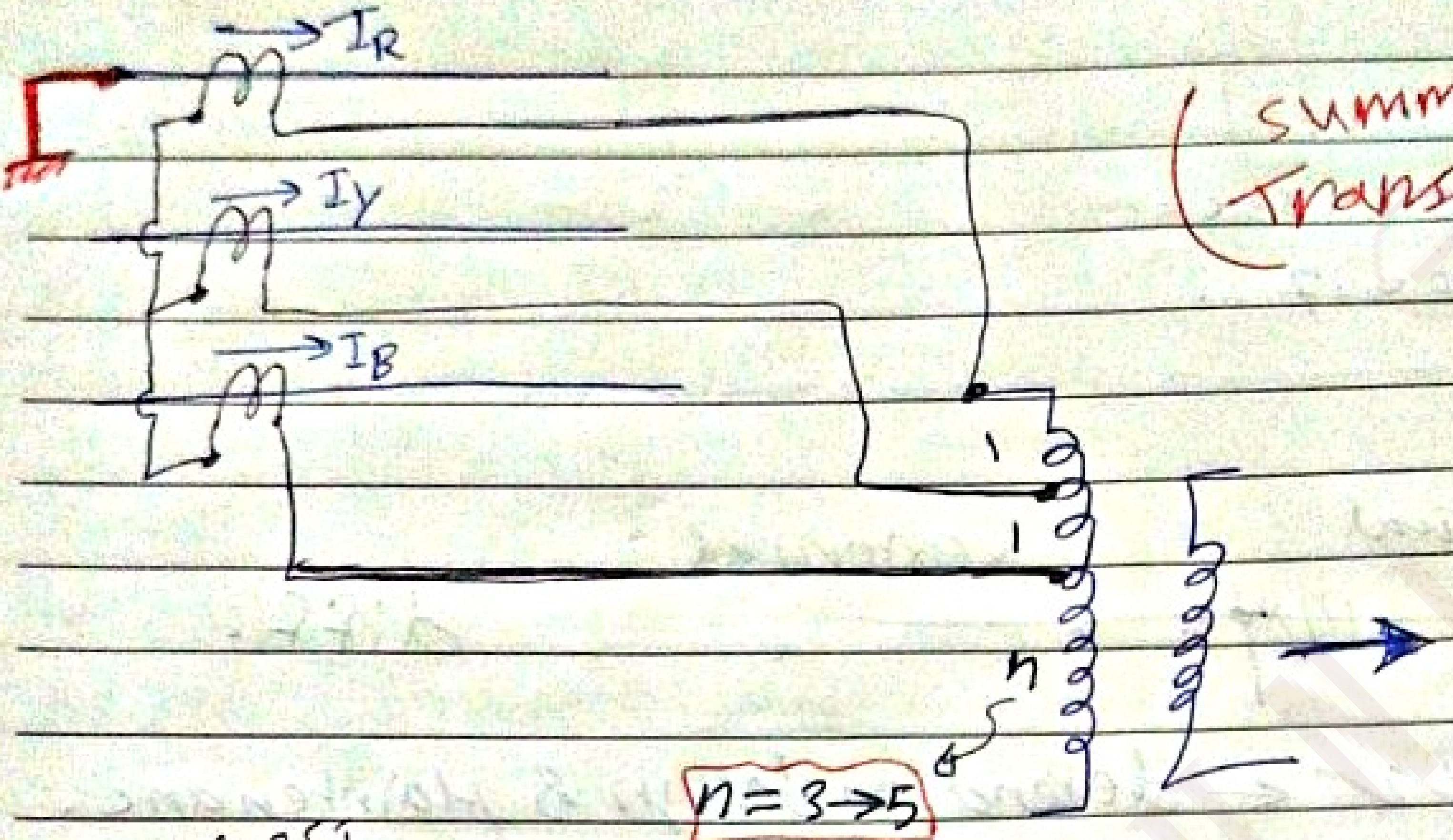


(summation Transformer)

اكثر شي مستعمل

① R-E fault

$(n+2) I_f$

② Y-E fault

$(n+1) * I_f$

③ B-E fault

$(n) * I_f$

④ R-Y fault

$(1) * I_f$

⑤ Y-B fault

$(1) * I_f$

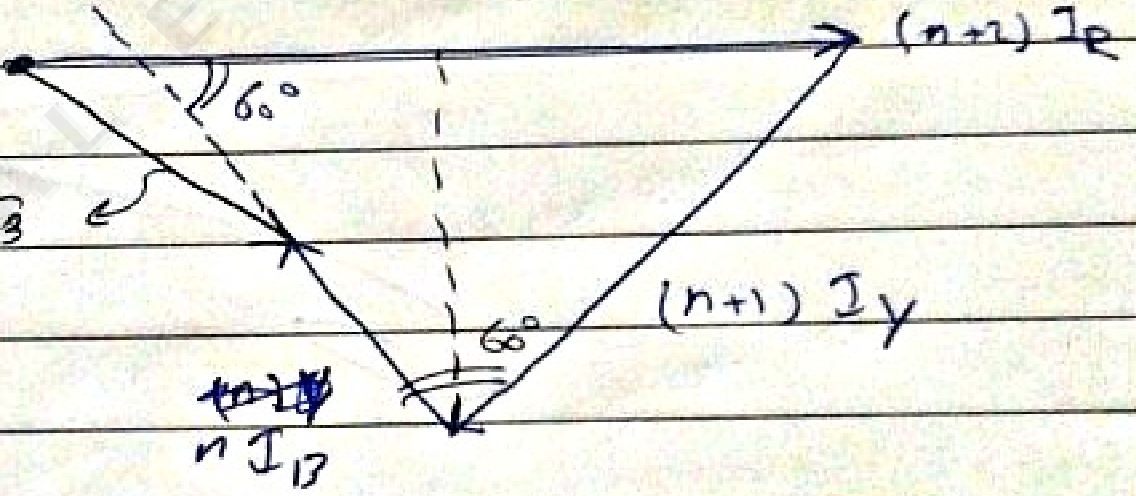
⑥ R-B fault

$(2) * I_f$

⑦ 3-Phase fault «R-Y-B» Balanced:-

$|I_R| = |I_Y| = |I_B|$

$I_R(n+2) + I_Y(n+1) + I_B(n)$



$\Rightarrow \equiv \boxed{(\sqrt{3})(I_f)}$

- → operating quantity
- → biased quantity

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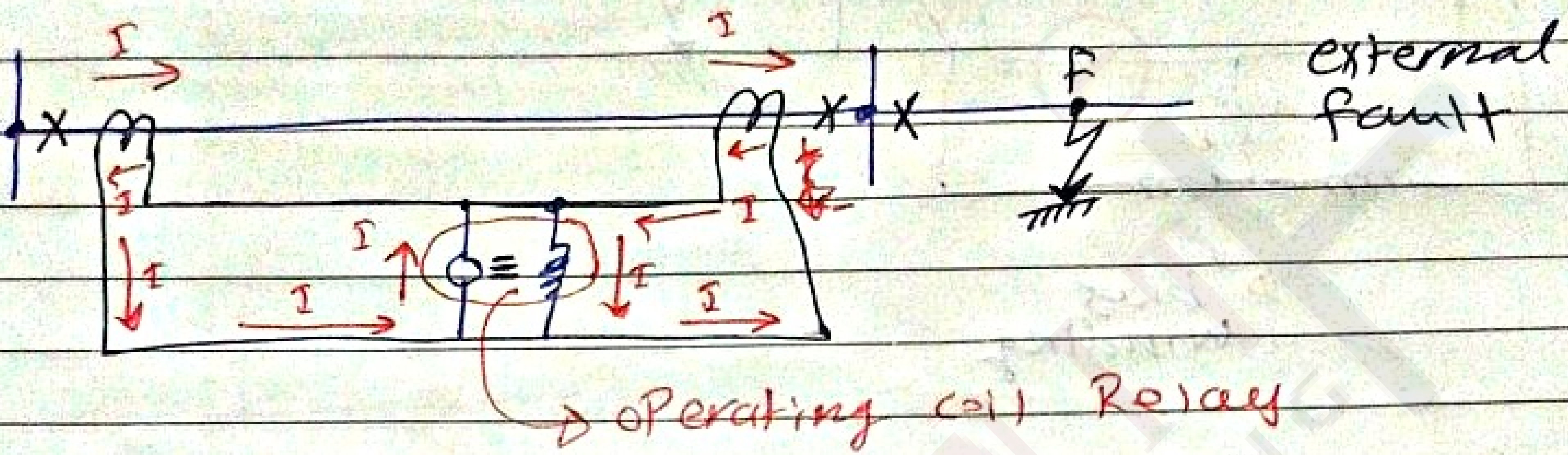
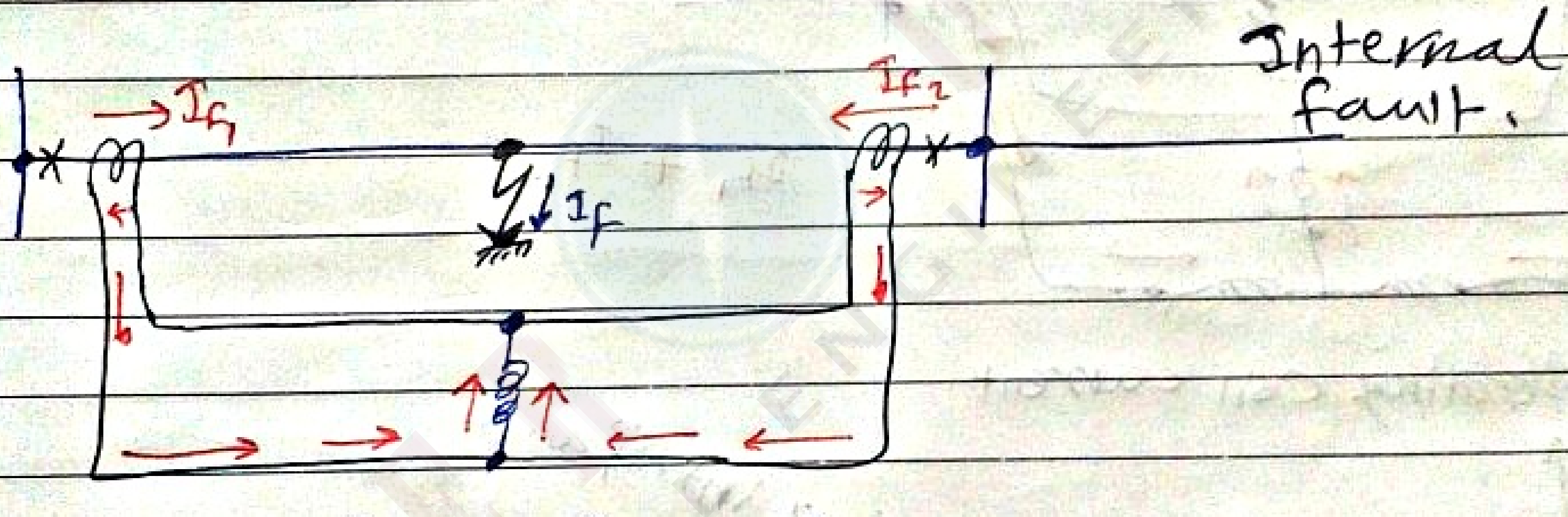
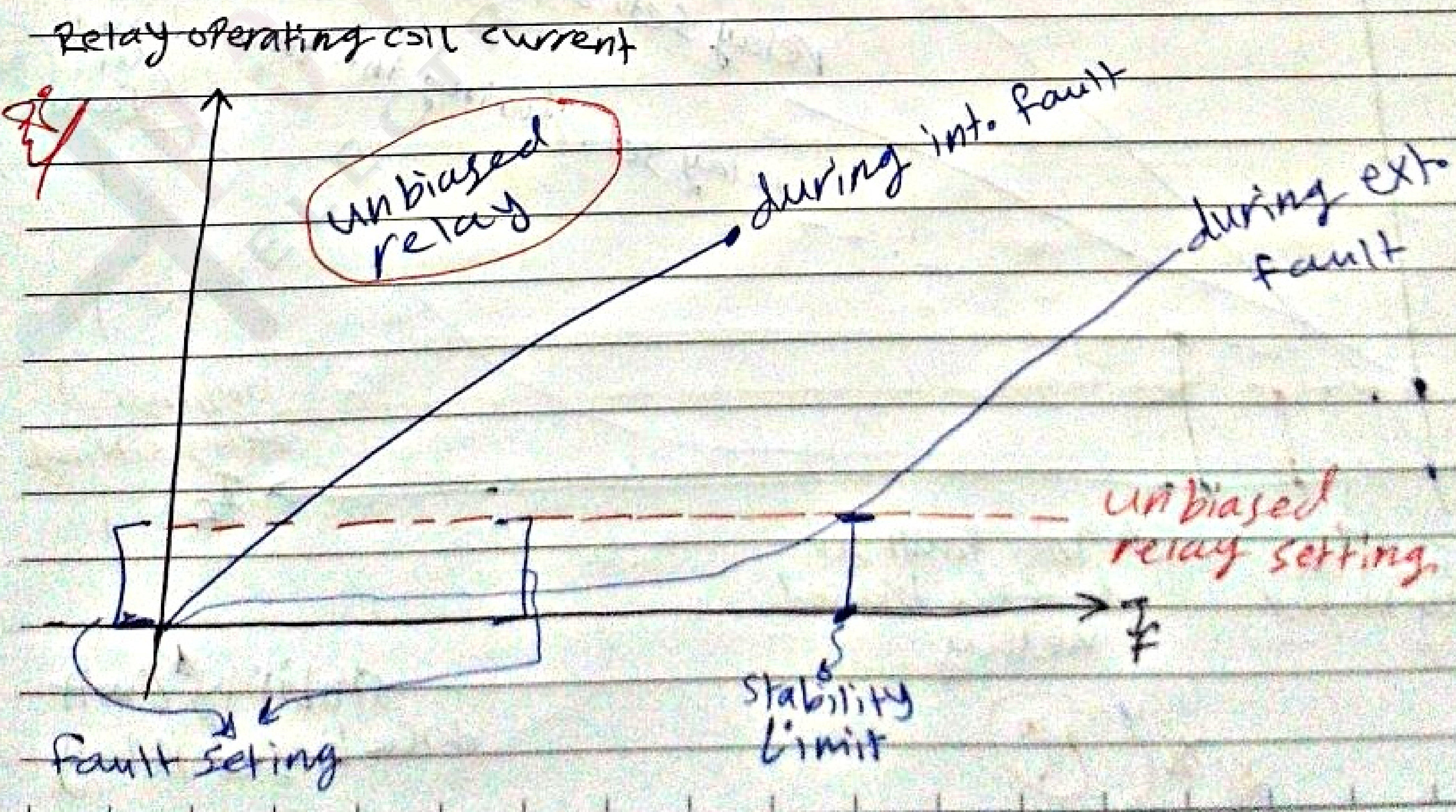
## * Biased Differential Relay :~





$$I_{Relay} = \frac{I_F}{C.T\,Ratio} = \frac{I_{f_1}}{C.T\,ratio} + \frac{I_{f_2}}{C.T\,Ratio}$$



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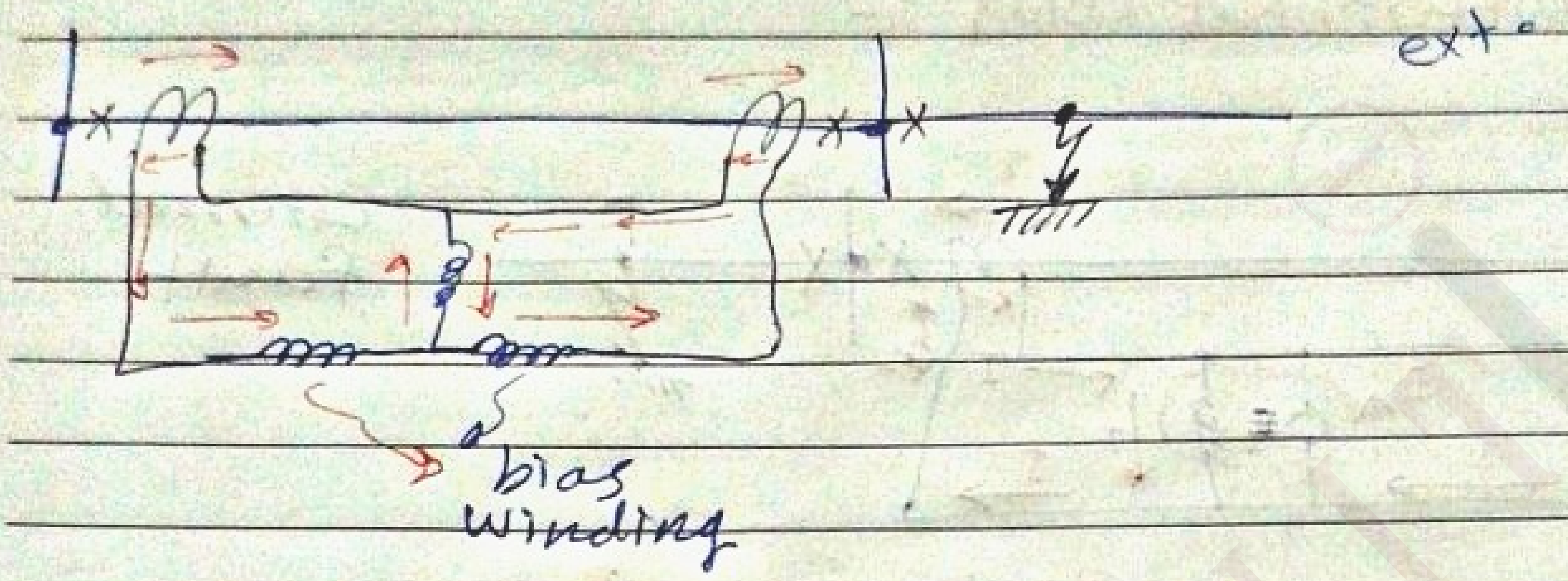

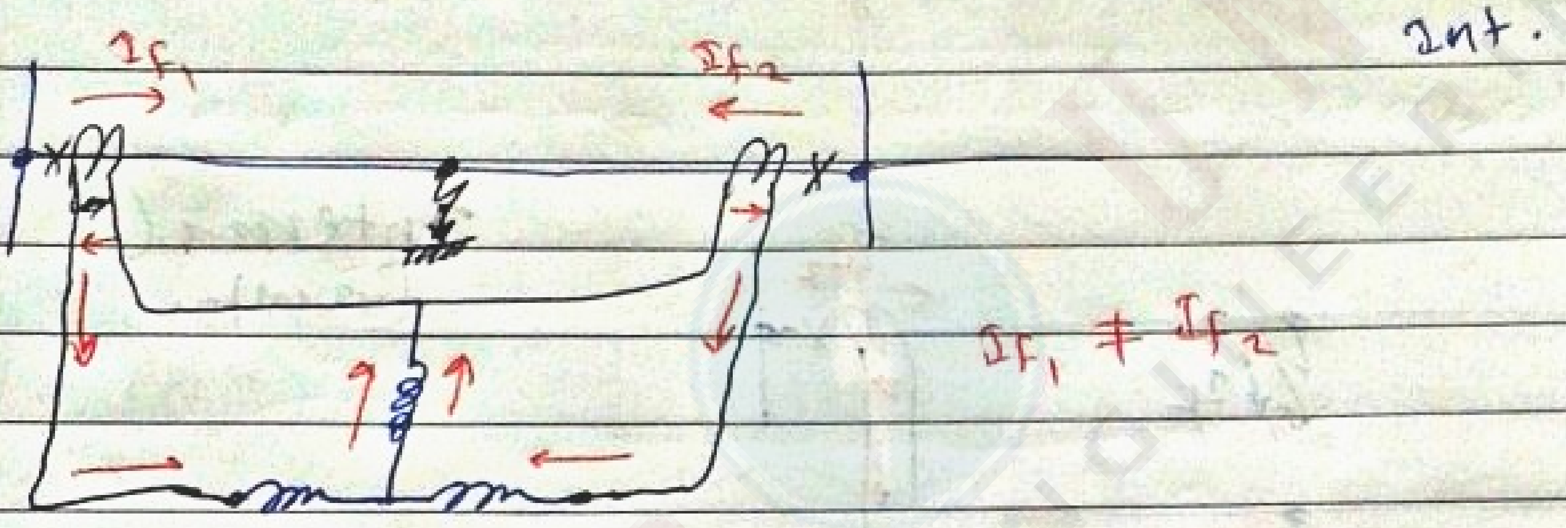

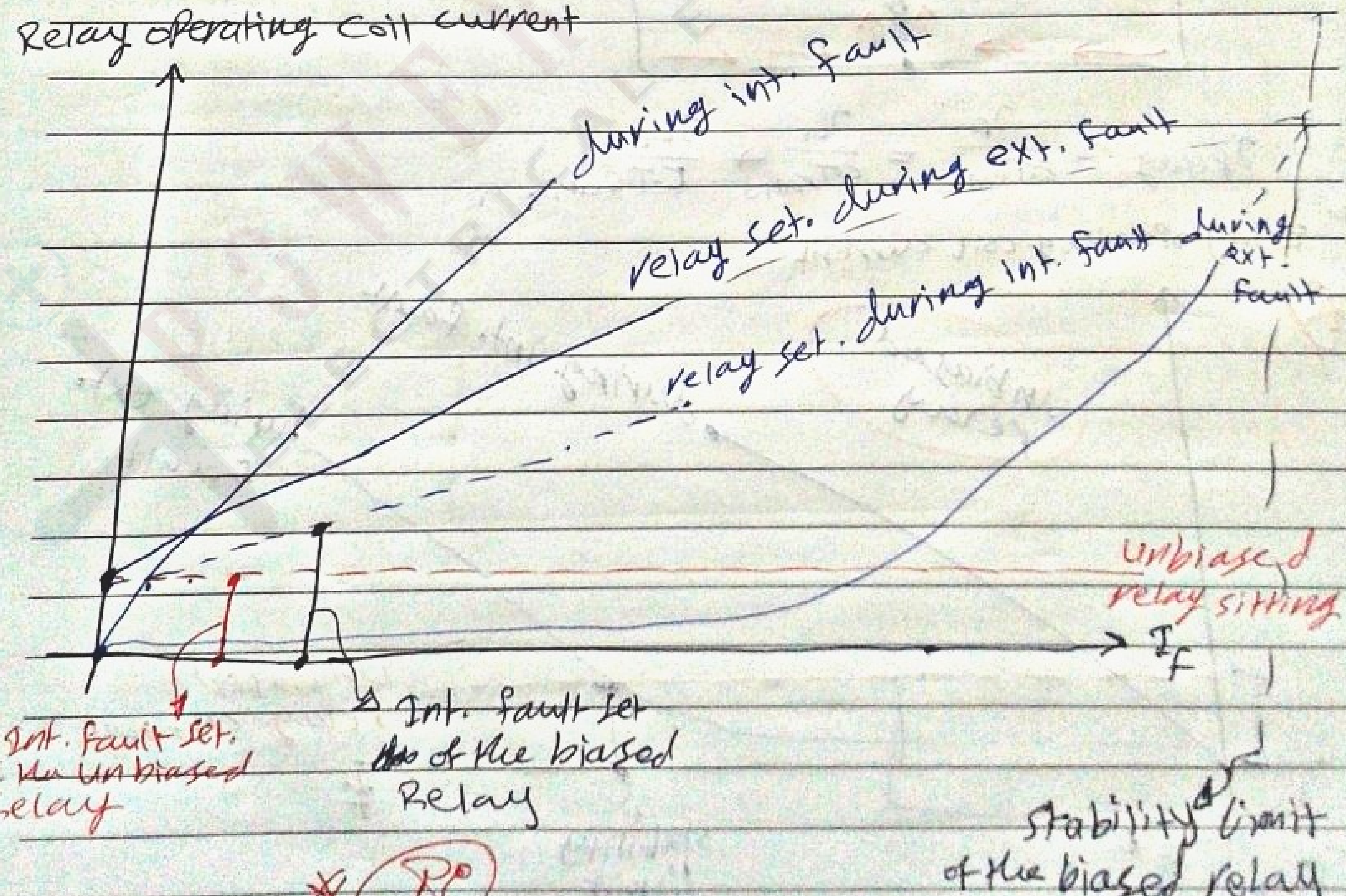

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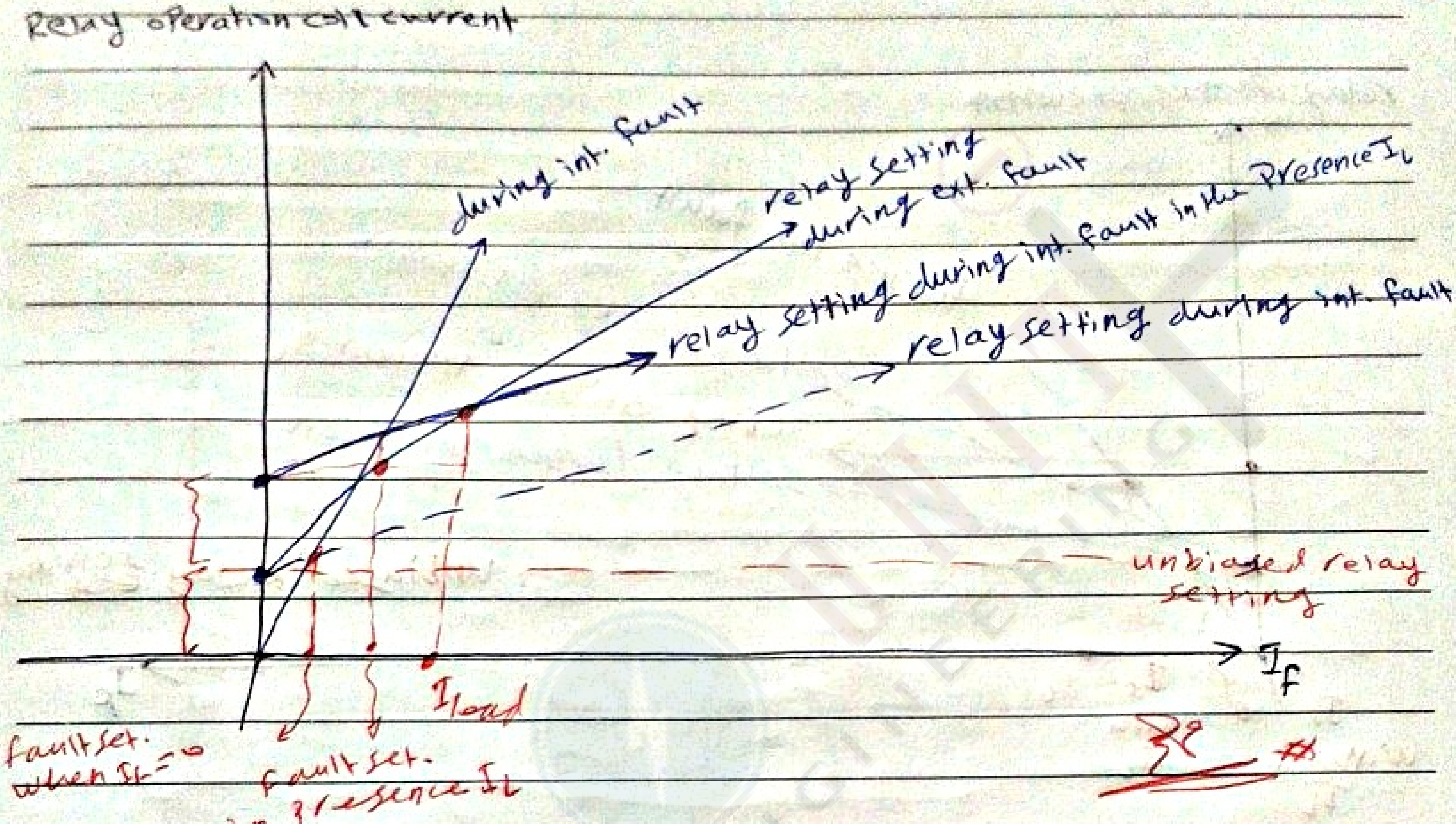
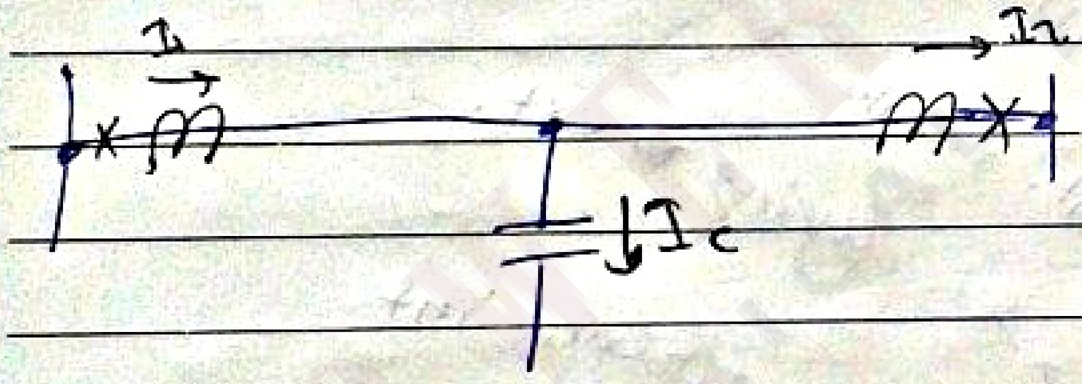
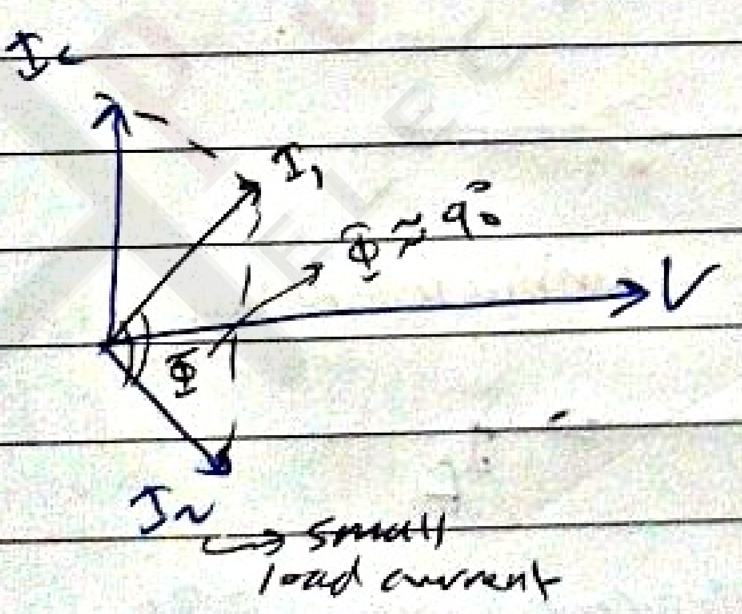
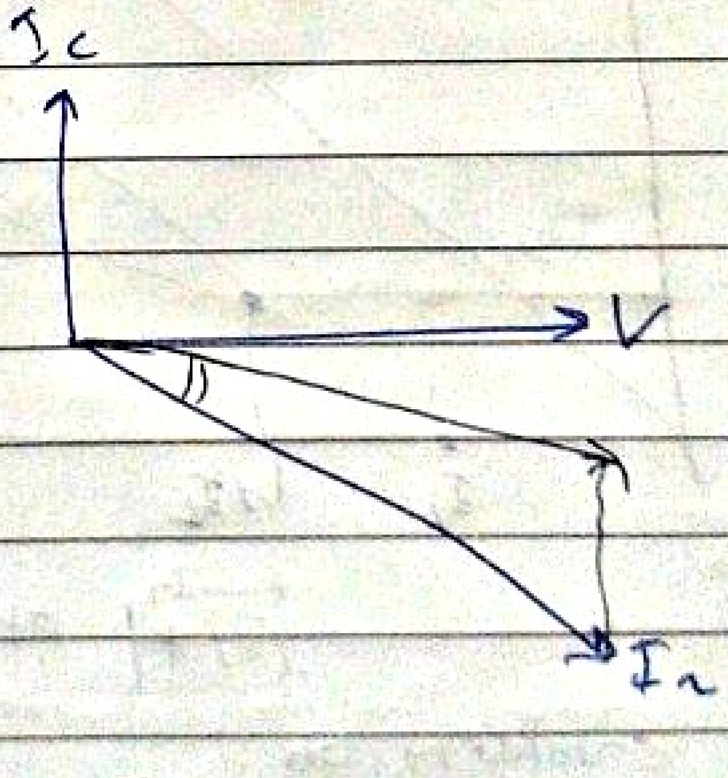




at High ext. fault current

$I_1' \neq I_2'$





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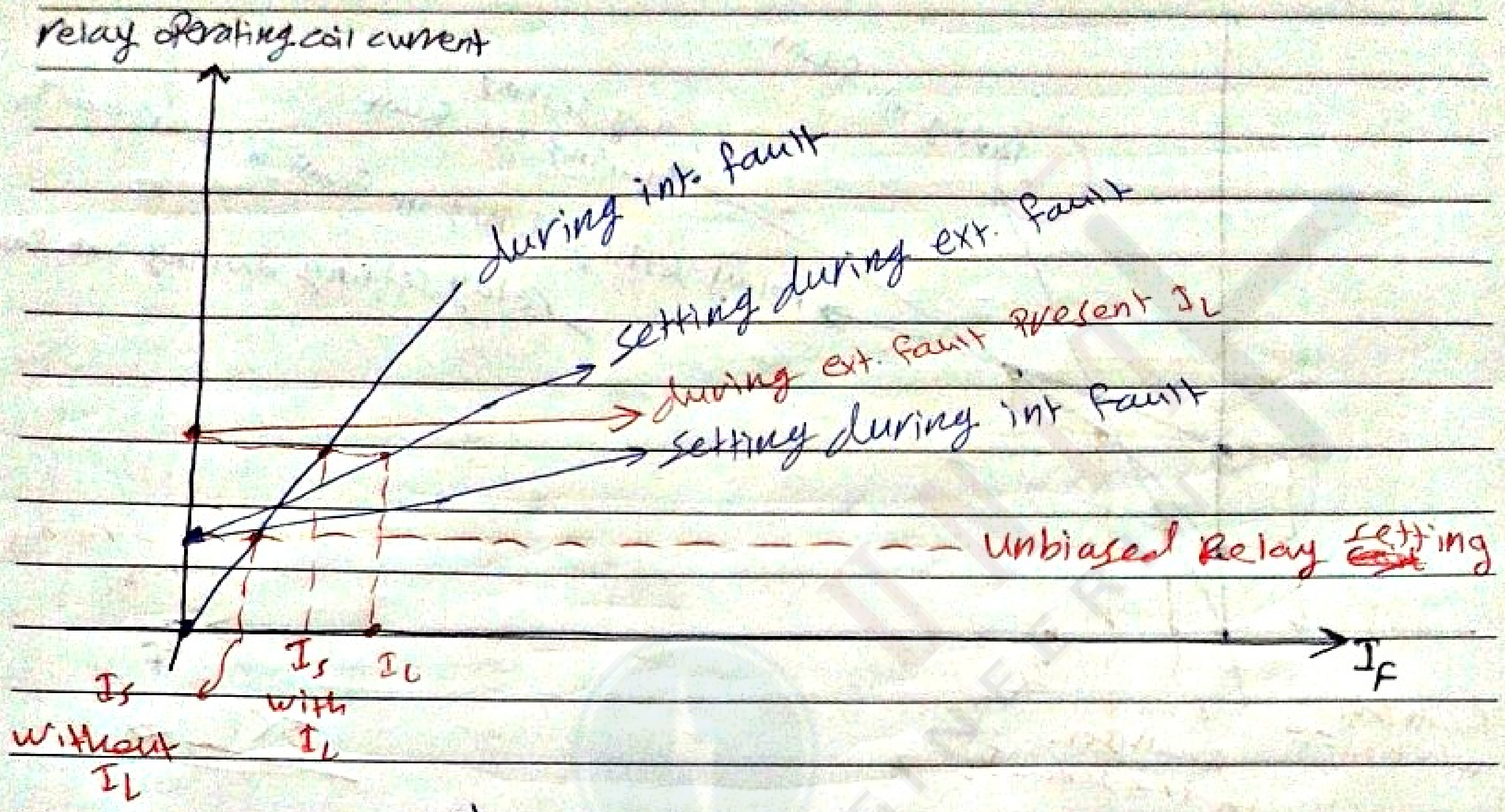
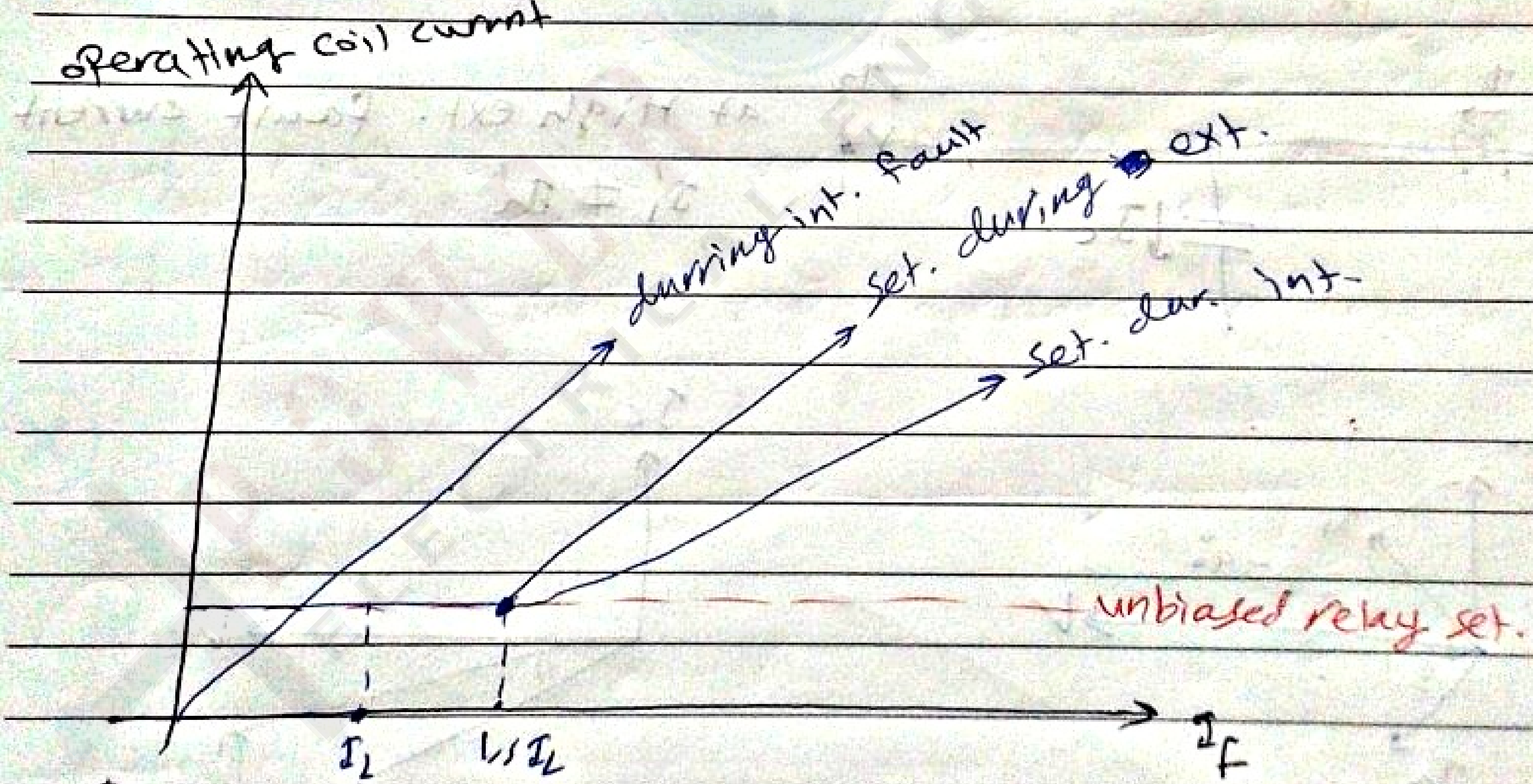
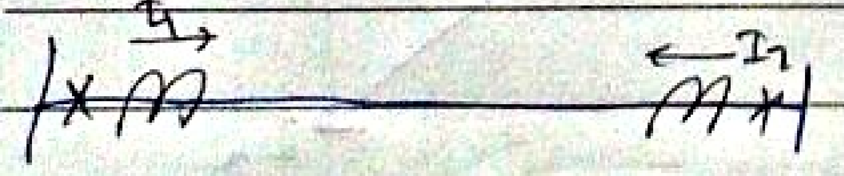
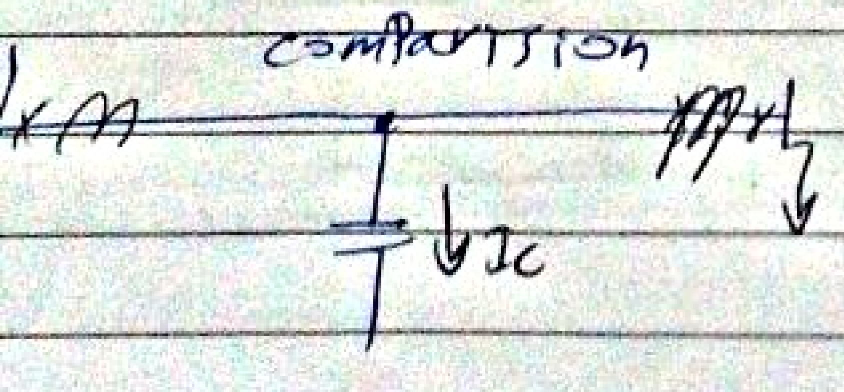
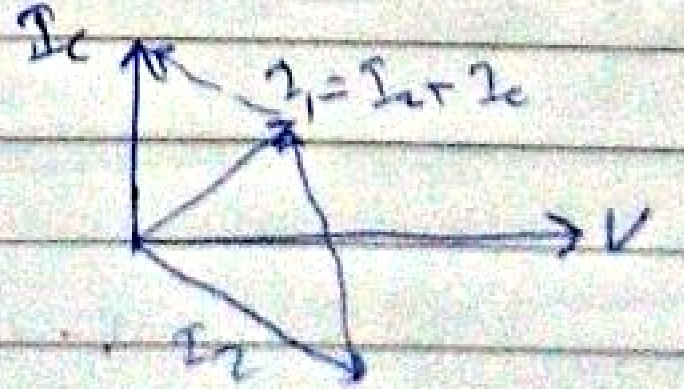




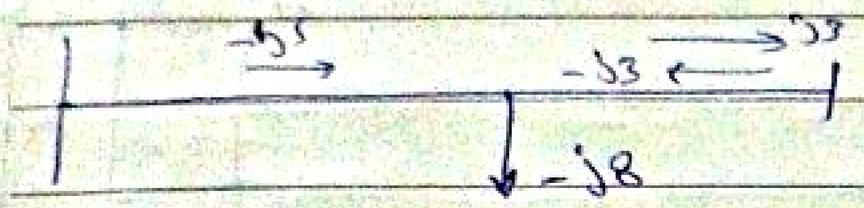


at low current Phasor «Mag. & Phase»



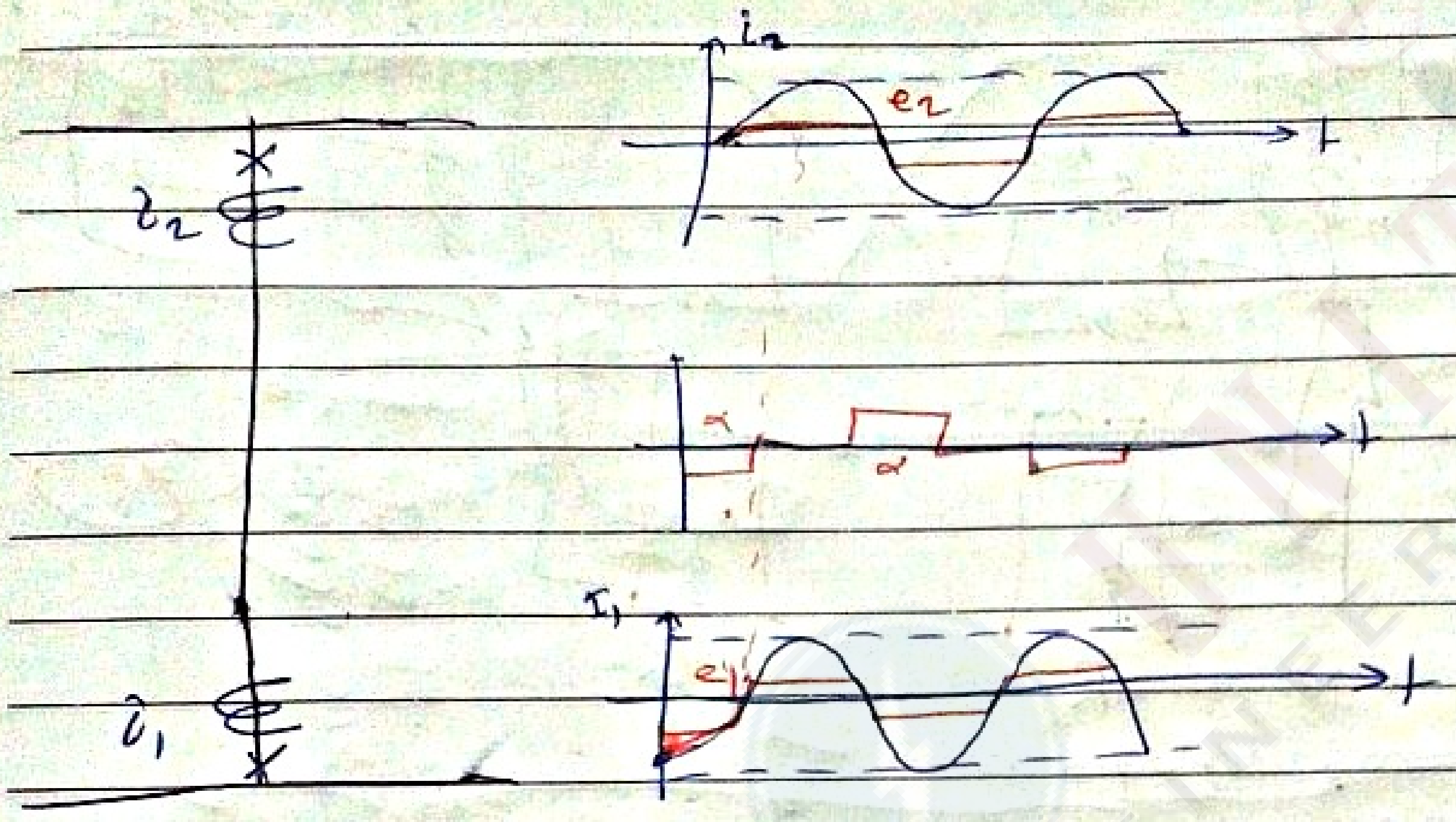


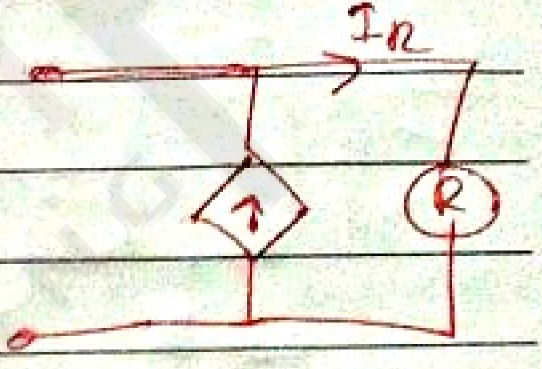
الاثنين 17/3/2014

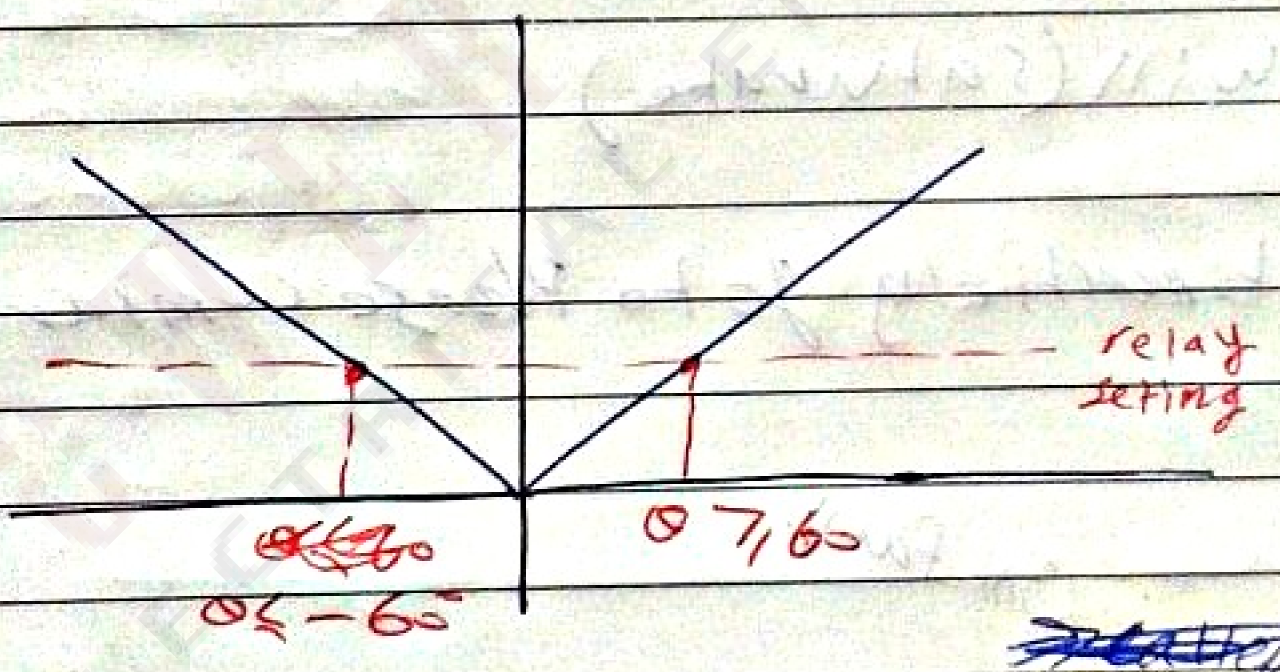


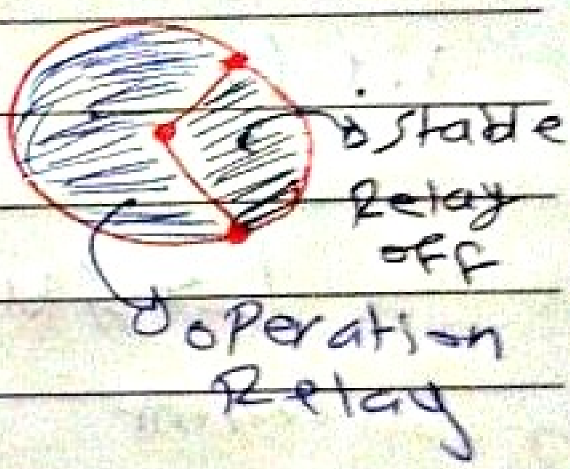
at High s.c currents Phase comparison is preferred

* start as Phasor (Mag. Phase), → Then got = only Phase comparison.





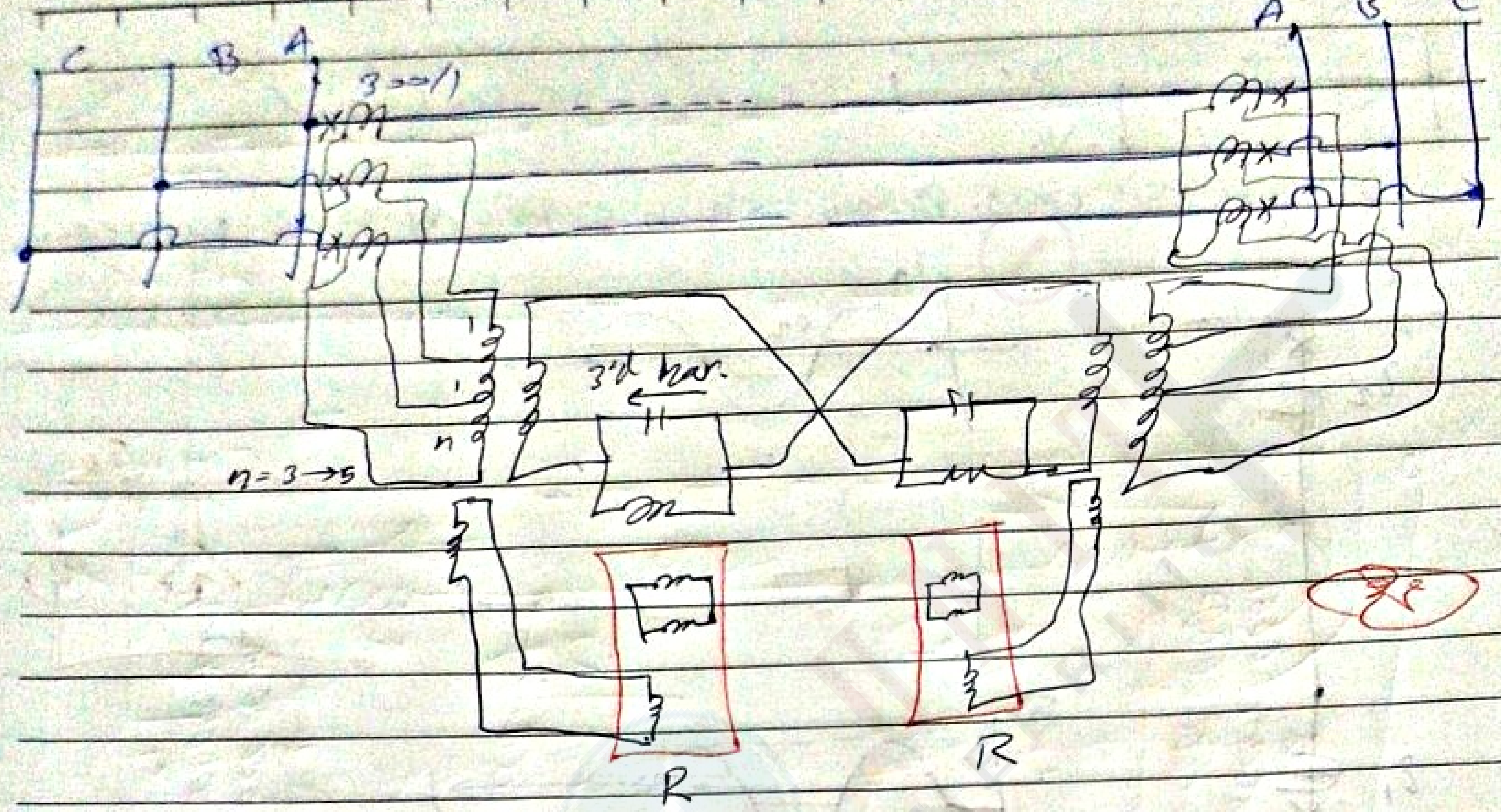




~~[illegible]~~ Phase

⇒ called Phase comperasion.

الاثنين 17/3/2014

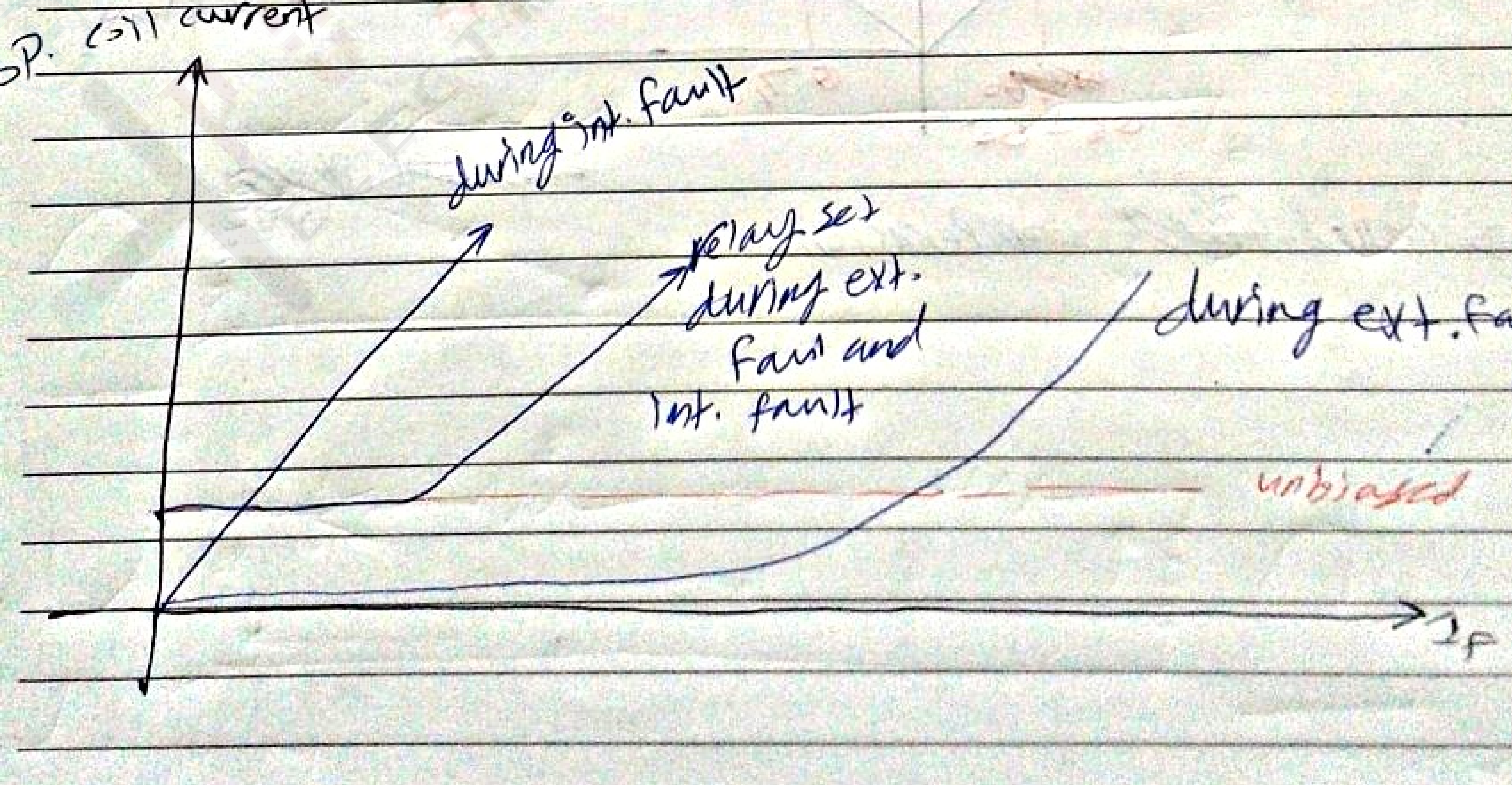


Phasor comparison up-to :-

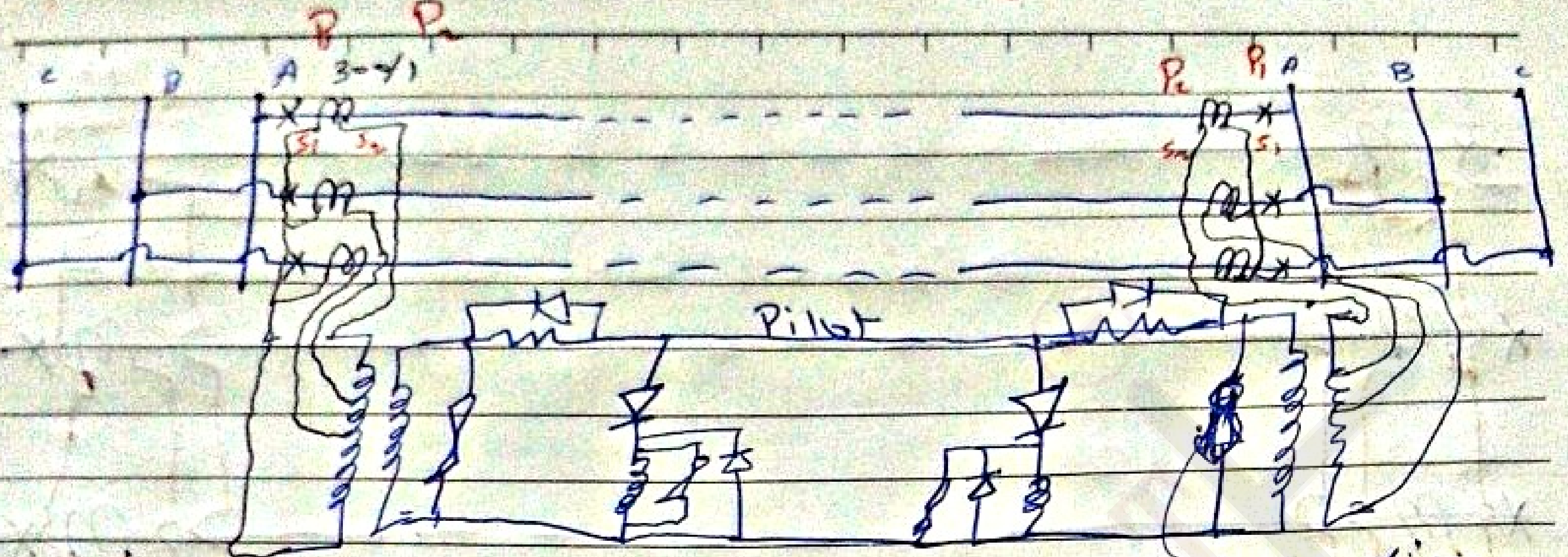
phase A earth fault = 1.5 × 300 ≃ 450A

1.5 (n+2) will (saturate)

→ Automaticly go to Phase comparison



الإثنين 17/3/2014

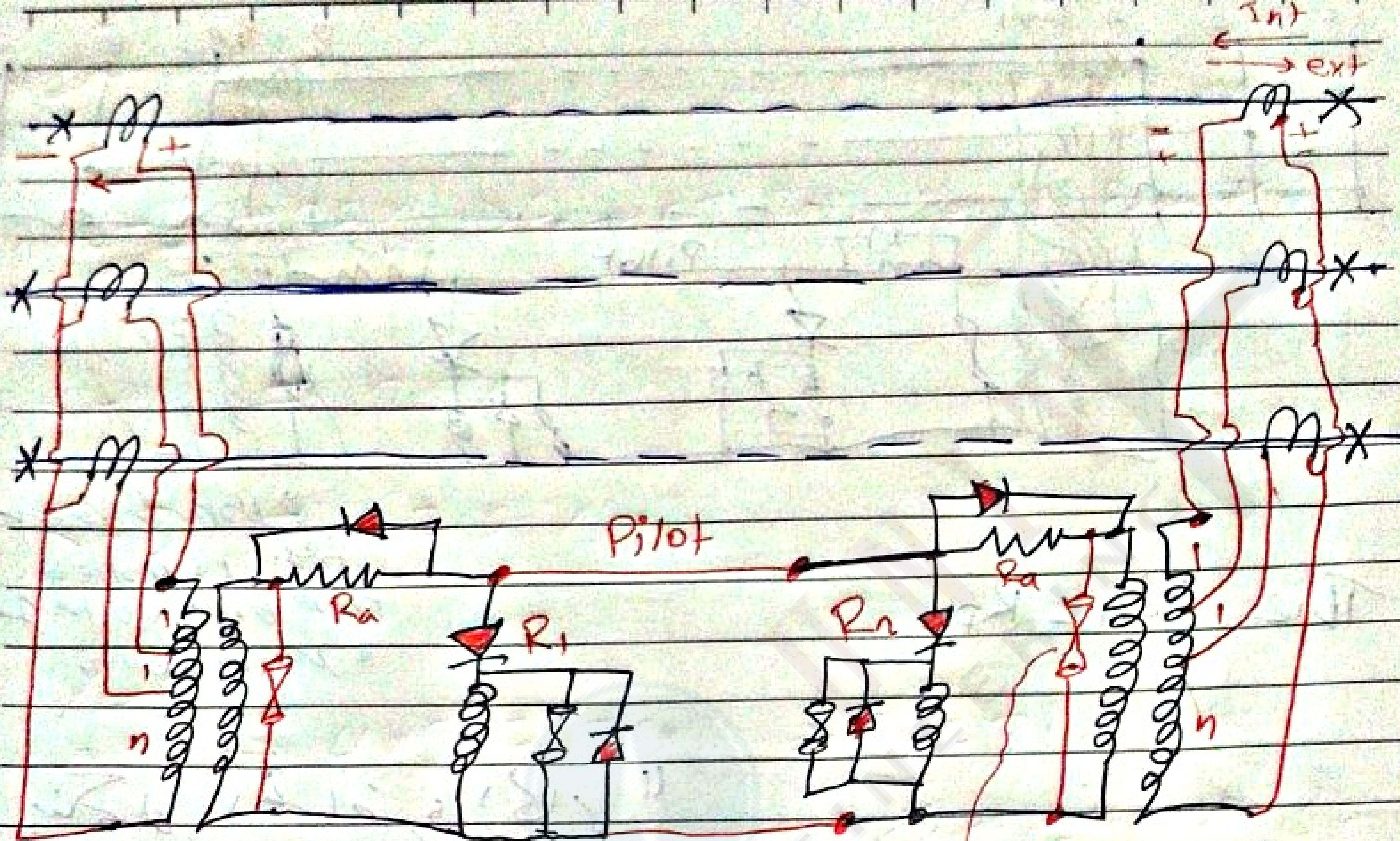


Non-Linear Res. to protect from high voltage « Micro cell »

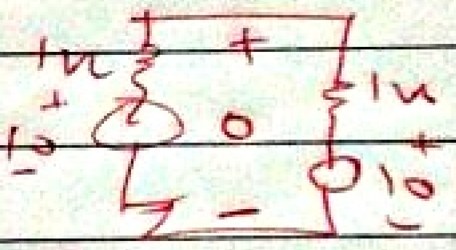
The $R_a = R_p$

"بنكمل المحاضرة الجاية"

الأربعاء 19/3/2014



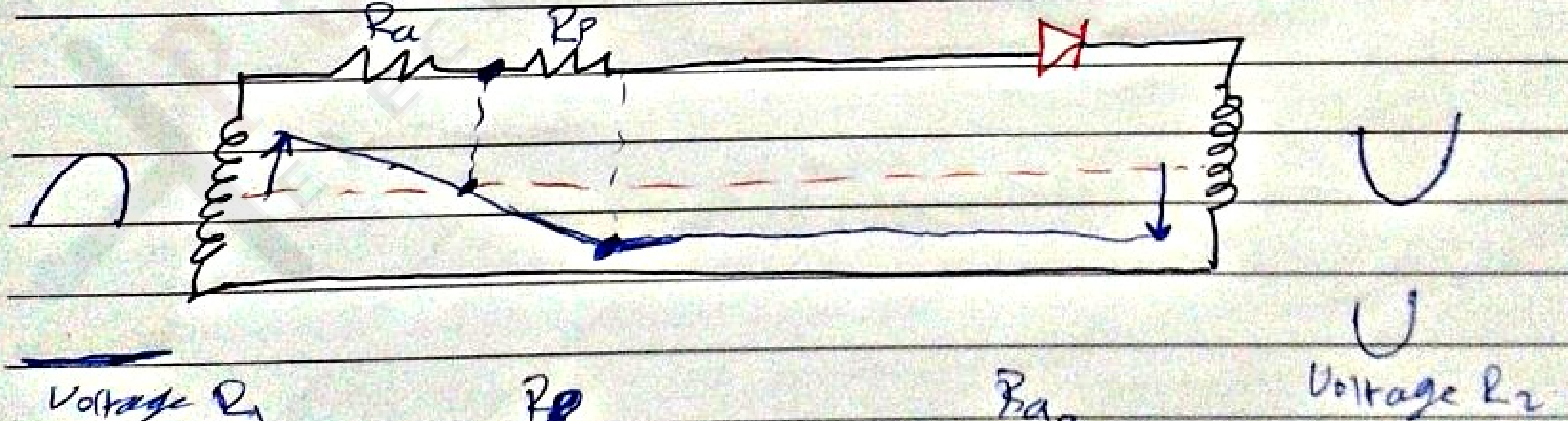
~~non-linear~~ non-linear Resistor to Protect from High Voltage «Micro-cell»

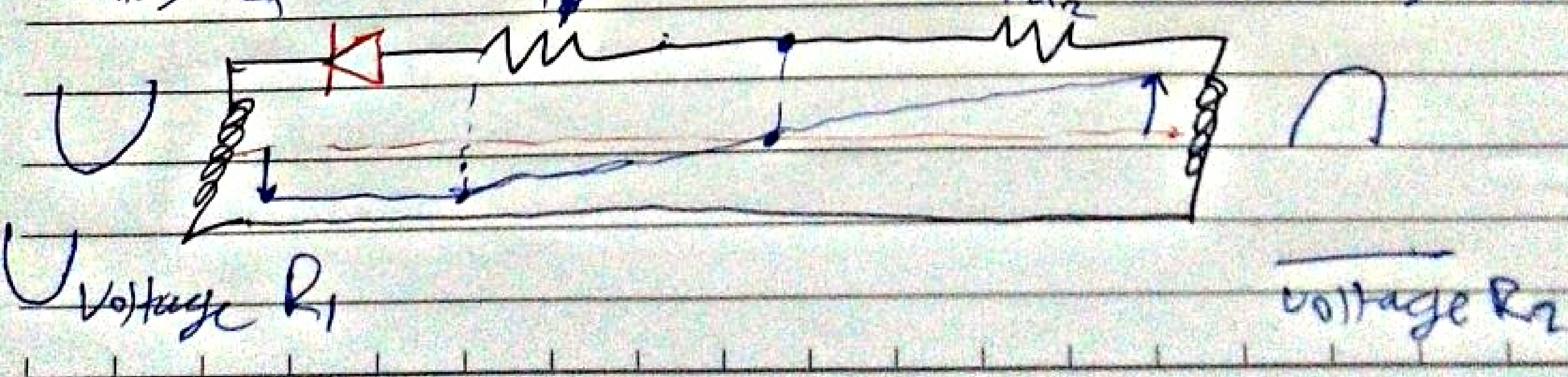


~~* The circuit for~~

* The circuit for Relay:-

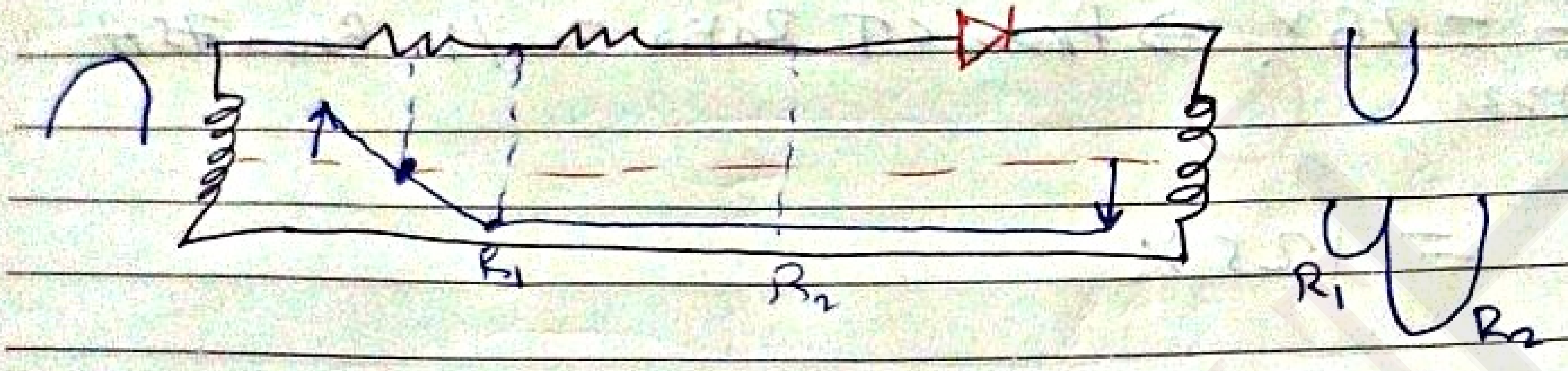
if Ra = Rp

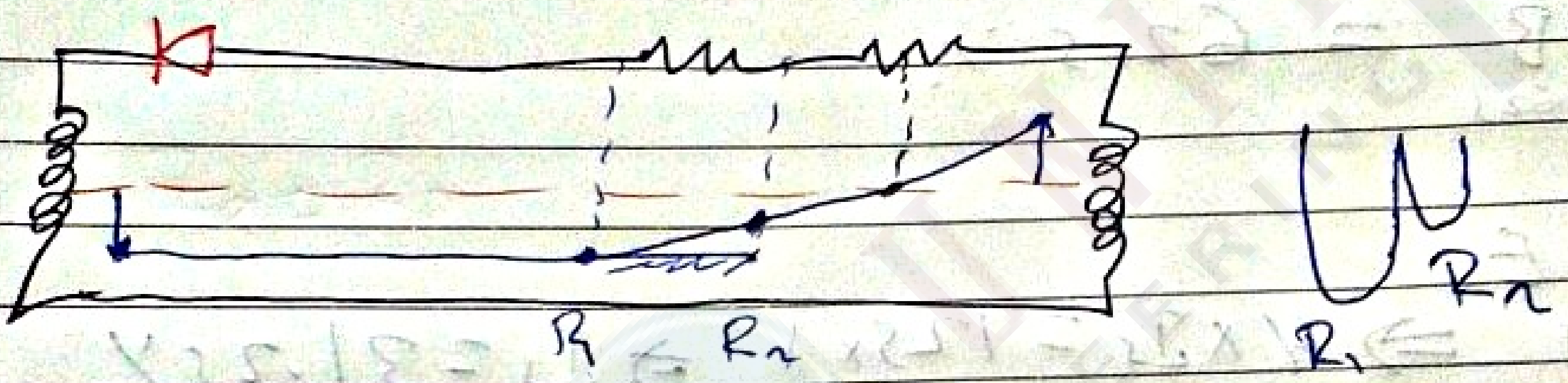




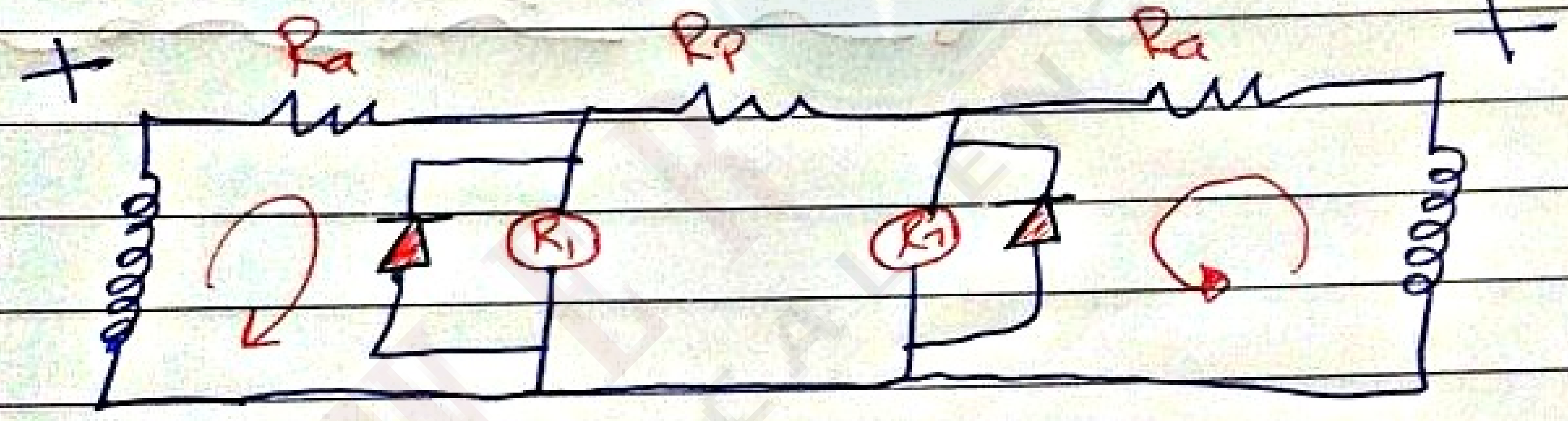
الاربعاء 19/3/2014

⇒ You must to be $\boxed{R_a > R_p}$

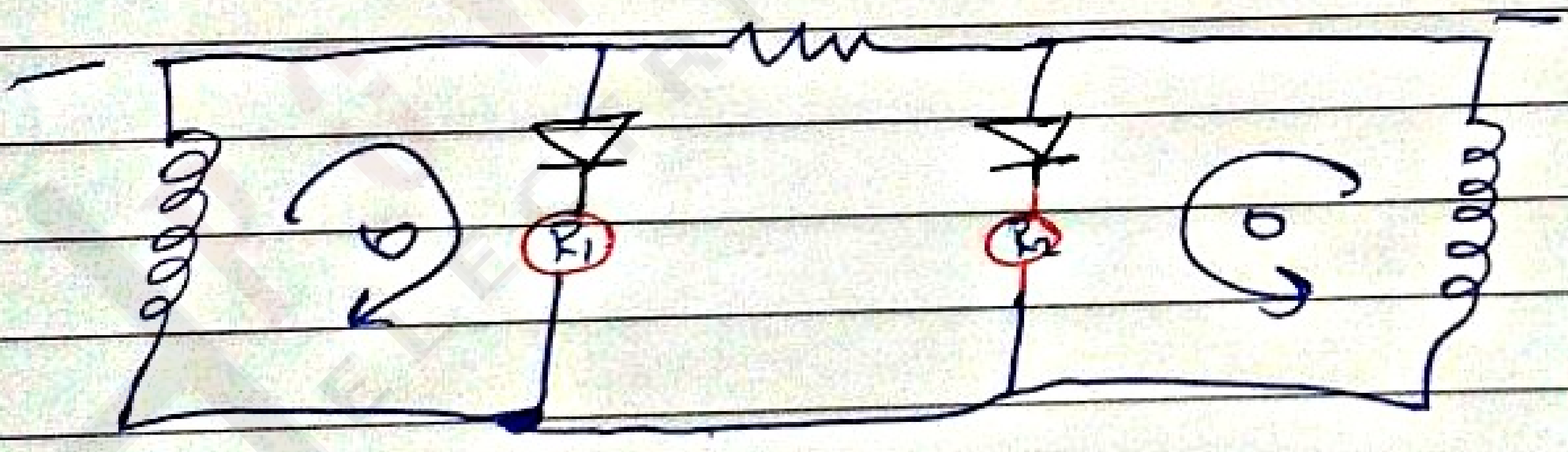




due to Internal fault



$R_1$ and $R_2$ wil be operat



$R_1$ and $R_2$ wil Not operat

شغلنا عطل خطيا

Free welling diode

~~* Setting:~~

~~operating Time 2 cycle at 3 Times setting.~~

~~$\frac{R-E}{(n+2)*0.15}$ = 2.5% → from CT ratio 800/1 from 75A~~

~~$\frac{R-B}{2*0.15}$ = 62.5%~~

*** Setting :-**

operating time 3-cycle at 3 Times setting

* R - E = 25 % ⇒ from CT Ratio 300/1 from 75 A
$(n+2)\,0,25$

* R - Y = 125 %
$1 \times 1,25$

* R - B = 62,5 %
$2 \times 0,625$

* Y - E
$(n+1) \Rightarrow 4 \times I_s = 125 \times 1 \Rightarrow I_s = 31,25\,\%$

إلى هنا الفيرست

# Power II

# NoteBook

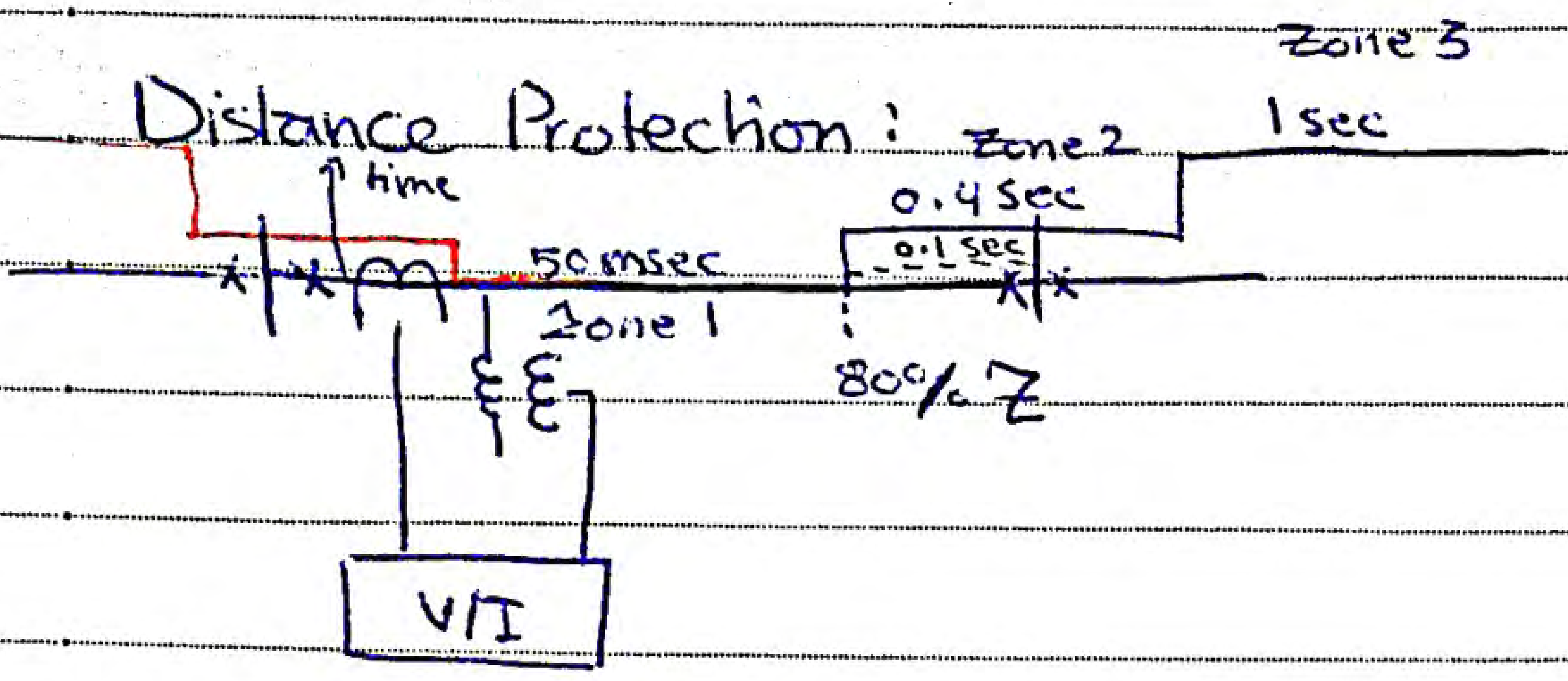
19/3/2014-23/4/2014

POWER UNIT
ELECTRICAL ENGINEERING

Lec # 10

wednesday
19/3/2014

## Distance Protection :



> 10 - 20 miles

Distance Relay

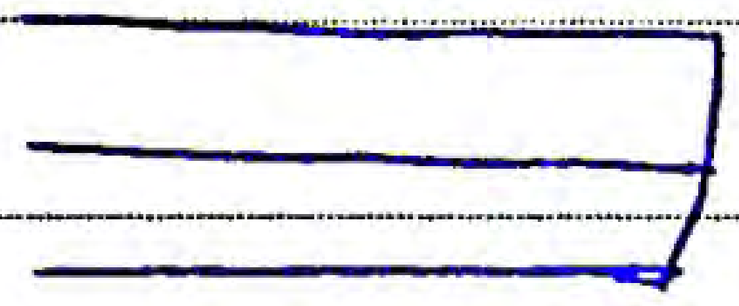
$Z_1$ ⇒ our refrence. the Relay will measure $Z_1$

$Z_2$

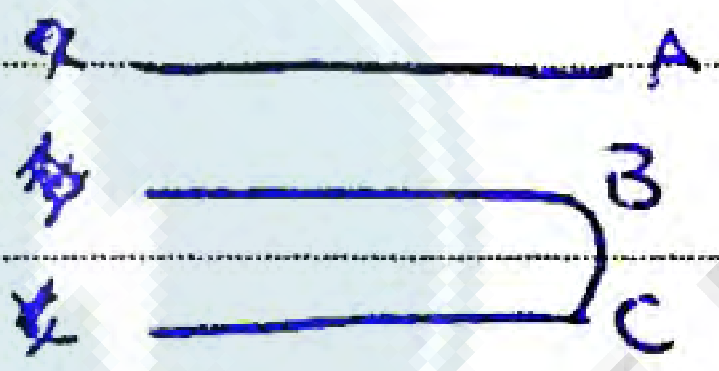
$Z_0$

3φ fault

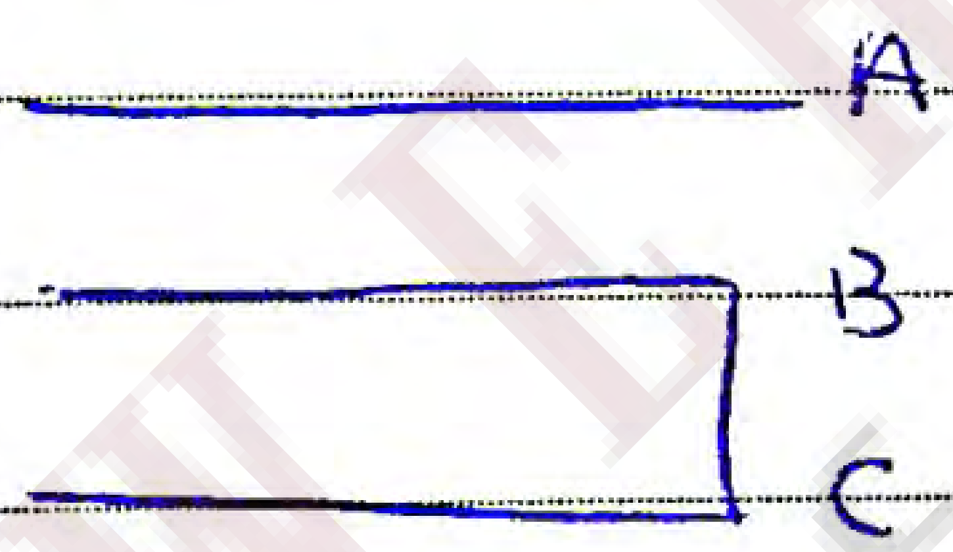
$V_{an}/I_a$

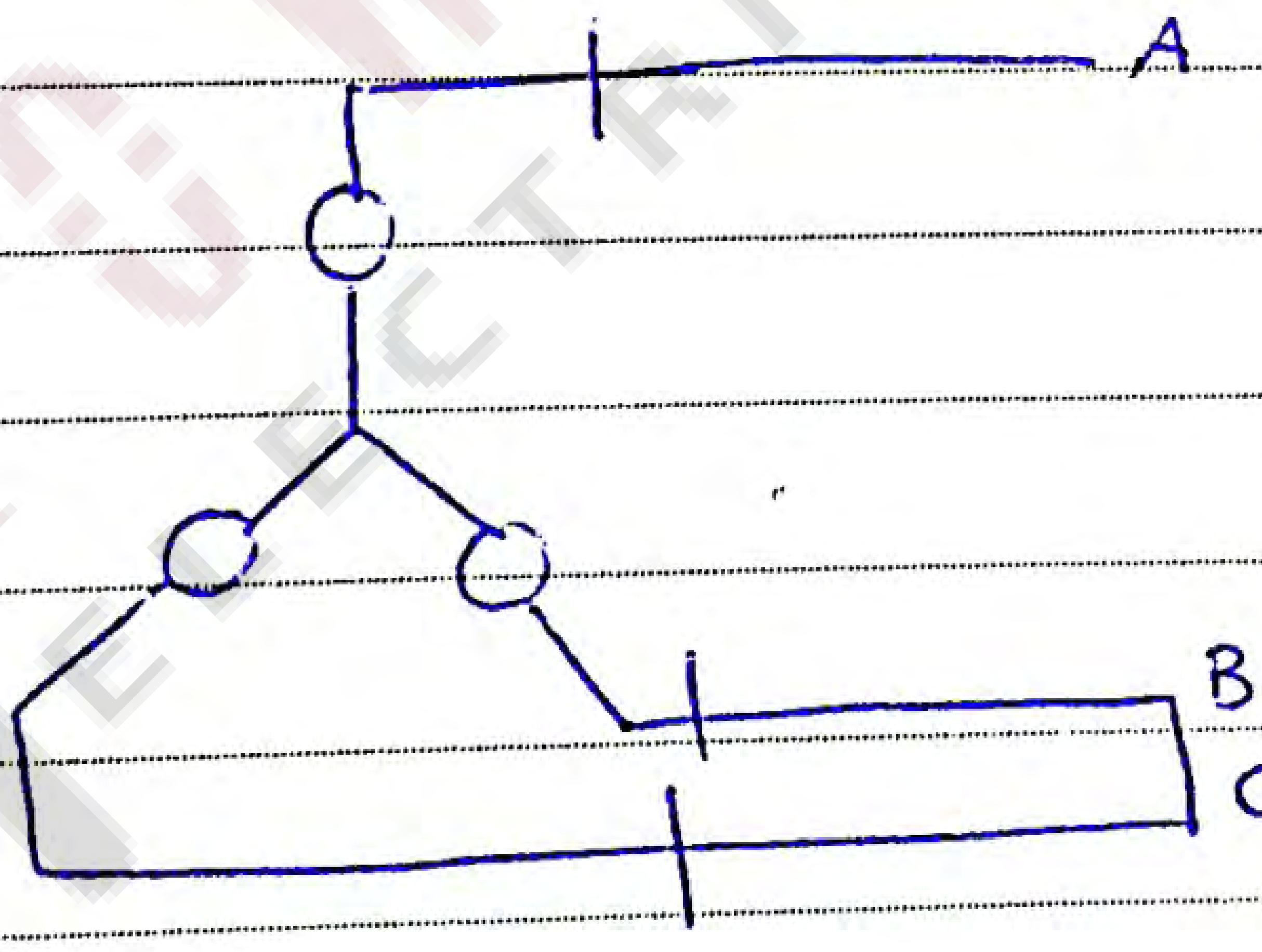


φ-φ fault

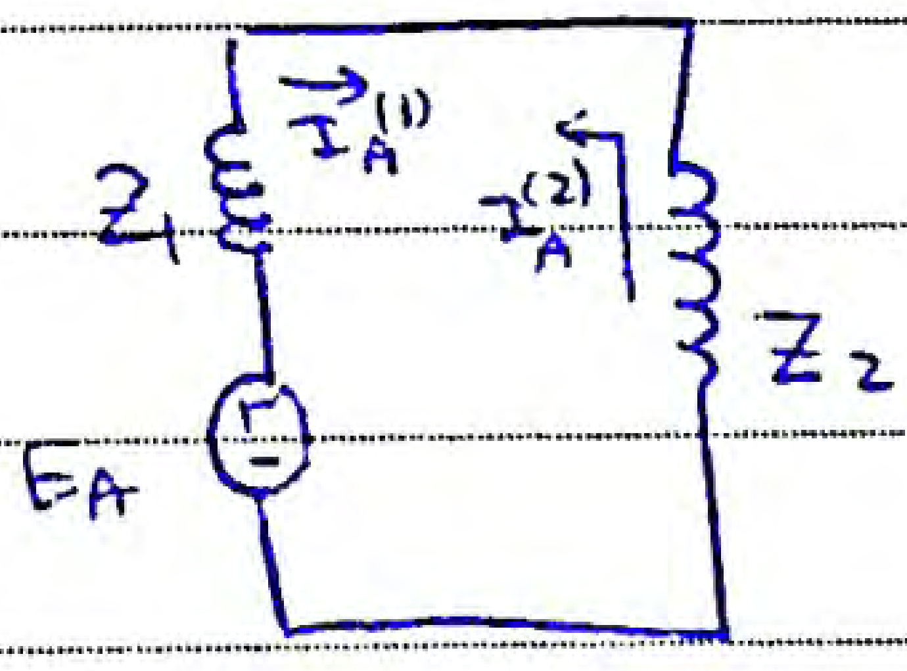


Phase - Phase fault :





+ve and -ve sequence.



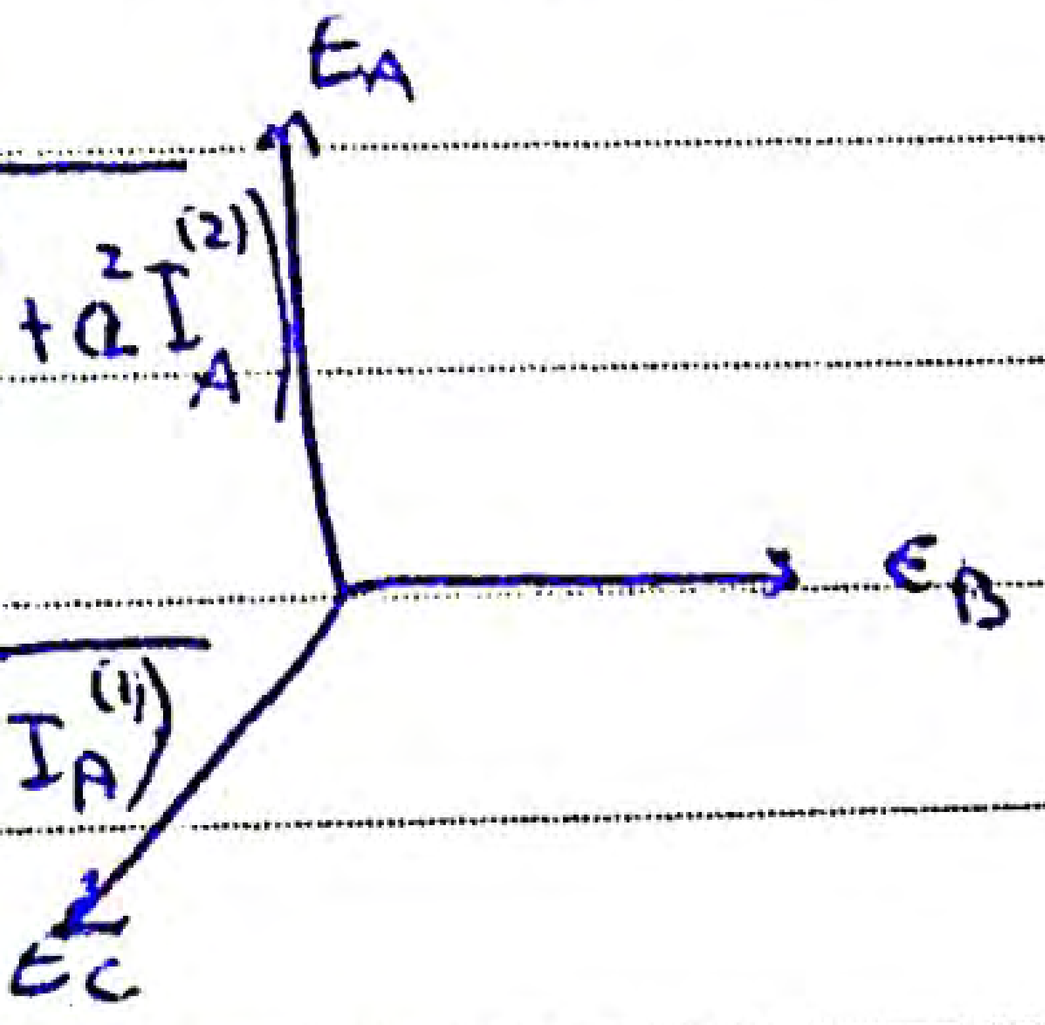
$$I_A^{(1)} = \frac{E_A}{Z_1 + Z_2}$$

$I_A^{(2)} = -I_A^{(1)}$ , $I_A^{(0)} = 0$

$$\frac{E_B - E_C}{I_B - I_C} = \frac{a^2 E_A - a E_A}{a^2 I_A^{(1)} + a I_A^{(2)} - (a I_A^{(1)} + a^2 I_A^{(2)})}$$

$$= \frac{a^2 E_A - a E_A}{a^2(I_A^{(1)} - I_A^{(2)}) + a(I_A^{(2)} - I_A^{(1)})}$$

$$= \frac{a^2 E_A - a E_A}{(a^2 - a)(\underbrace{I_A^{(1)} - I_A^{(2)}}_{2 I_A^{(1)}})}$$



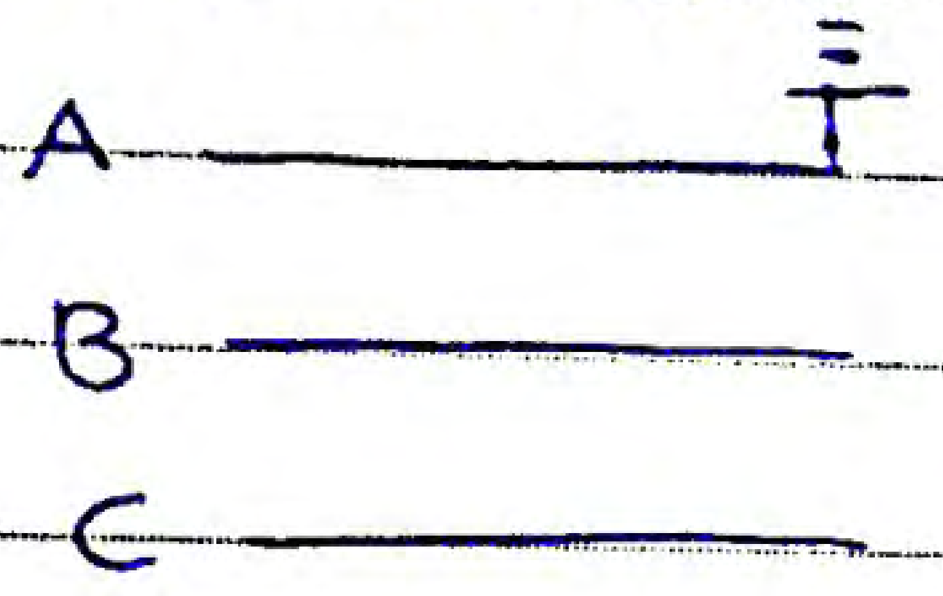
lec # 10

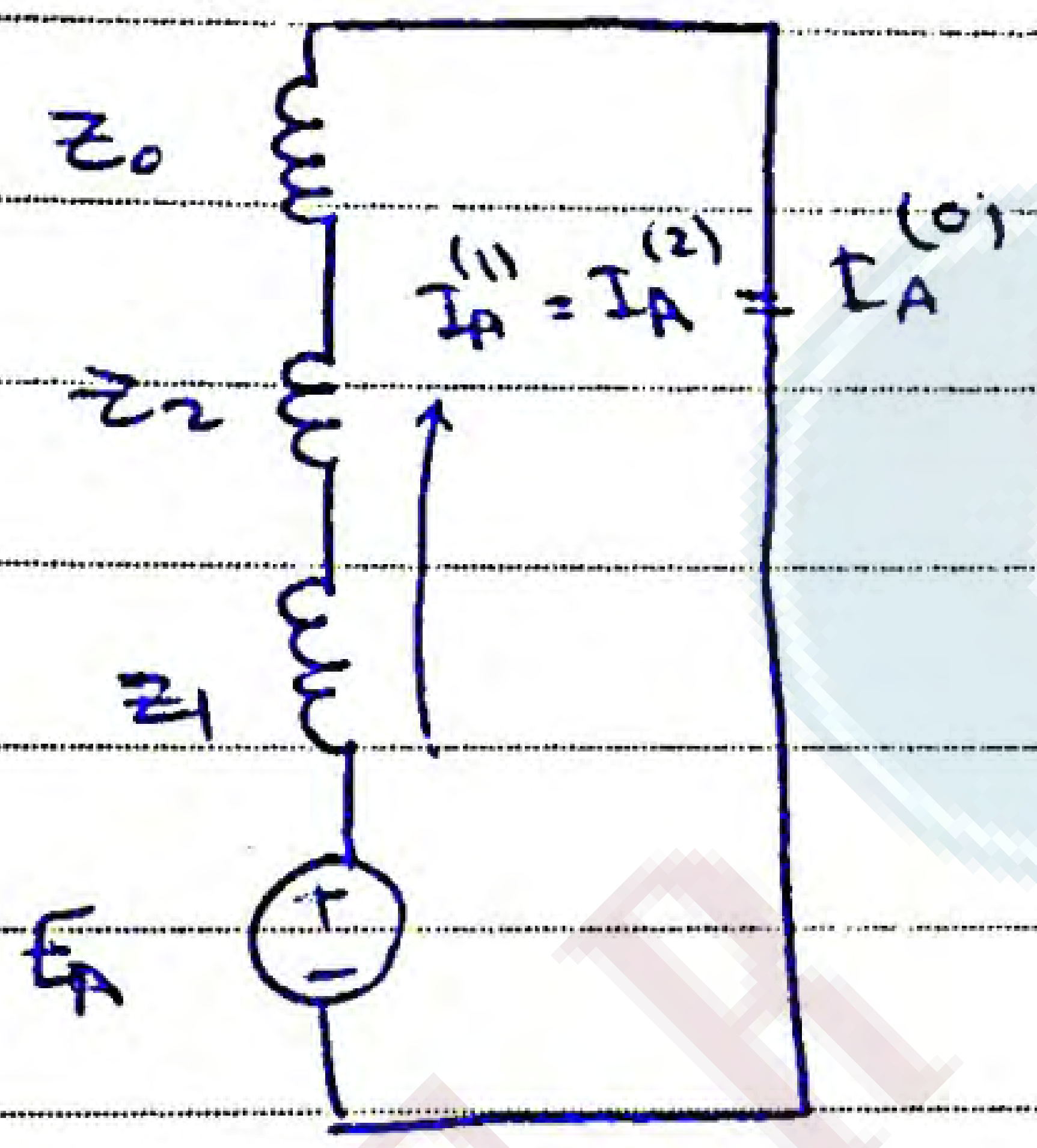
Wednesday
19/3/2014

$$2I_A^{(1)} = \frac{2\ E_A}{Z_1 + Z_2} = \frac{E_A}{Z_1}$$

$$\frac{E_B - E_C}{I_B - I_C} = \frac{(a^2-a)E_A}{(a^2-a)\ E_A/Z_1} = Z_1$$

Phase - Earth fault





$$E_A = I_A^{(1)} Z_1 + I_A^{(2)} Z_2 + I_A^{(c)} Z_c$$

$$E_A = I_A^{(1)} Z_1 + I_A^{(2)} Z_2 + I_A^{(0)} Z_c$$

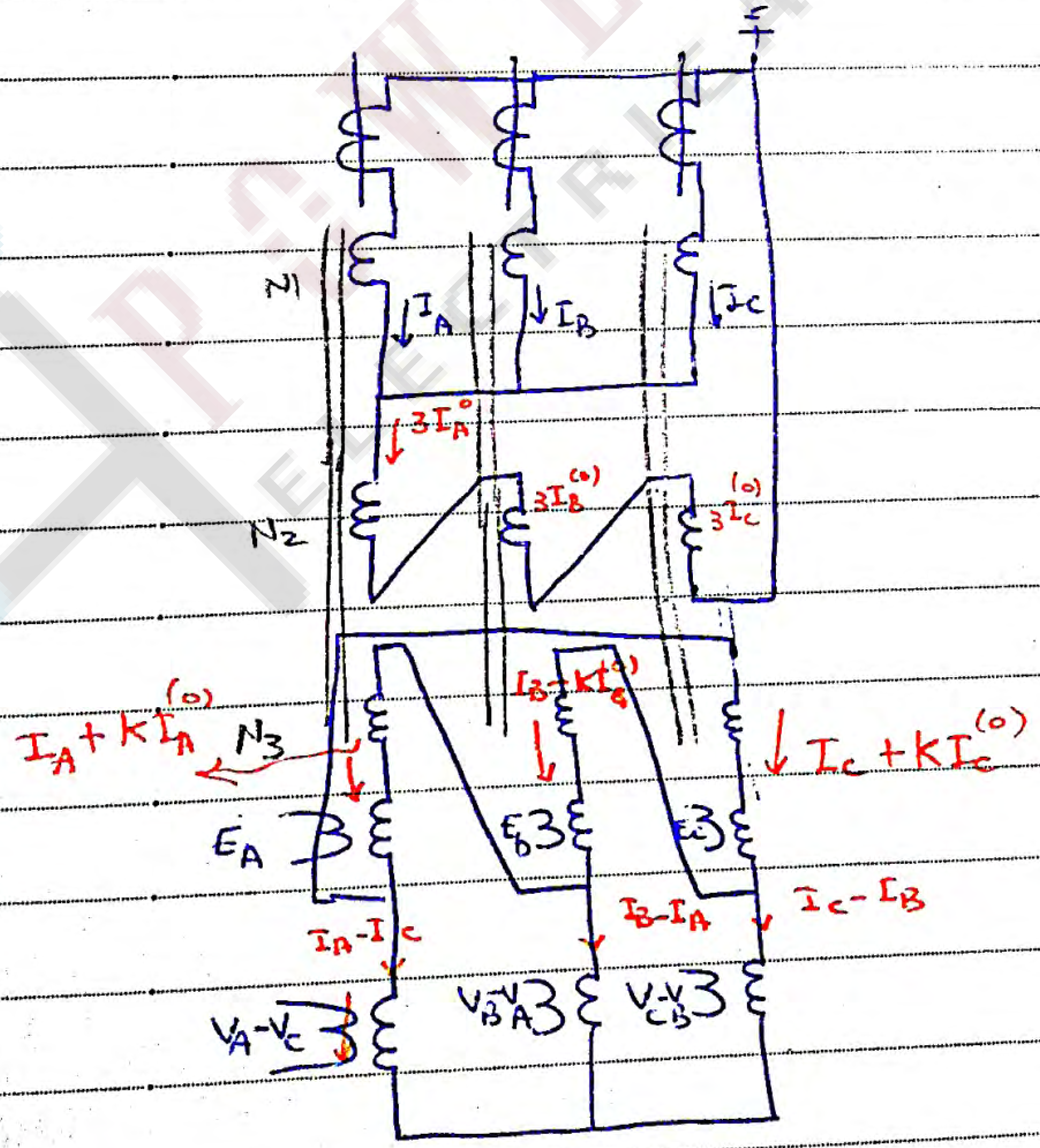
$$E_A = \left(I_A^{(1)} + I_A^{(2)}\right) Z_1 + I_A^{(0)} Z_c$$

$$E_A = \left(I_A - I_A^{(0)}\right) Z_1 + I_A^{(0)} Z_0$$

$$E_A = \left[\left(I_A\right) + \left(I_A^{(0)}\right)\left(\frac{Z_0 - Z_1}{Z_1}\right)\right] Z_1$$

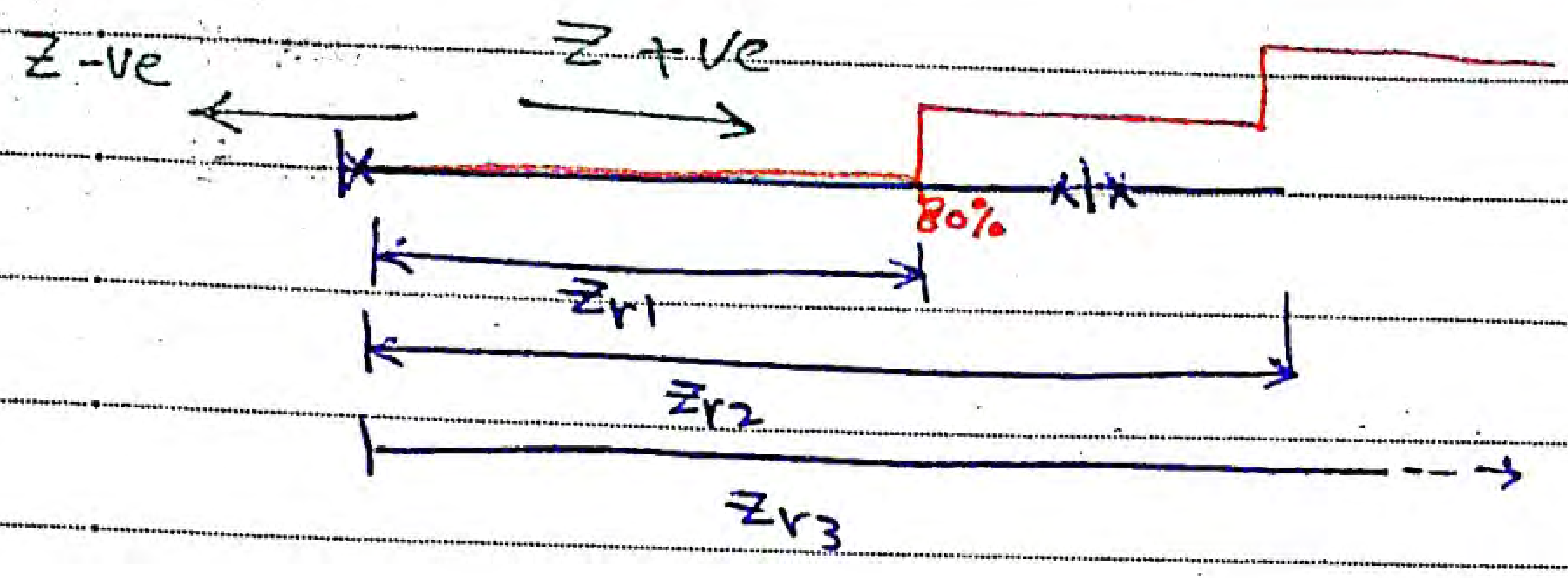
$$Z_1 = \frac{E_A}{I_A + I_A^{(0)} \frac{Z_0 - Z_1}{Z_1}} \begin{array}{l} \Rightarrow V \\ \Rightarrow I \end{array}$$

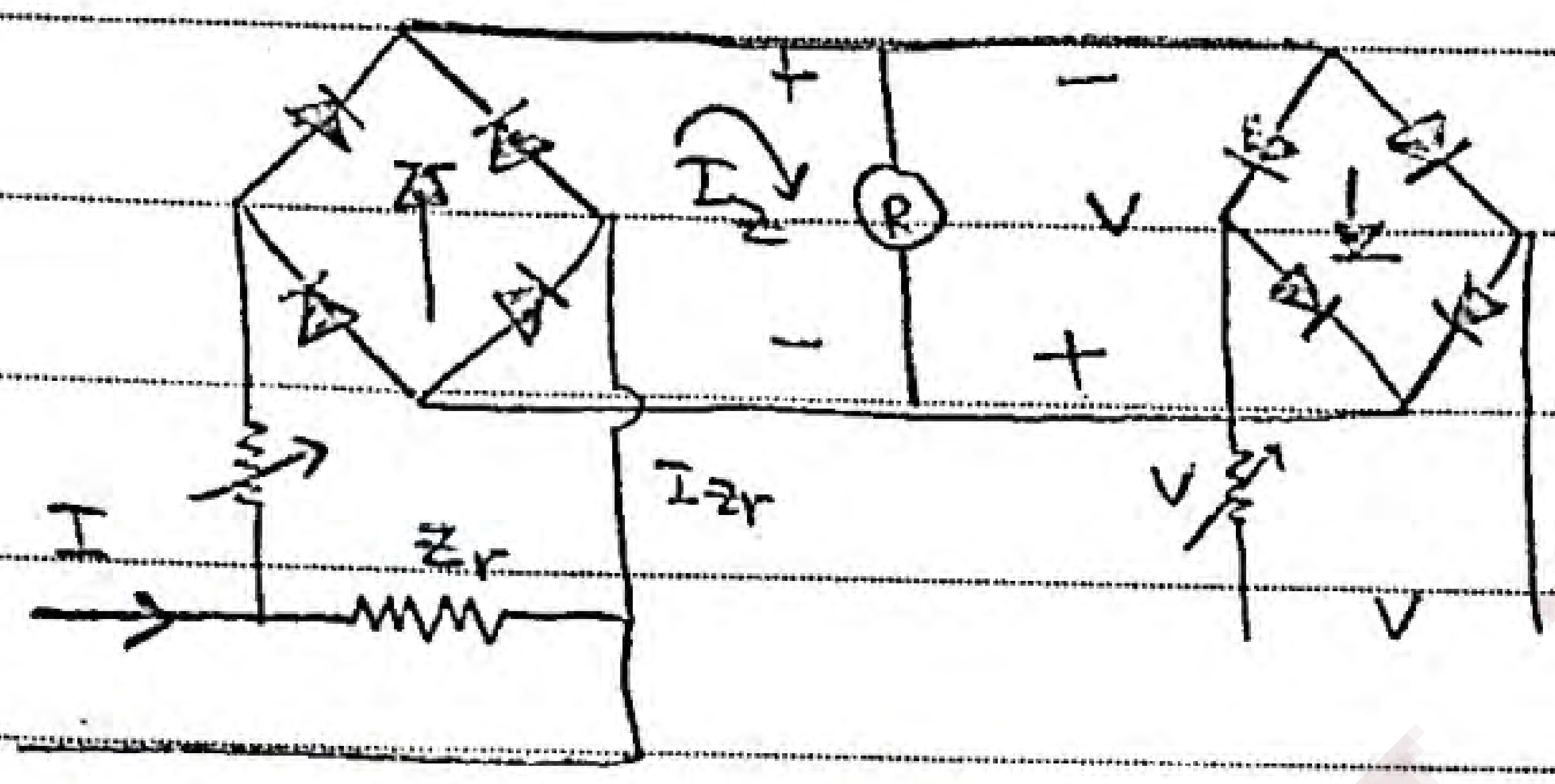
$$I_A^{(0)} = \frac{1}{3}\left(I_A + I_B + I_C\right)$$



lec # 11

24/3/2014
Monday





Type of distance Relays:

1. Directional Relay

$|V + IZ_r|$ operation

$|V + IZ_r|$ operation

$|V - IZ_r|$ restraining

Amplitude comparison:

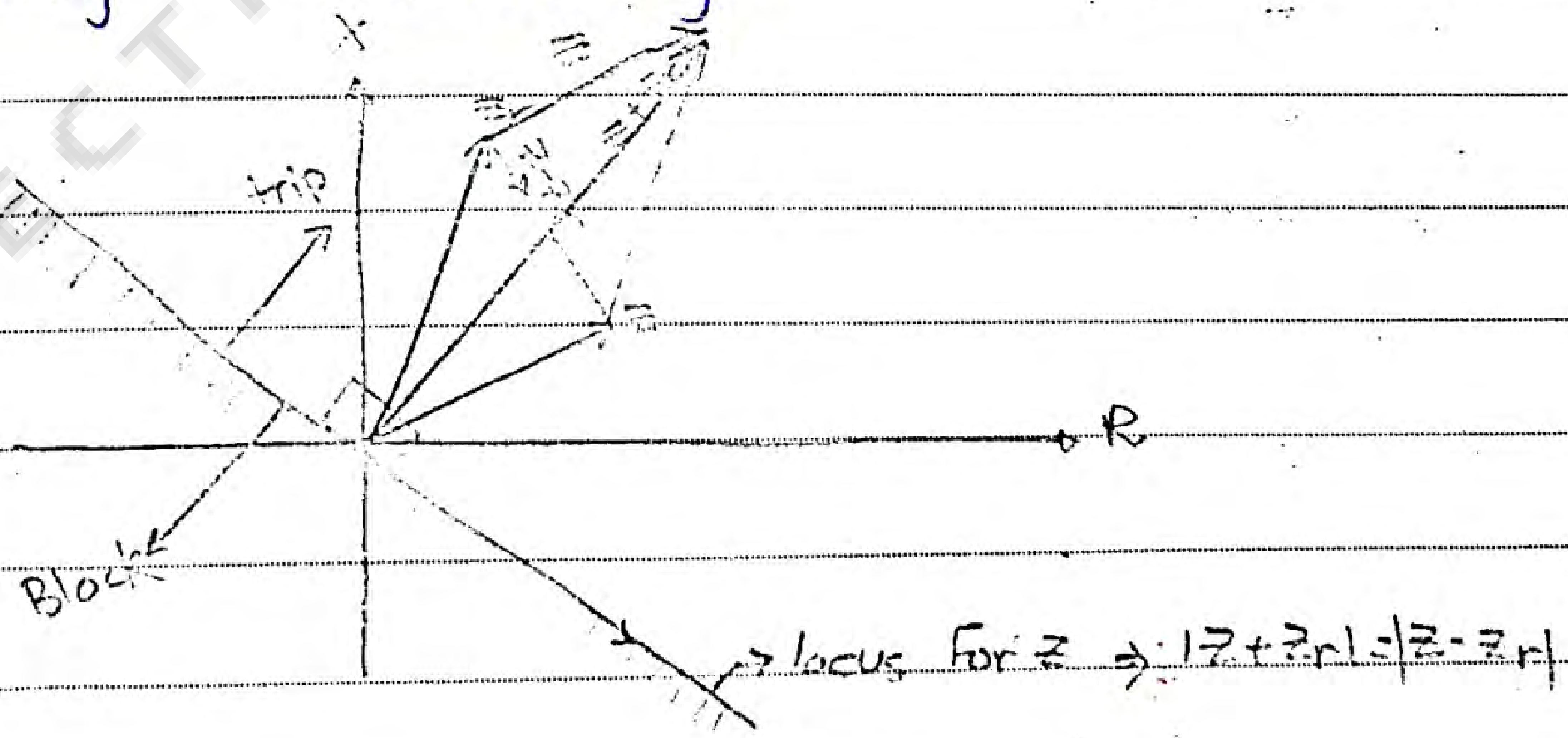
$|V + IZ_r| \longrightarrow |V - IZ_r|$

$\div I$

$Z_r \angle 90° - 60°$

$|Z + Z_r| \longrightarrow |Z - Z_r|$

operating restraining



2. Impedance Relay or called ohm Relay

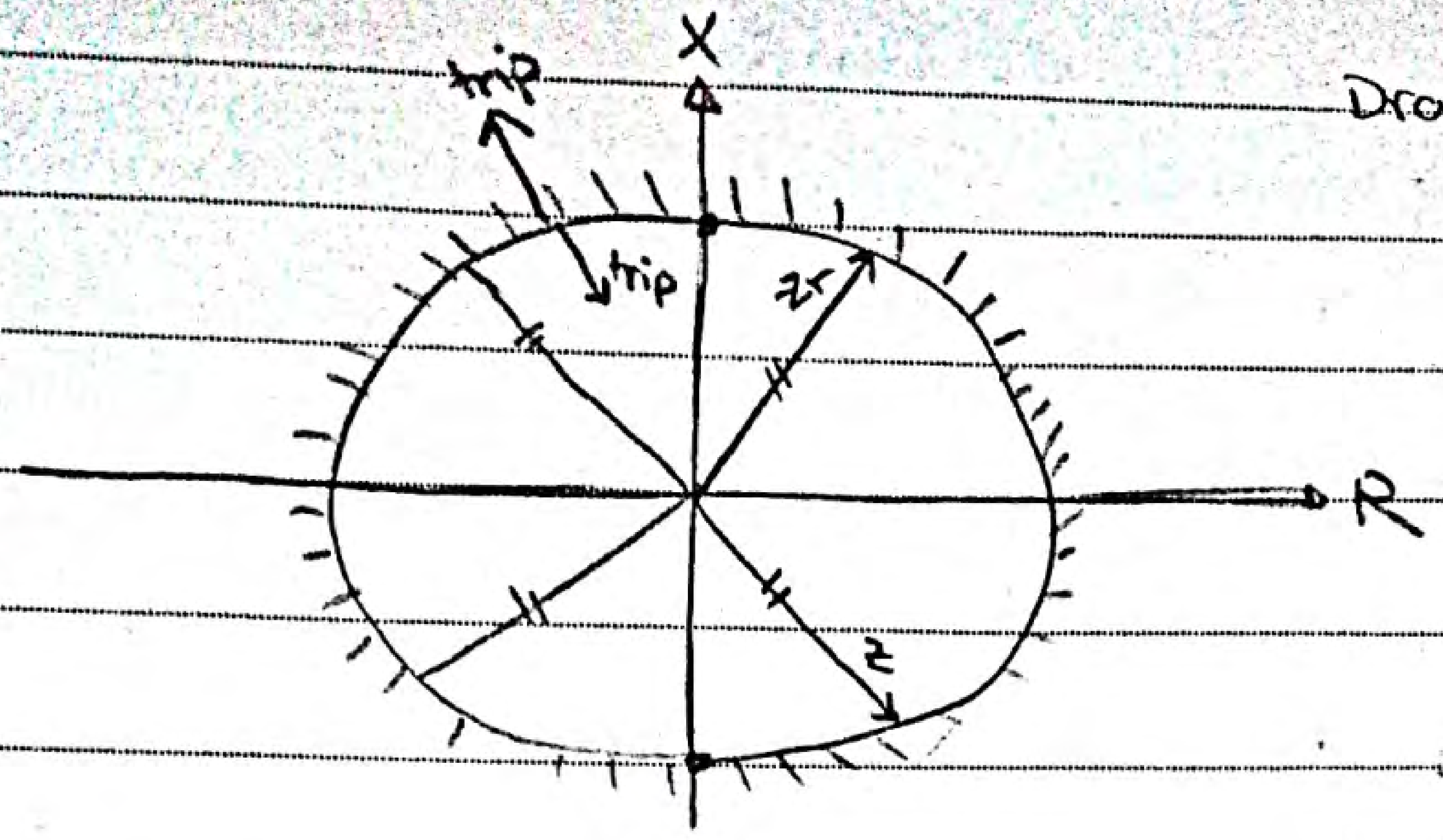
$|IZ_r| \longrightarrow |V|$

op. restraining

$\div I$

$|Z_r| \longrightarrow |Z|$

24/3/2014



DrawBacks : Non-directional relay
it will see Zr in all direction.

## 3. Reactance Relay

$$|\underbrace{2IZ_r - 2IR_r}_{2IX_R} - V| \longrightarrow |V|$$

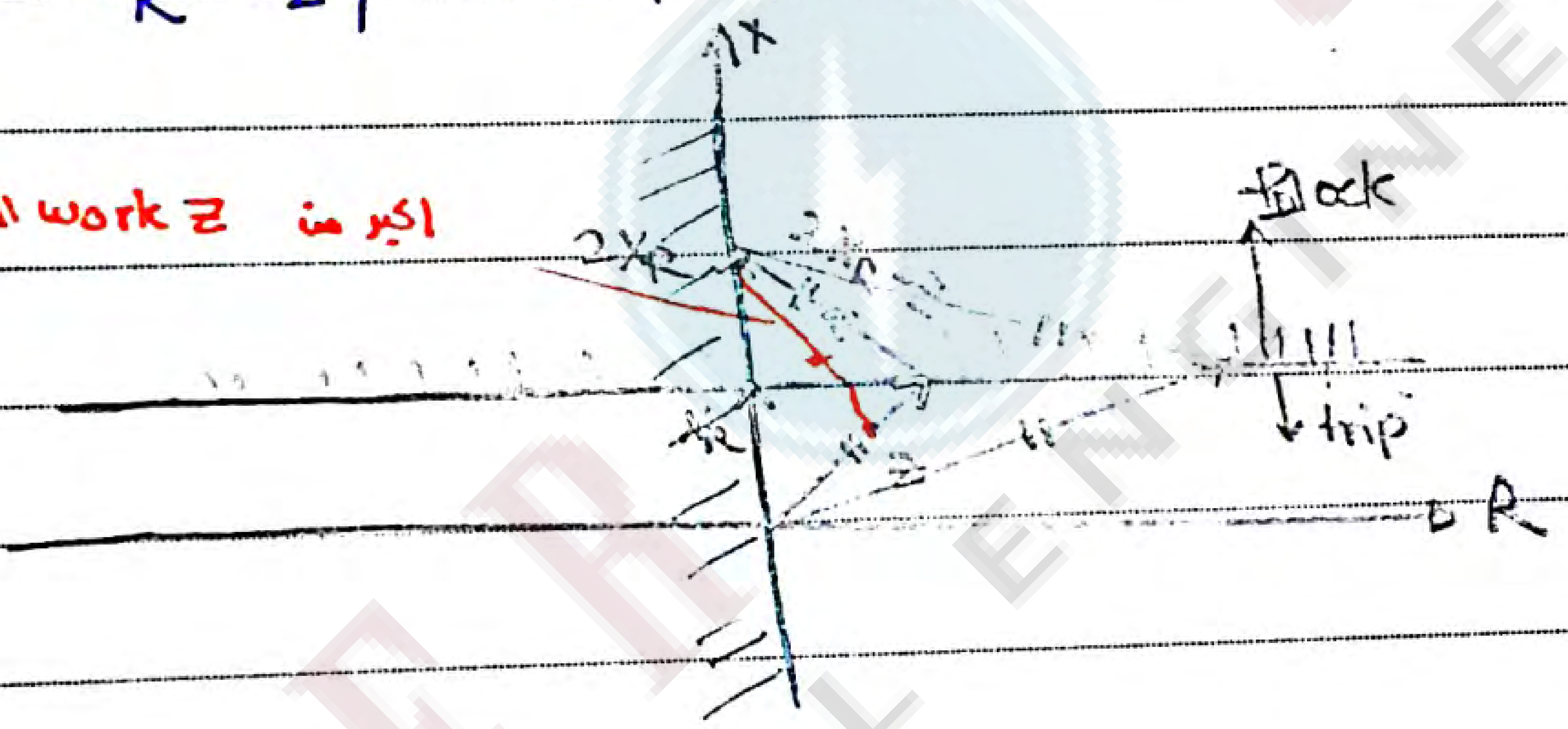
op. restraining

÷ I

$$|2X_R - Z| \longrightarrow |Z|$$

DrawBacks:
not directional relay
to make relay directional)
Adv. : not sensitive for $R_{arc}$

will work Z اكبر من



$\frac{V}{I} = Z + R_{arc}$

## 4. mho Relay

$$|IZ_r| \longrightarrow |2V - IZ_r|$$

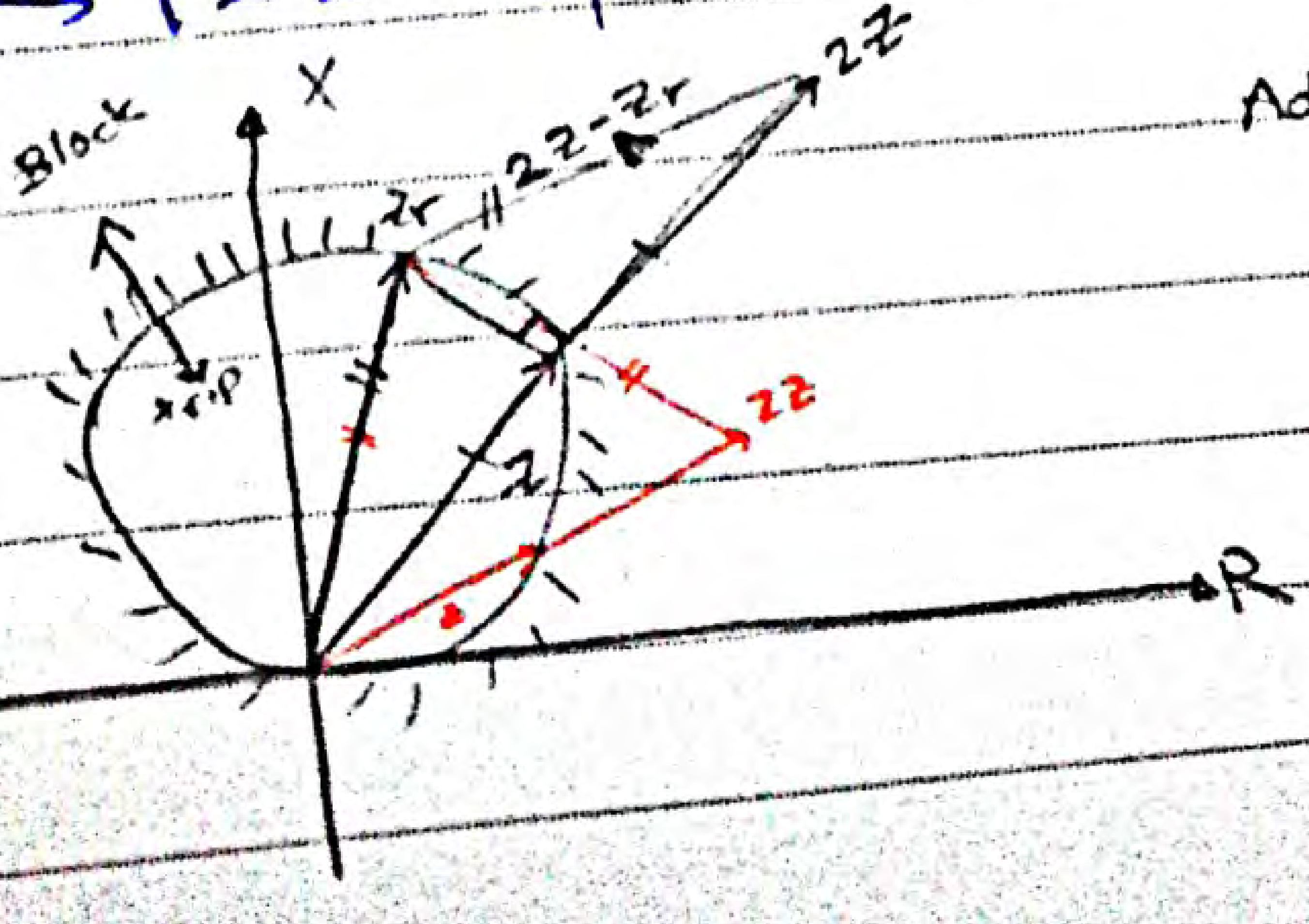
operating restraining

÷ I

$$|Z_r| \longrightarrow |2Z - Z_r|$$

Z-phone

Adv → directional



Y-Plane: $Y = G + jB$

$|IZ_r| \rightarrow |2V - IZ_r|$

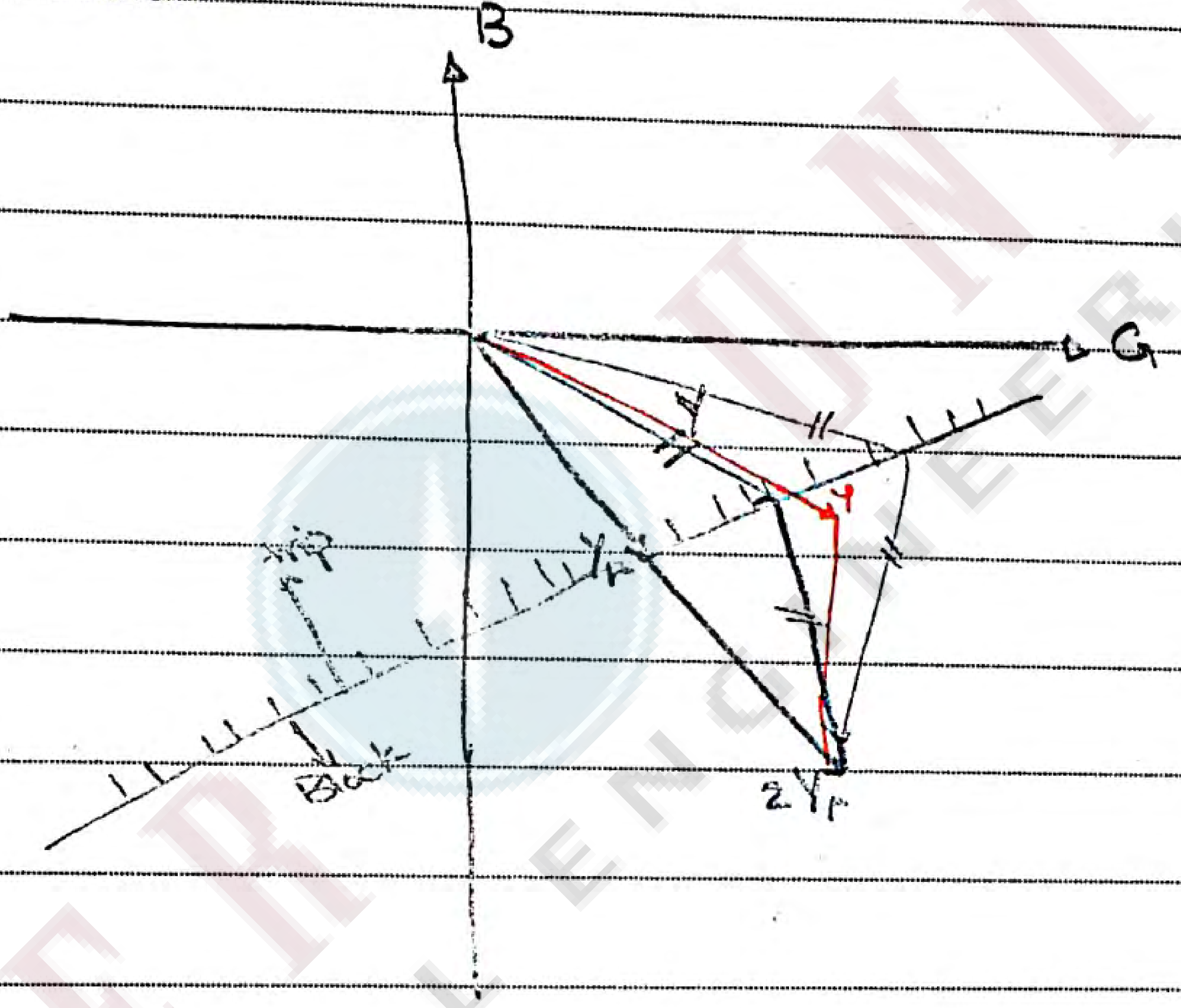
$\div Z_r$

$|YV| \rightarrow |2VY_r - YV|$

$\div V$

$|Y| \rightarrow |2Y_r - Y|$

op. resh.

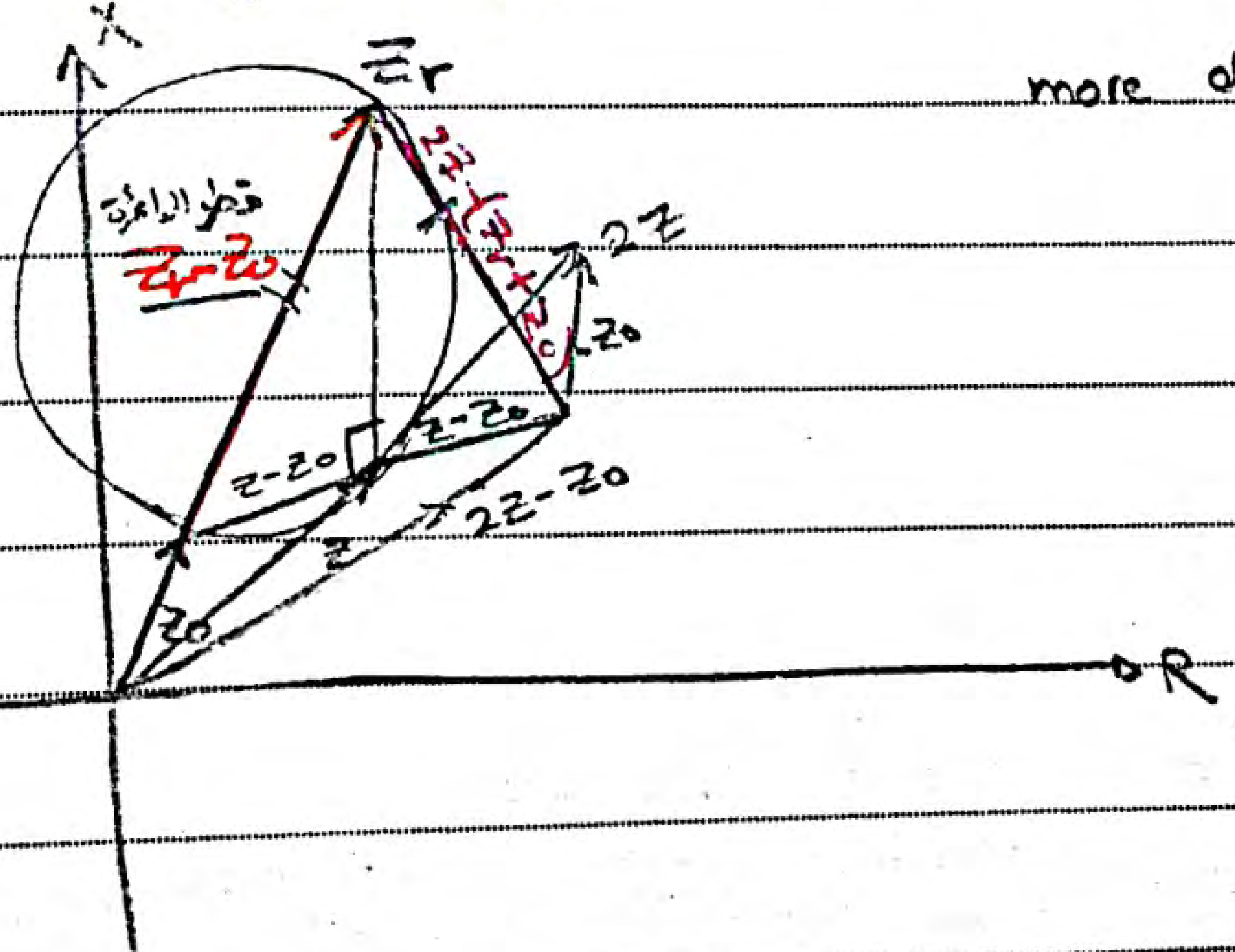


5. Off-set Mho Relay

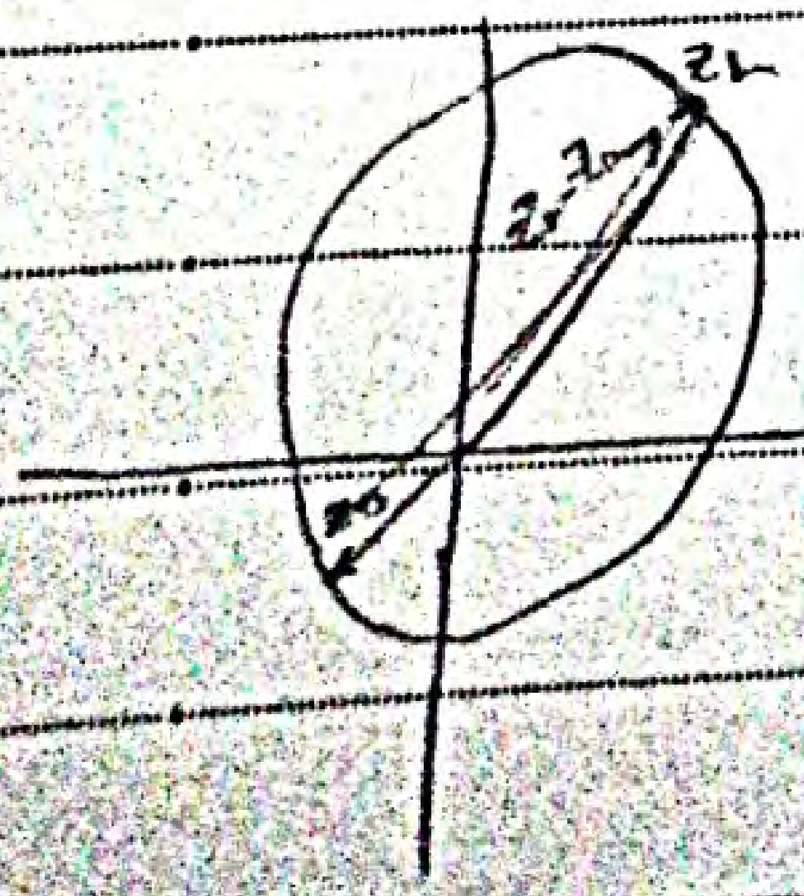
$|I(Z_r - Z_0)| \rightarrow |2V - I(Z_r + Z_0)|$

$\div I$

$|Z_r - Z_0| \longrightarrow |2Z - (Z_r + Z_0)|$



more directional



lec # 11

Monday

24/3/2014

Zone 1

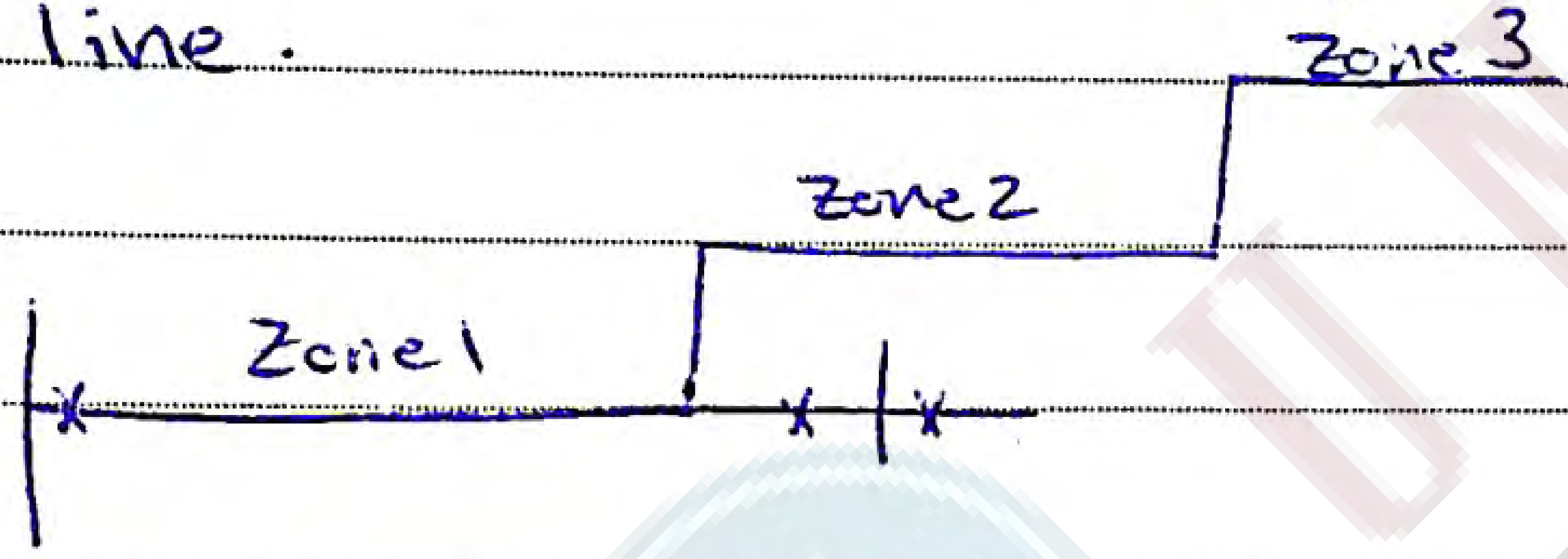
$Z_{r1}$ → Stage 1 extends to 80% of protected line

$Z_r$ → Zone 2

protected line +50% of the seconed shortest line

$Z_r$ → Zone 3

protected line + 2nd longest line + 25% of 3rd longest line.

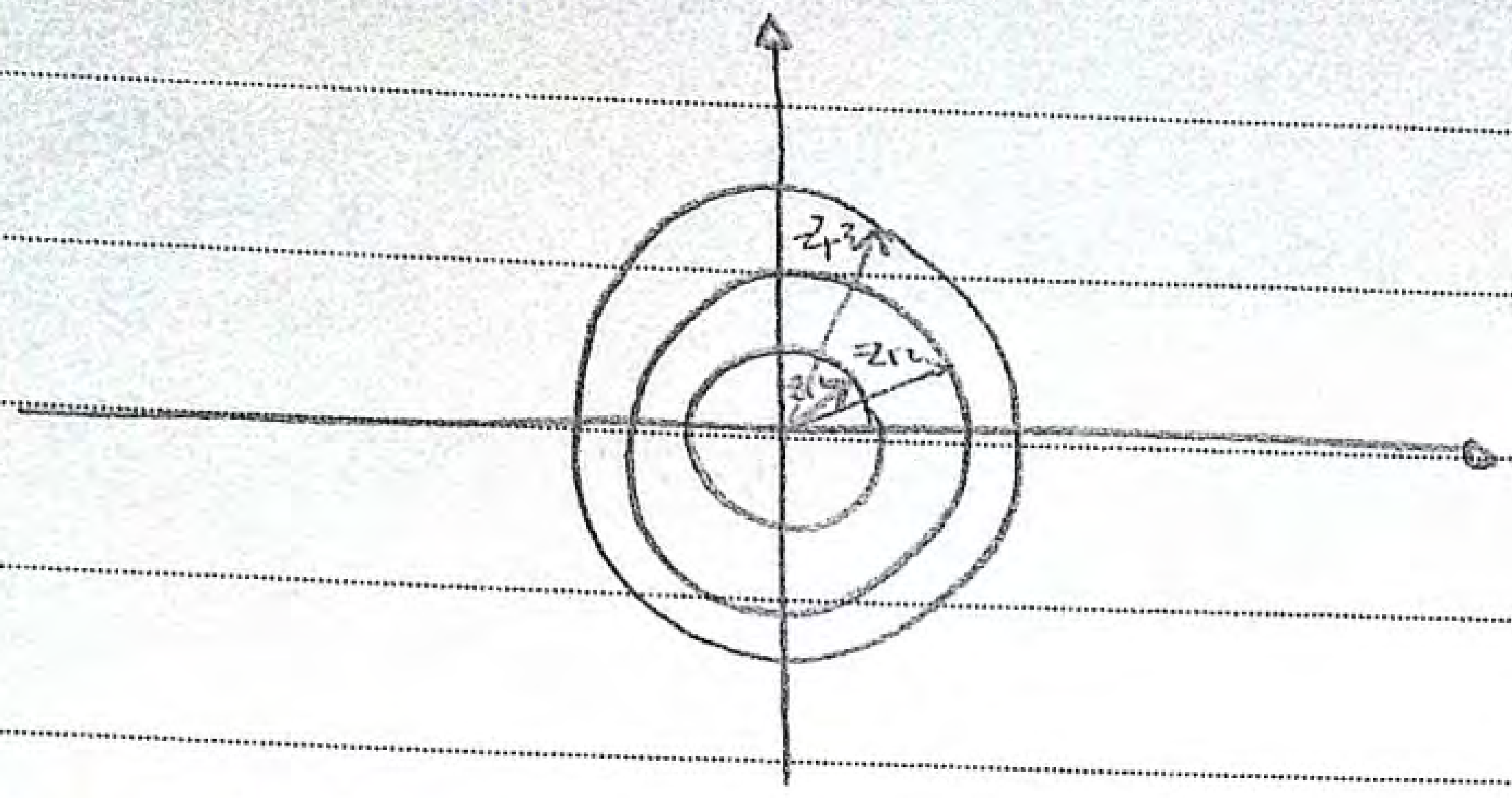


lec # 12

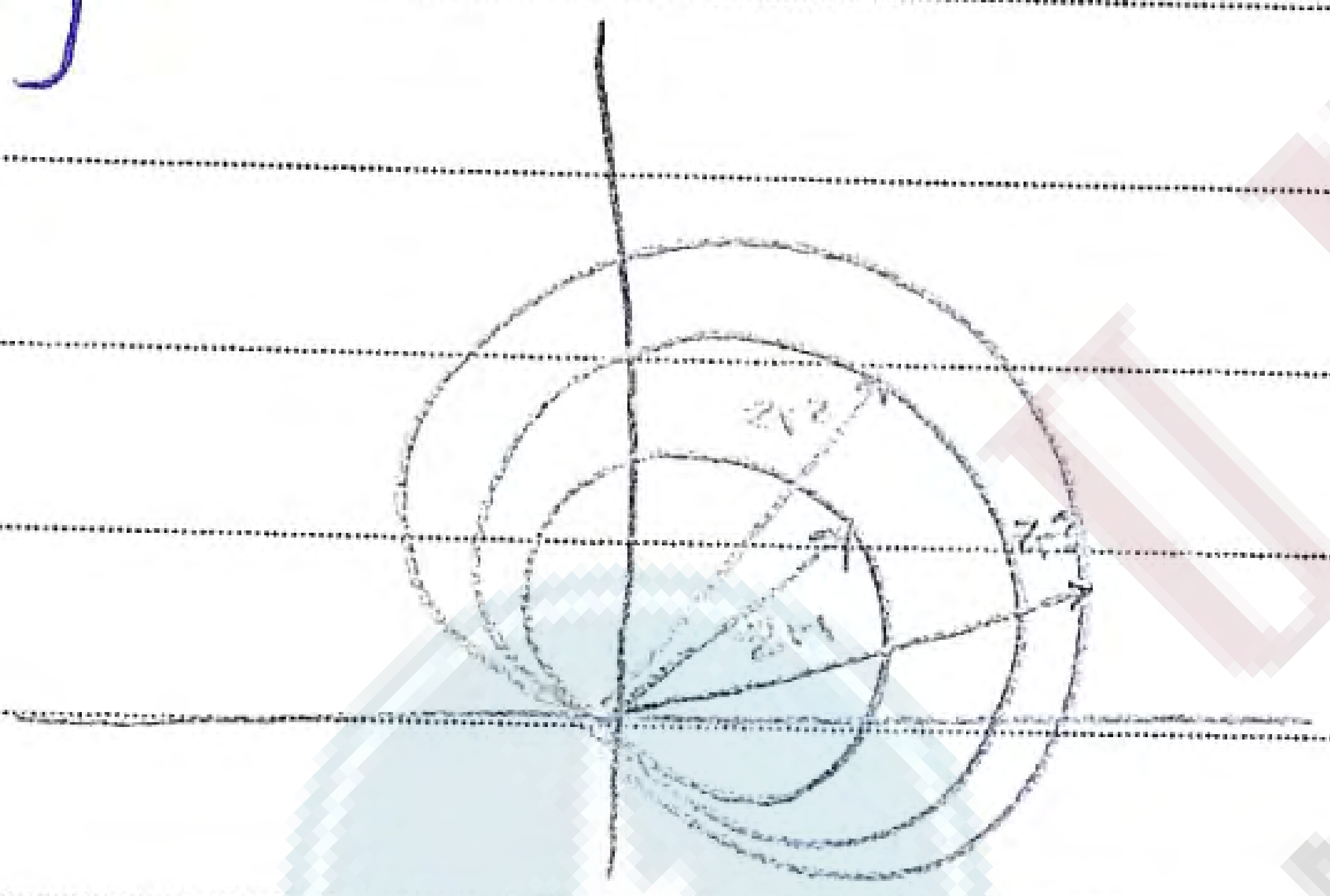
Wednesday

26/3/2014

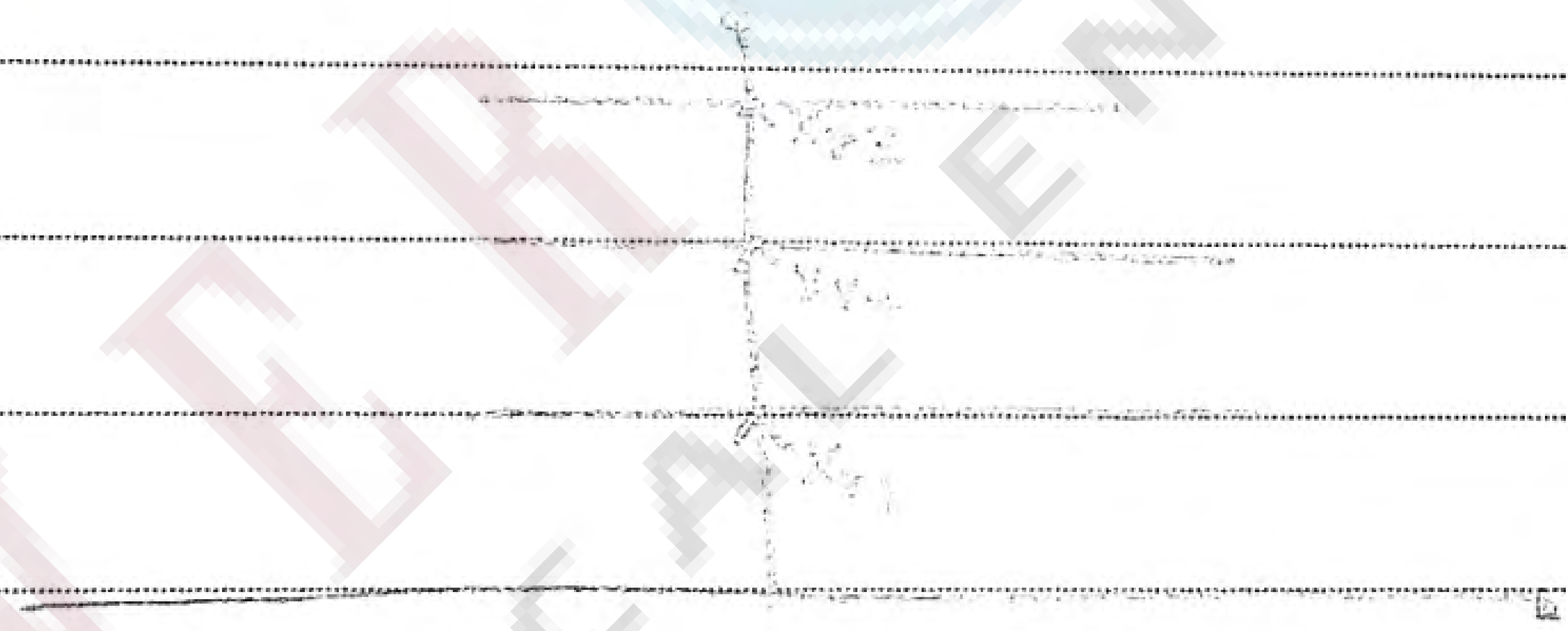
## Ohm relay



## Mho Relay

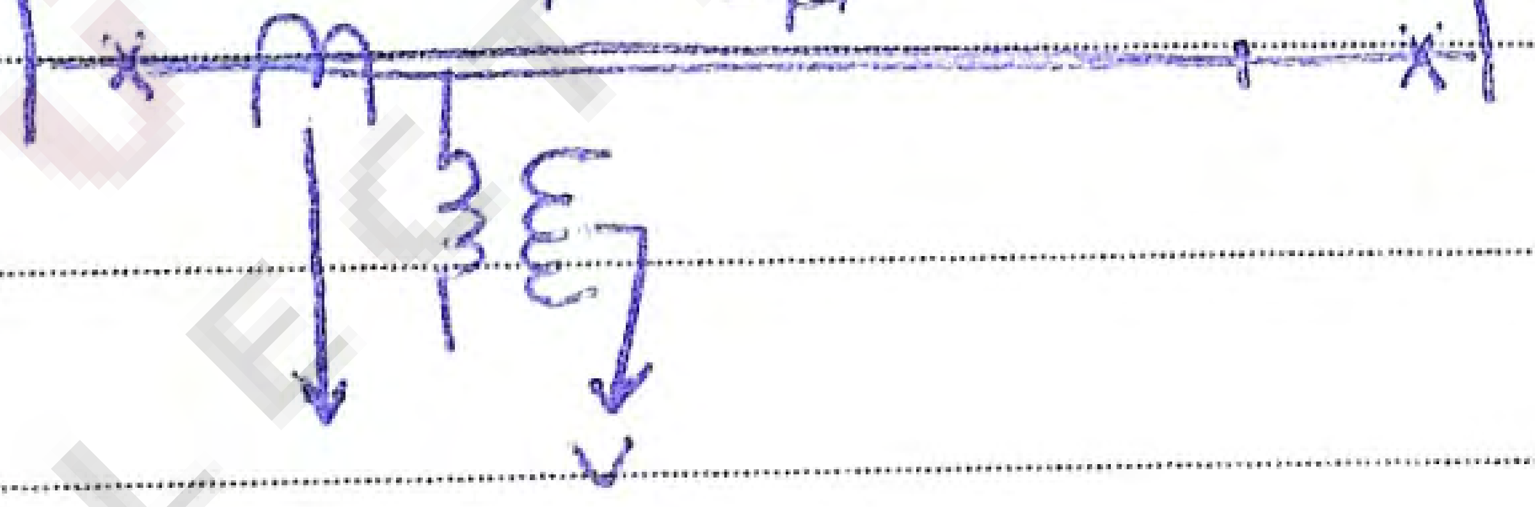


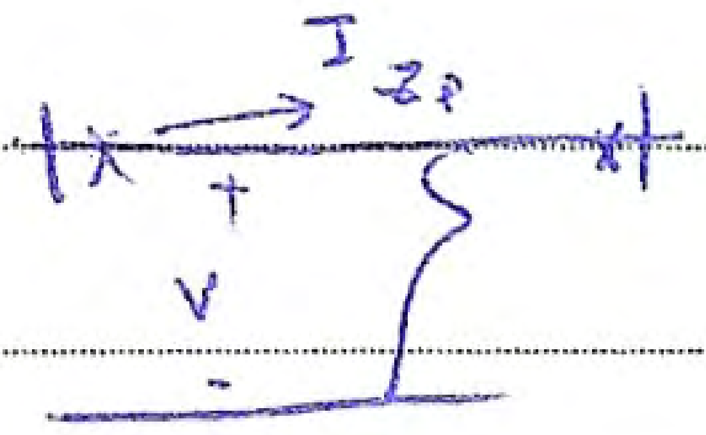
## Reactance Relay



in Primary

$Z_p = Z_p'' = 100\angle 70° \Omega$





in Secondary

$$\boxed{Z_s} = \frac{V_s}{I_s} = \frac{V_p / V.T \text{ ratio}}{I_p / C.T \text{ ratio}} = Z_p \frac{C.T \text{ ratio}}{V.T \text{ ratio}}$$

$Z_{r1}$

$$= 100\angle 70 \frac{500/1}{(132K/\sqrt{3})/(110/\sqrt{3})}$$

lec # 12

Wednesday
26/3/2014

## Power System Stability:

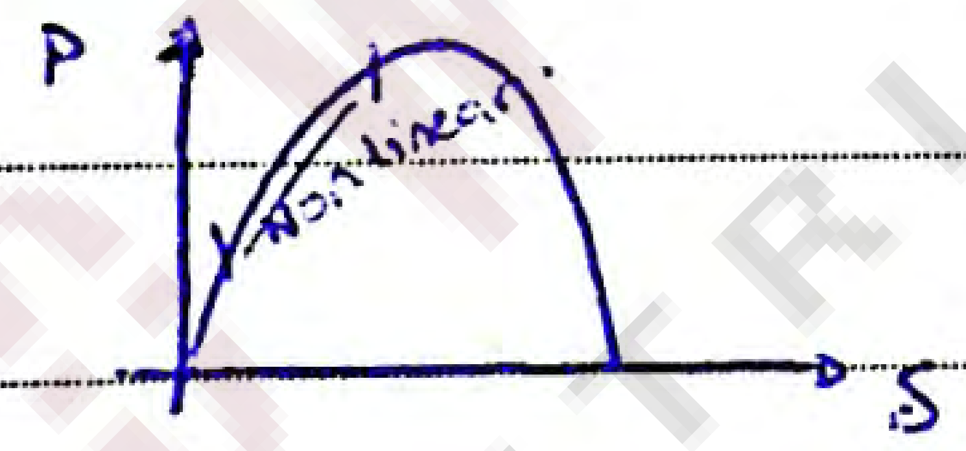
is the ability of the synchronous generator in the power system to run in synchronism (at $W_{sm}$ (Single mechanical speed (it is constant))) Following a ~~distance~~ disturbance.

- Large Disturbance
  Fault 3-ph fault For 0.1 sec
  generator out of service
  Large change in load
- Small Disturbance
  Small change in power
  Small change in controller setting. { power, voltage

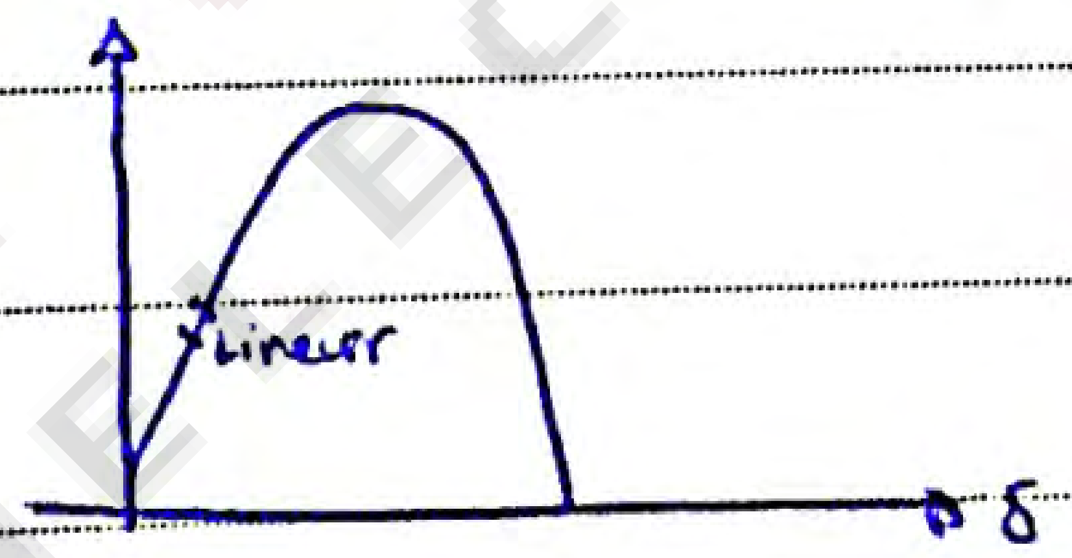
This Called Transient Stability
non-Linear differential equations (DE) + algebric equation (initial values). → in large Disturbance.

1 gen → infinite bus

26 D.E



10:04



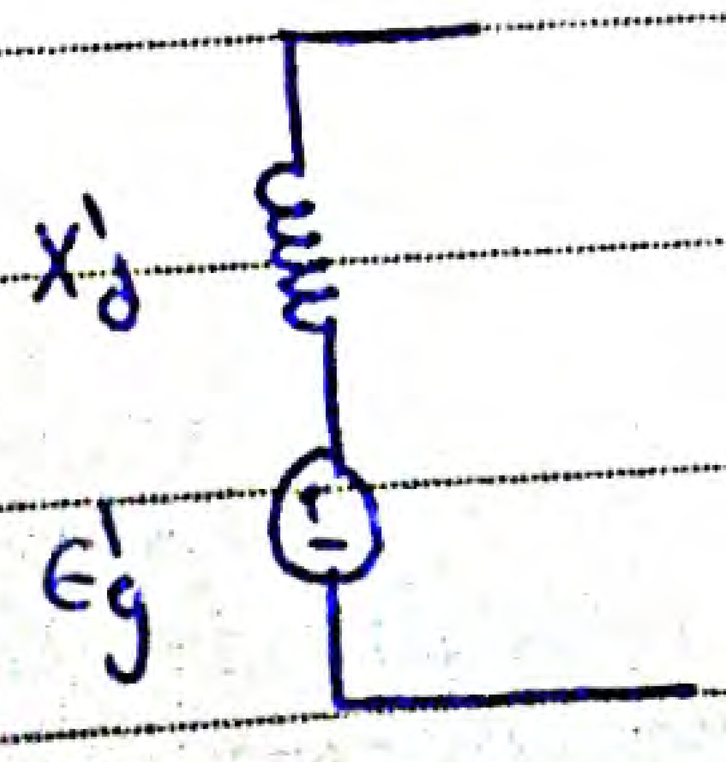
This called Steady State stability
linearisation of equation

$x' = AX + BU$

$Y = CX + DU$

$[SI - A]$ → in Small Disturbance.

First swing → 1sec



→ controllers are not considered.

$E'_g$ = constant not affected by speed change.

lec # 12

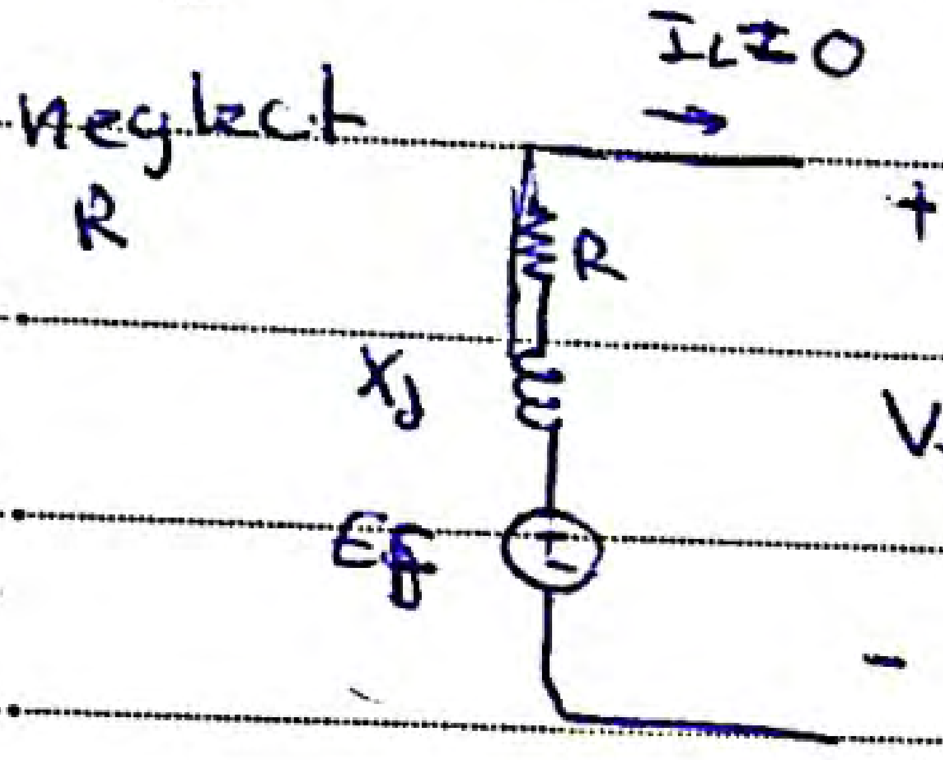
Wednesday
26/3/2014

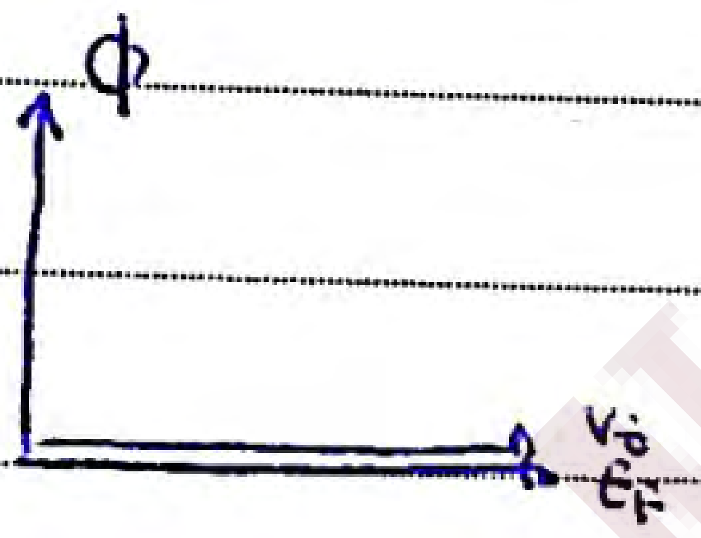
- neglect D.C
- neglect harmonics
- 3φ fault →

Unbalanced : Symmetrical Component

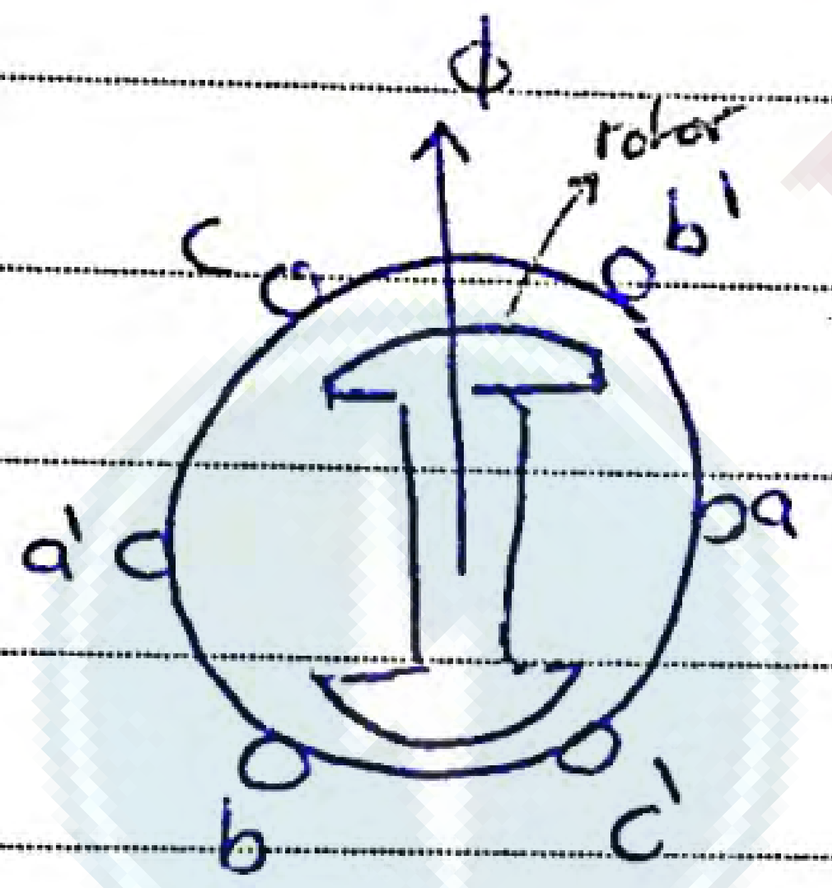
10:21

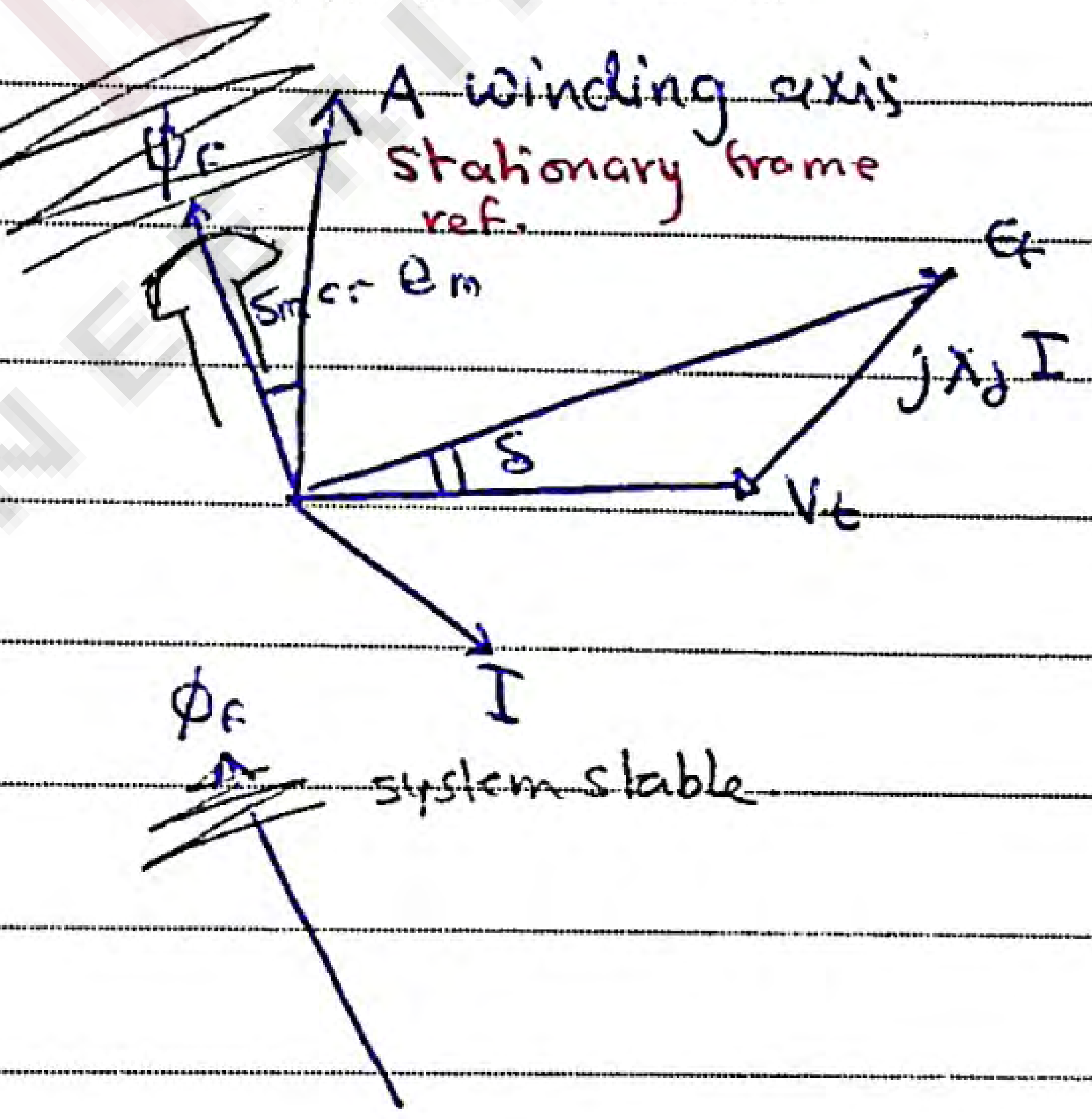
generator at Steady State:





$\phi_f \perp E_f$





Equation of motion:

$$J \frac{d^2\theta_m}{dt^2} = \underset{\text{constant}}{\underline{\underline{T_m}}} - T_e = T_a$$ → this for generator

$J$ → moment of inertia $Kg.m^2$

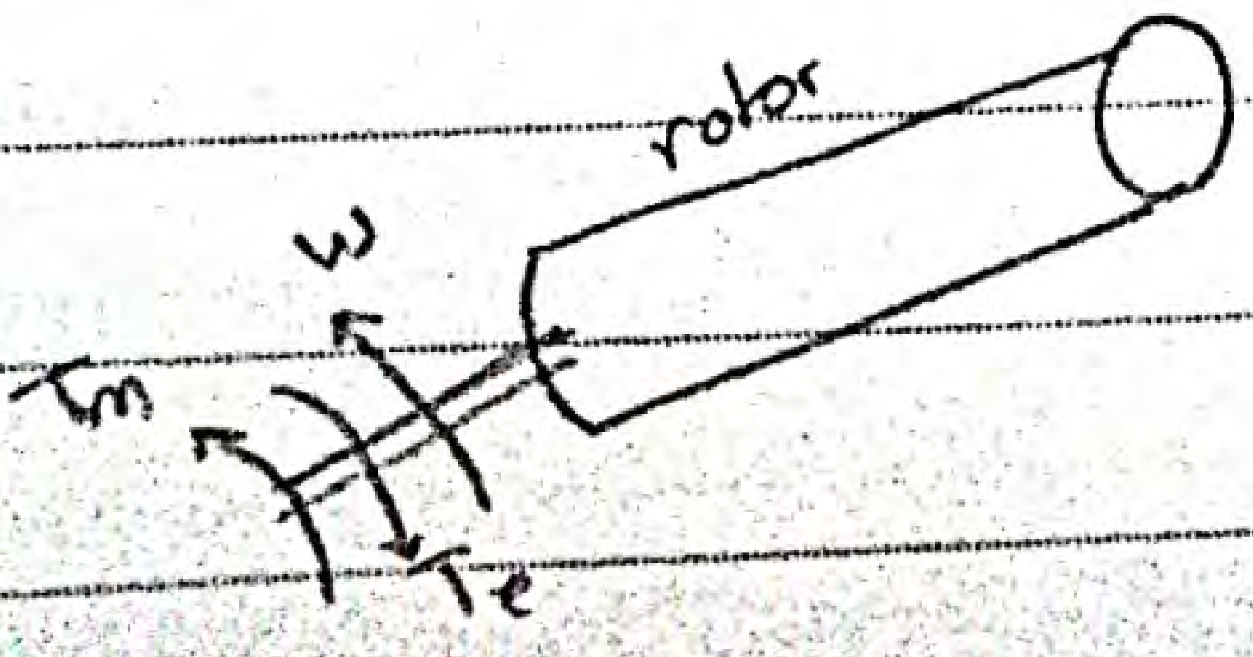
$\theta_m$ : angular displacement in mech. rad

$t$ : time sec

$T_m$ : net mechanical Torque (torque supplied by the prime-mover - F. & W. losses).

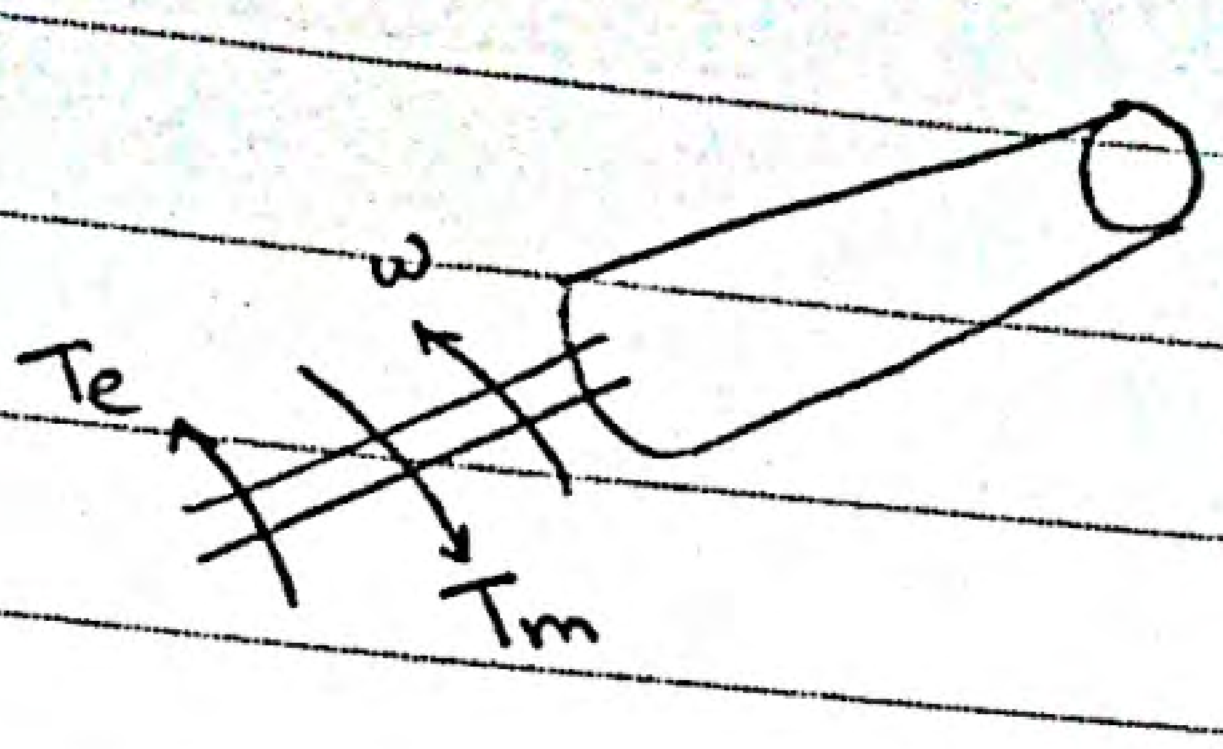
$T_e$: net air gap electrical torque.

generator:

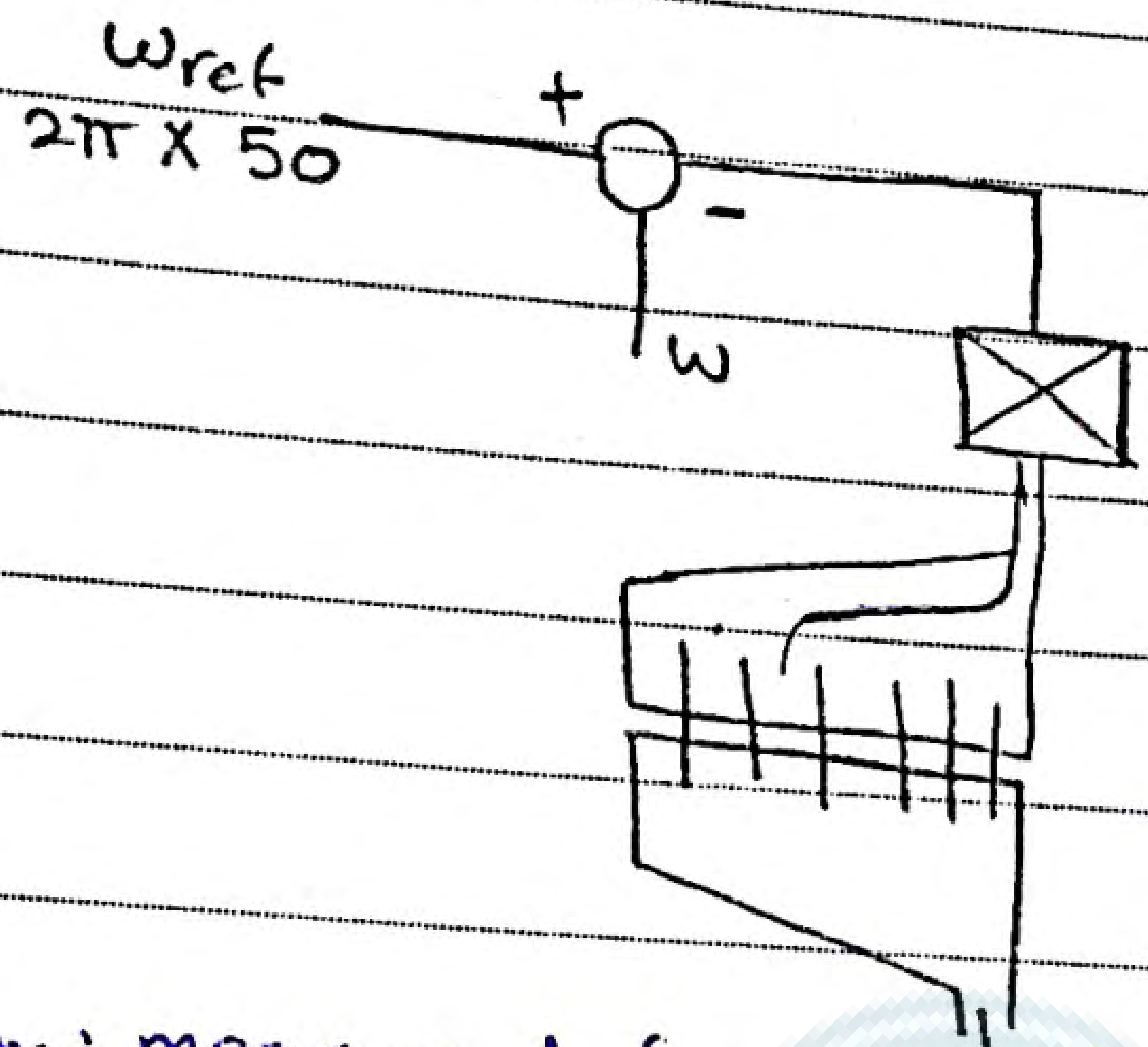


Wednesday
26/3/2014

motor:



$T_a = T_e - T_m$ in motor



$\theta_m$: measured from a stationary frame of refrence mech. rad

$\theta_m = \delta_m + \omega_{sm} t$

$\delta_m$: measured from a synchronously rotating frame of reference. mech. rad.

at $t = 0$ , $\theta_m = \delta_m$

$$\frac{d\theta_m}{dt} = \frac{d\delta_m}{dt} + \omega_{sm}$$

$\hookrightarrow \omega_m$ mech. speed mech. rad/sec

$$\omega_m = \omega_{sm} + \frac{d\delta_m}{dt} \quad , \quad \omega_m \simeq \omega_{sm} \simeq \text{constant}$$

$$\frac{d^2\theta_m}{dt^2} = \frac{d\delta_m^2}{dt^2}$$

$$\omega_m \left( \frac{J d^2\delta_m}{dt^2} = T_m - T_e = T_a \right)$$

$$J\omega_m \frac{d^2\delta_m}{dt^2} = T_m\omega_m - T_e\omega_m$$

$$M \frac{d^2\delta_m}{dt^2} = P_m - P_e$$

$P_m$ : net mechanical power , $P_e$ : net air gap electrical Power

lec # 12

Wednesday
26/3/2014

M : inertia Constant

$P_m - P_e$ (Joule/ sec)

$\frac{d^2 \delta_m}{dt^2}$ (mech rad/ $s^2$)

$$M \left( \frac{\text{Joule}}{s} \times \frac{s^2}{\text{mech. rad}} \right)$$

$$\rightarrow \frac{\text{Joule } s}{\text{mech. rad}}$$

lec # 13

Monday
31/3/2014

constant → $M = J\omega_m$

$$\omega_m = \omega_{sm} + \frac{d\delta_m}{dt}$$

mechrad/sec

$$M \frac{d^2\delta_m}{dt^2} = P_m - P_e \qquad \text{Joule/sec}$$

$$M \longrightarrow \frac{\text{Joule. Sec}}{\text{mech. rad}}$$

$H \triangleq \dfrac{\text{K.E. stored in the rotor (M Joule)}}{S_{machine} \text{ (MVA)}}$

$$= \frac{\frac{1}{2} \overset{M}{\boxed{J \cdot \omega_m}} \cdot \omega_{sm}}{S_{machine}} \quad \text{(sec)}$$

$$= \frac{\frac{1}{2} J\omega_{sm}}{S_{machine}} \quad \text{(sec)}$$

$$H = \frac{M\omega_{sm}}{2 S_{machine}}$$

$$M = \frac{2H S_{machine}}{\omega_{sm}}$$

$$\frac{2H \cancel{S_{machine}}}{\omega_{sm}} \frac{d^2\delta_m}{dt^2} = \frac{P_m - P_e}{S_{machine}} = P_m - P_e \text{ in P.U.}$$

lec # 13

Monday

31/3/2014

$$\frac{2H}{\omega_{sm}} \frac{d^2 \delta_m}{dt^2} = P_m - P_e$$

$\delta_m$ mech. rad

$\omega_{sm}$ mech. rad/sec

$$\delta_e = P . \delta_m$$

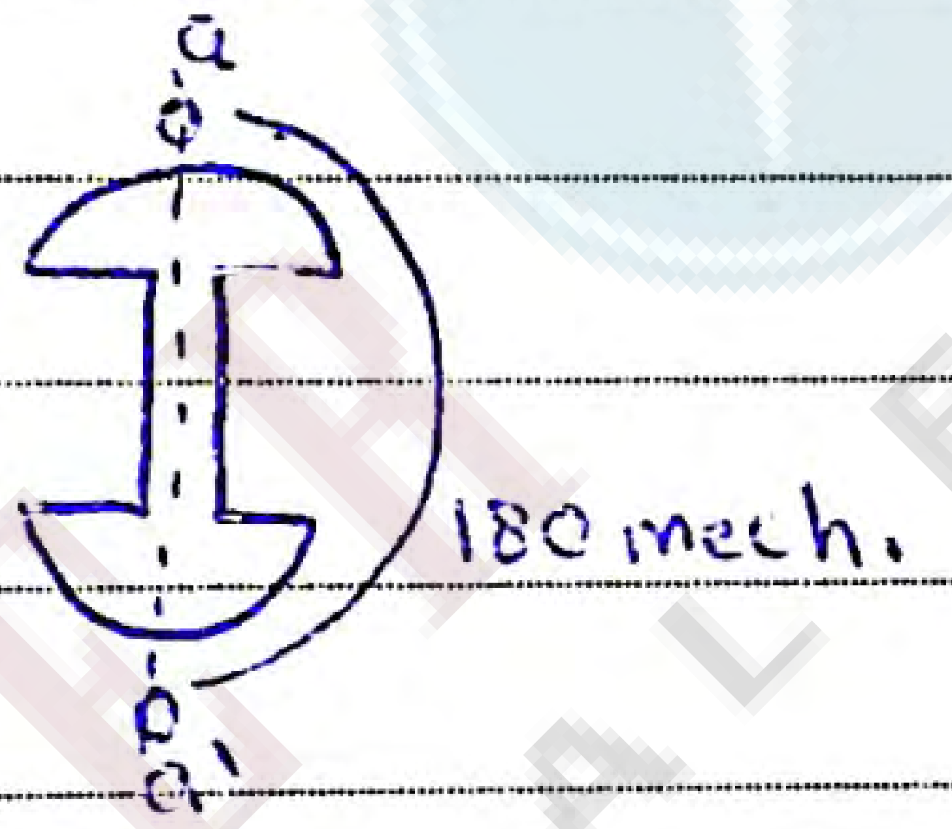
$$\omega_{se} = P . \omega_{sm}$$

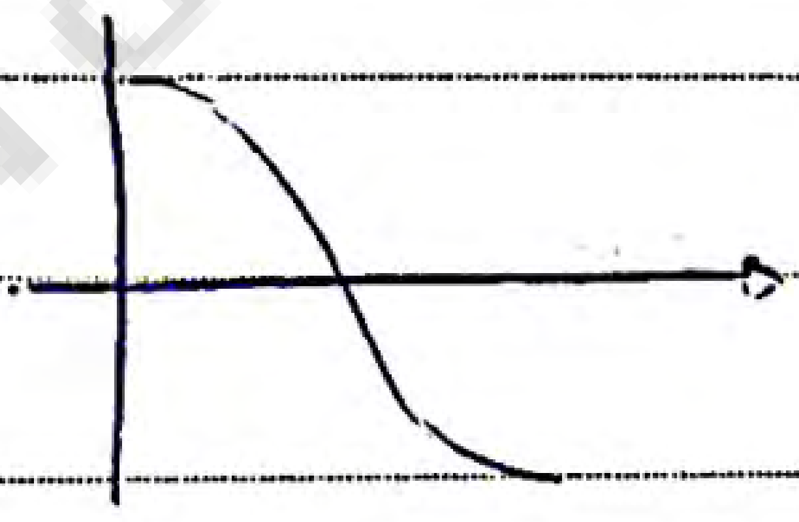
$$f = P \frac{n}{60}$$

P : Pairs of Poles

$$\omega_{sm} = 2\pi . \frac{n}{60}$$

$$\omega_{se} = 2\pi f = 2\pi \frac{Pn}{60}$$





$$\frac{2H}{\omega_s} \frac{d^2 \delta}{dt^2} = P_m - P_e$$

$$\frac{2H}{2\pi f} \frac{d^2 \delta}{dt^2} = P_m - P_e$$

$$\frac{H}{\pi f} \frac{d^2 \delta}{dt^2} = P_m - P_e$$ $\delta$ in rad

$$\frac{H}{180 f} \frac{d^2 \delta}{dt^2} = P_m - P_e$$ $\delta$ in degree

$$\omega = \omega_s + \frac{d\delta}{dt} \quad ①$$

$$\frac{d\omega}{dt} = \frac{d^2 \delta}{dt^2}$$

lec # 13

Monday

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$$\frac{2H}{\omega_s}\frac{d\omega}{dt} = P_m - P_e \quad ②$$

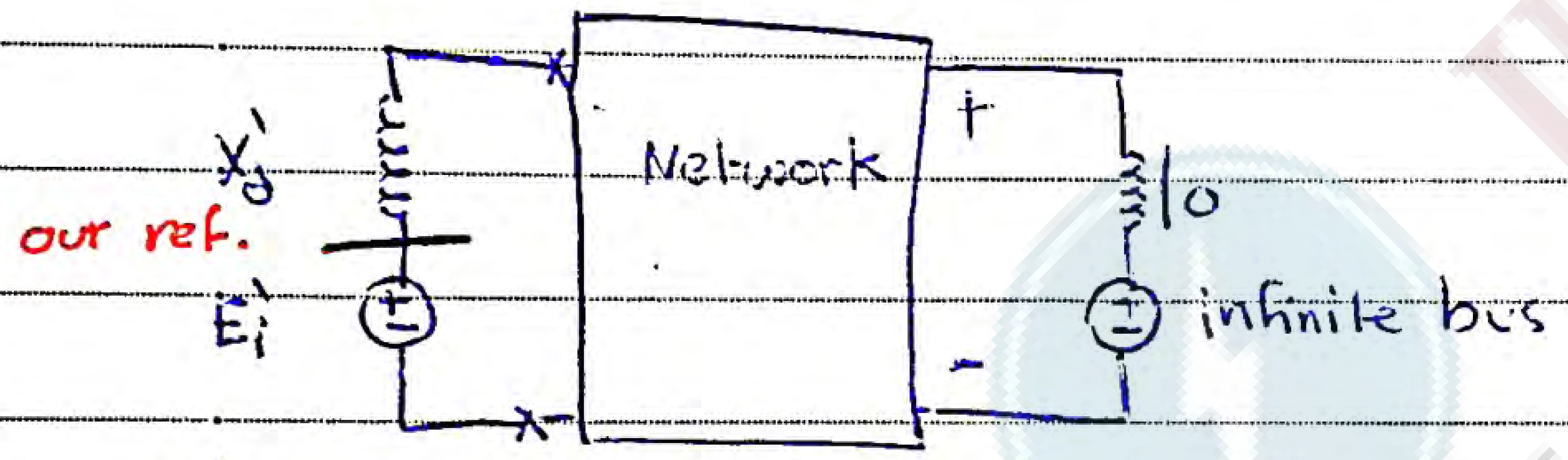
$$\boxed{\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} = P_m - P_e}$$

if $P_m = P_e$ we are in Steady state

$P_m > P_e$ " " " accelarate mode

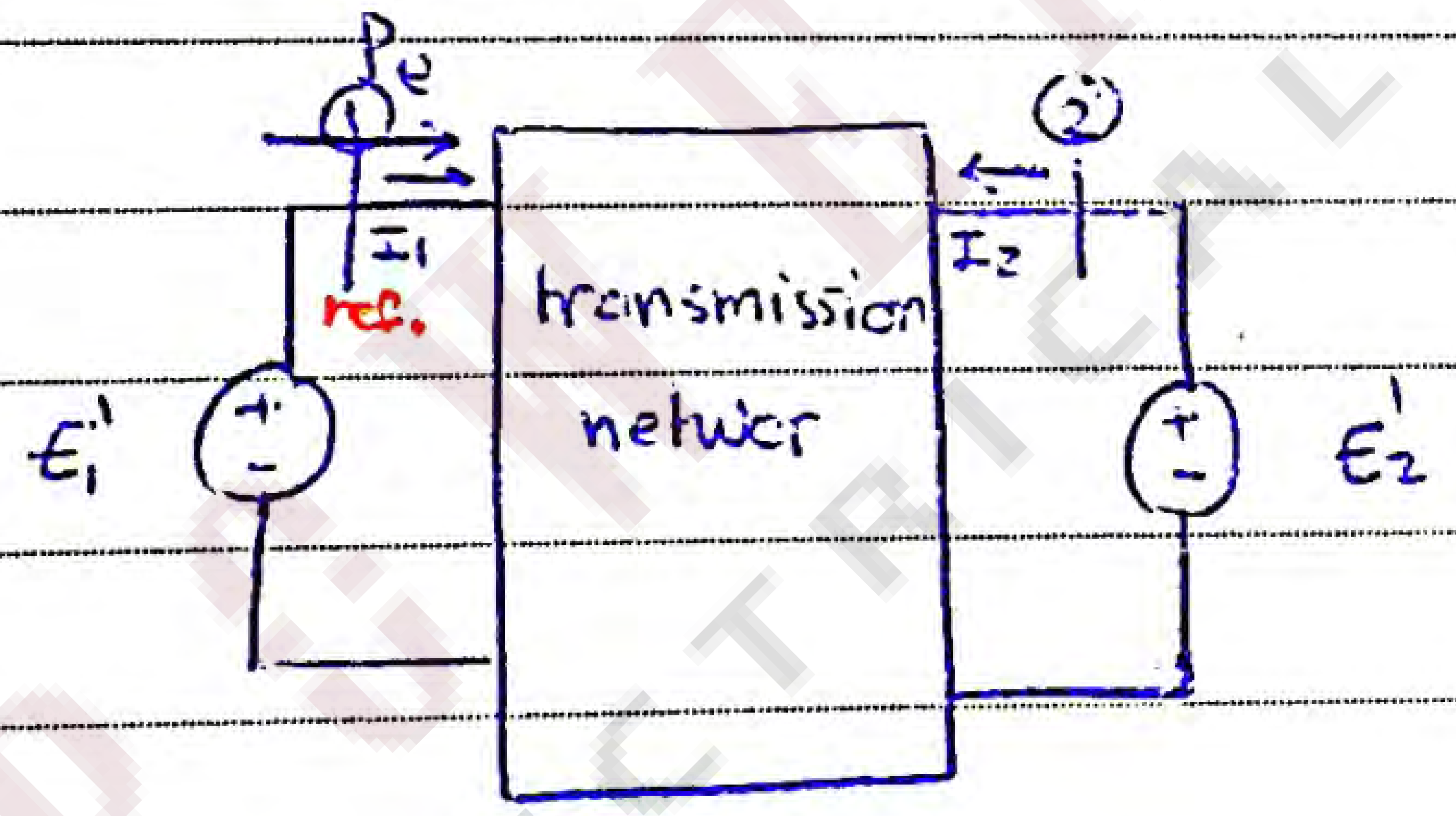
$P_m < P_e$ deaccelarate mode

$P_m$ constant



$E_1' \rightarrow$ constant $\propto \omega$

↳ change By field But we assume $E_1'$ constant.



$$S_1 = V_1 \sum_{k=1}^{n} Y_{1k}^* V_k^*$$

$$= E_1' \sum_{k=1}^{n} Y_{1k}^* E_k'^*$$

$$S_1 = E_1' \cdot Y_{11}^* E_1'^* + E_1' Y_{12}^* E_2'^*$$

$Y_{11} = G_{11} + jB_{11}$

$E_1' = |E_1'| \angle \delta_1$

$E_2' = |E_2'| \angle \delta_2$

$Y_{12} = |Y_{12}| \angle \theta_{12}$

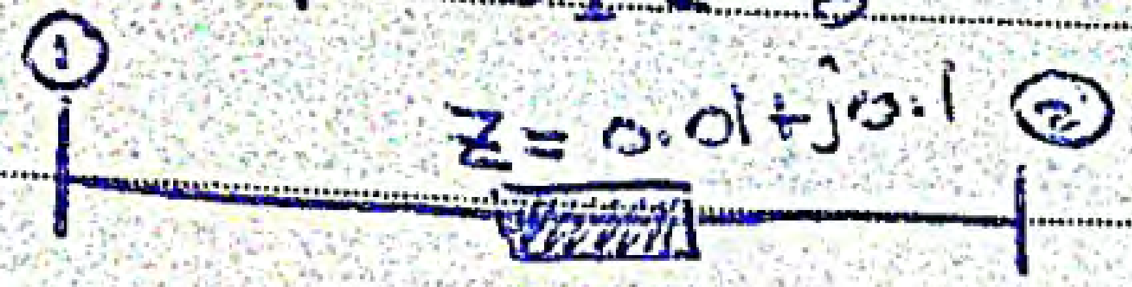
lec # 13

Monday
31/3/2014

$$S_1 = |E_1'|^2 (G_{11} - jB_{11}) + |E_1'||E_2'||Y_{12}| \angle \delta_1 - \delta_2 - \theta_{12}$$

$$P_1 = |E_1'|^2 G_{11} + |E_1'||E_2'||Y_{12}| \cos(\underbrace{\delta_1 - \delta_2}_{\delta} - \underbrace{\theta_{12}}_{-\frac{\pi}{2} - \gamma})$$

$$\delta_1 - \delta_2 = \delta$$



$$Y = \frac{1}{Z} = \frac{1\,(0.01 - j0.1)}{\underbrace{(0.01 + j0.1)(0.01 + - j0.1)}_{0.0001 + 0.01}} \simeq 1 - j10$$

$$Y_{12} = -Y = -1 + j10$$

$$\sqrt{101}\ \angle 95^\circ$$

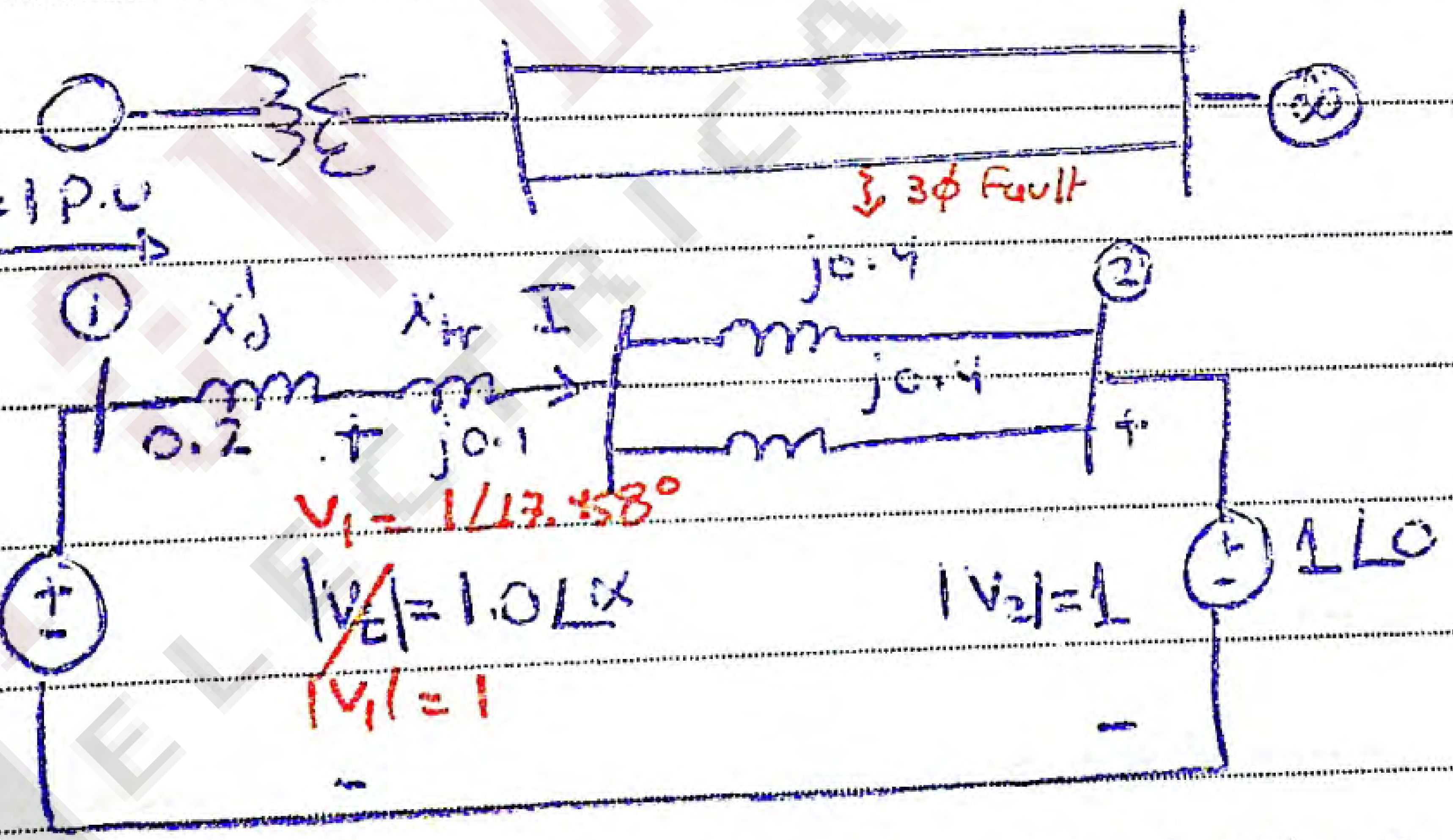
$$\theta_{12} = \frac{\pi}{2} + \gamma$$

$$P_1 \underset{2}{=} |E_1'| G_{11} + |E_1'||E_2'||Y_{12}| \sin(\delta - \gamma)$$

For lossless system

$$P_1 = |E_1'||E_2'||Y_{12}| \sin\delta \qquad P = \frac{|V_1||V_2|}{|B|} \sin\delta$$

Example :



Power angle equation ? $P = \frac{|V_1||V_2|}{|X_{12}|} \sin \overset{\alpha}{\cancel{\delta}}$

$$1 = \frac{1 * 1}{0.3} \sin\alpha$$

$$\alpha = \sin^{-1}(0.3) = 17.458^\circ$$

$$I = \frac{1\angle 17.458 - 1\angle 0}{j0.3} = 1.012 \angle 8.729^\circ$$

$$E_1' = 1\angle 17.458 + j0.2 * 1.012 \angle 8.729^\circ = 1.05 \angle \underbrace{28.44^\circ}_{\delta}$$

lec # 13

Monday

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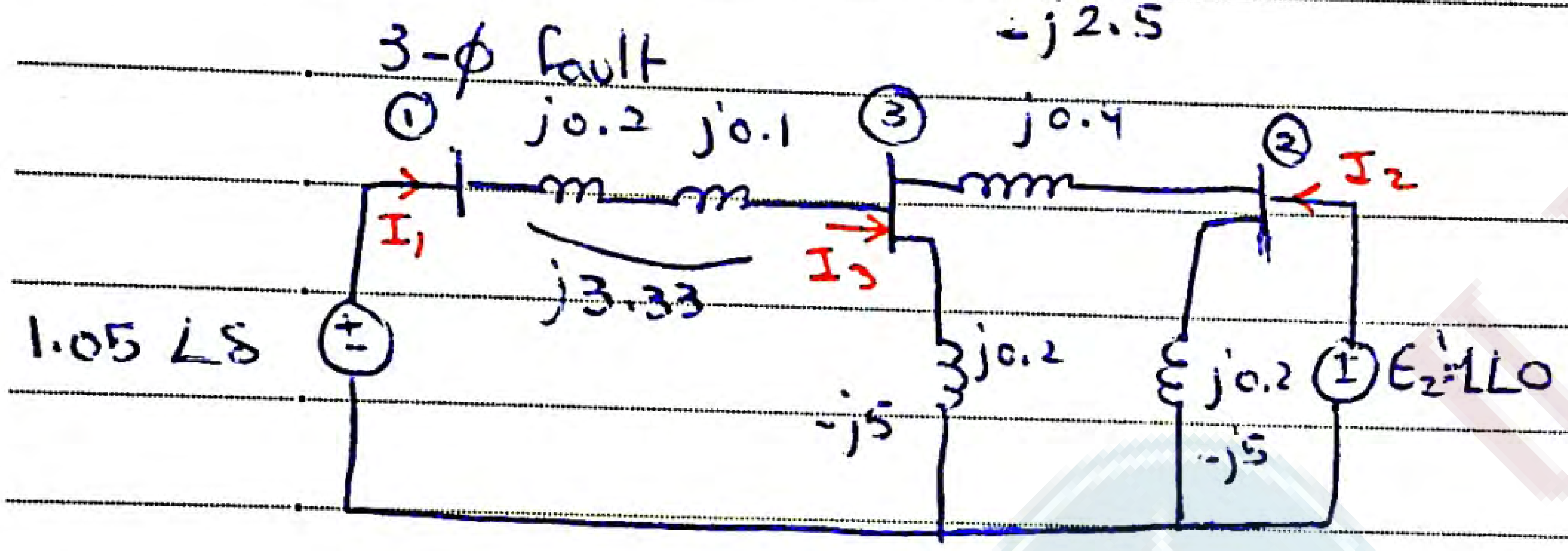
$E_2' = 1\angle 0$

## Prefault Condition :

$P_1 = |E_1'||E_2'|\,|Y_{12}| \sin\delta$

$= \dfrac{1.05 \times 1}{0.5} \sin\delta = 2.1 \sin\delta$

$\delta_0$ at steady state = 28.44°



$$Y = \begin{array}{c} \\ \\ \\ \\ \end{array}\begin{array}{ccc} & K & L \\ \left[\begin{array}{cc|c} -j3.33 & 0 & j3.33 \\ 0 & -j7.5 & j2.5 \\ \hline j3.33 & j2.5 & -j10.833 \end{array}\right] & & \\ L^T & & M \end{array}$$

eliminate bus 3

$Y = K - L M^{-1} L^T$

$$= \begin{bmatrix} -j3.33 & 0 \\ 0 & -j7.5 \end{bmatrix} - \begin{bmatrix} j3.33 \\ j2.5 \end{bmatrix} \left[-j10.833\right]^{-1} \left[j3.33 \quad j2.5\right]$$

$$= \begin{bmatrix} -j2.308 & j0.769 \\ j0.769 & -j6.923 \end{bmatrix}$$

## during Fault :

$P_1 = 1.05 * 1 * 0.769 * \sin\delta$

$= 0.808 \sin\delta$

$Y_{12} = \left.\dfrac{I_1}{V_2}\right|_{V_1 = 0}$ From Network $I_1 = Y_{11} V_1 + Y_{12} V_2$

lec#13

Monday

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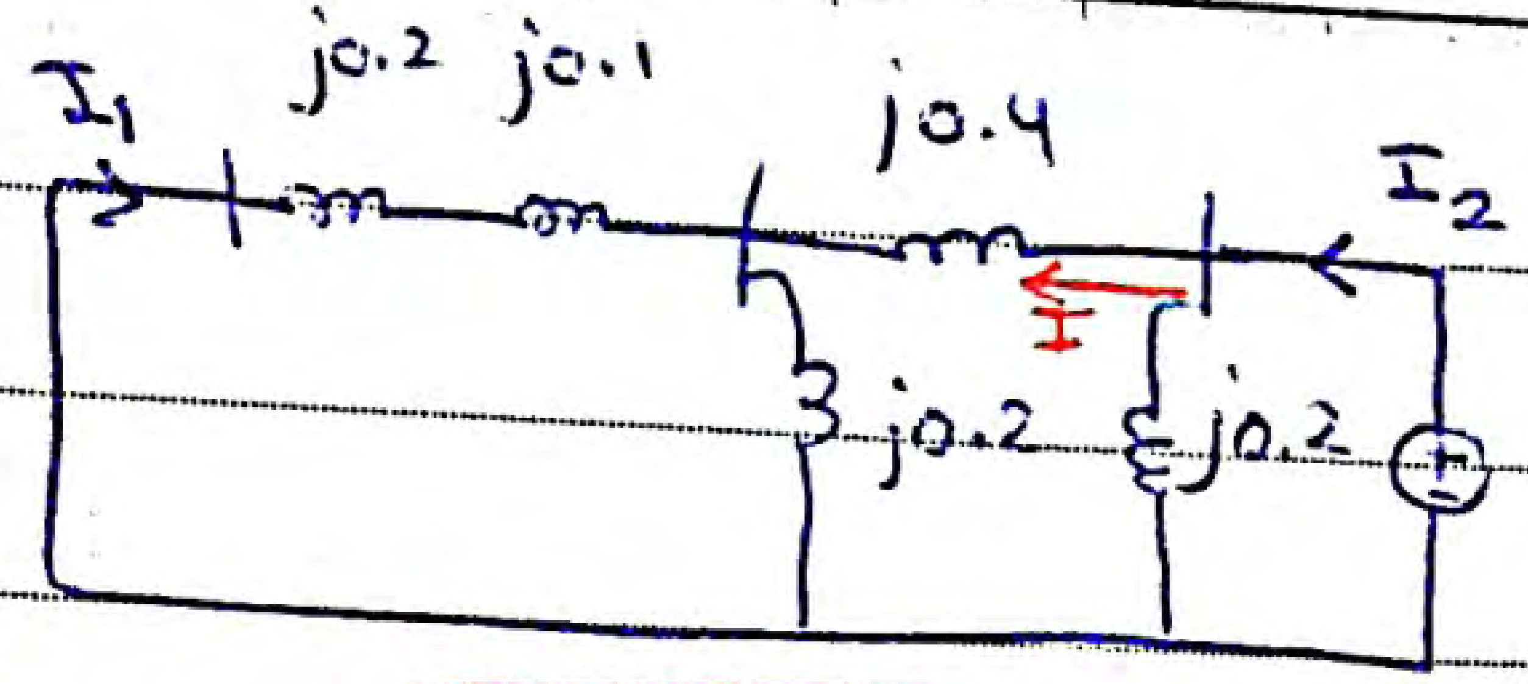
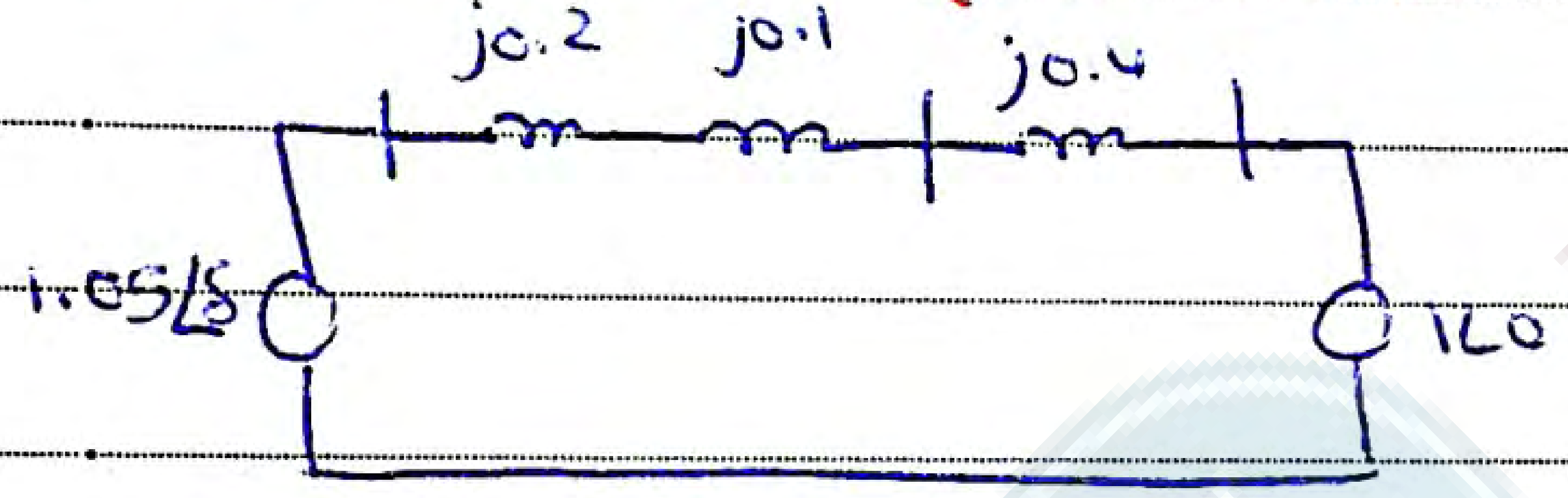


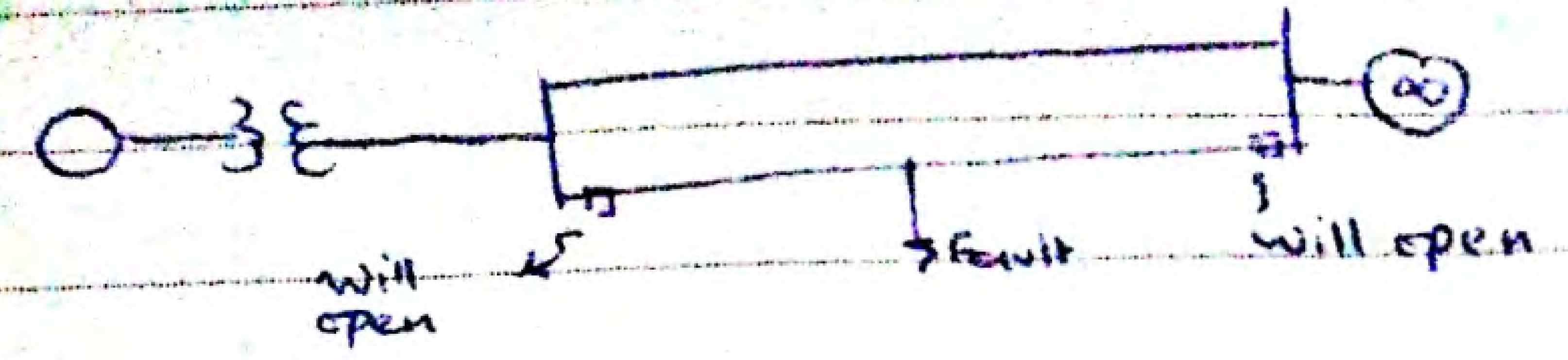
$$I_1 = \underbrace{\frac{-1\angle 0}{j0.4 + j0.2 // j0.3}}_{I} \times \frac{0.2}{0.5} = j0.769$$

## After fault (Post fault):



$$P_1 = \frac{1.05*1}{0.7} \sin\delta = 1.5 \sin\delta$$

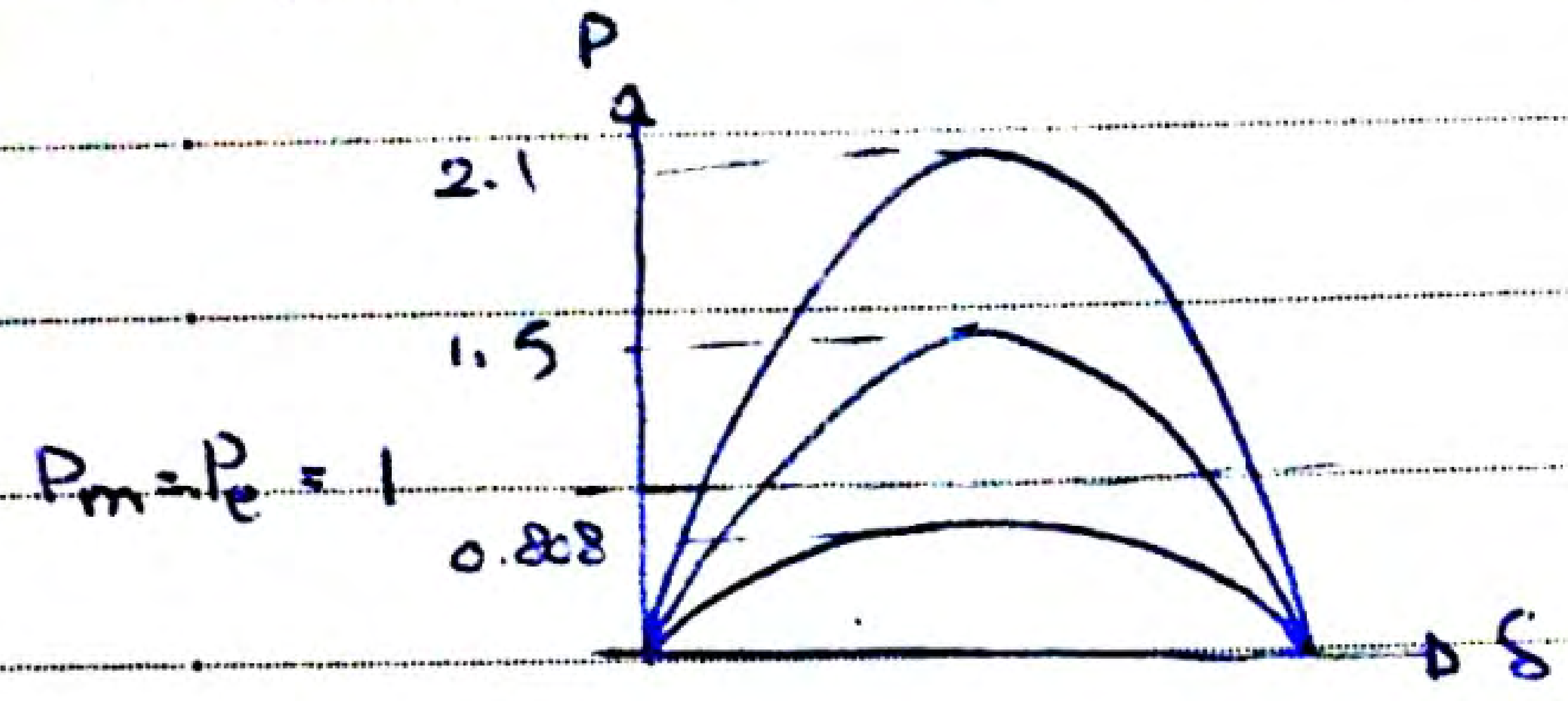
lec # 14 2/4/2014

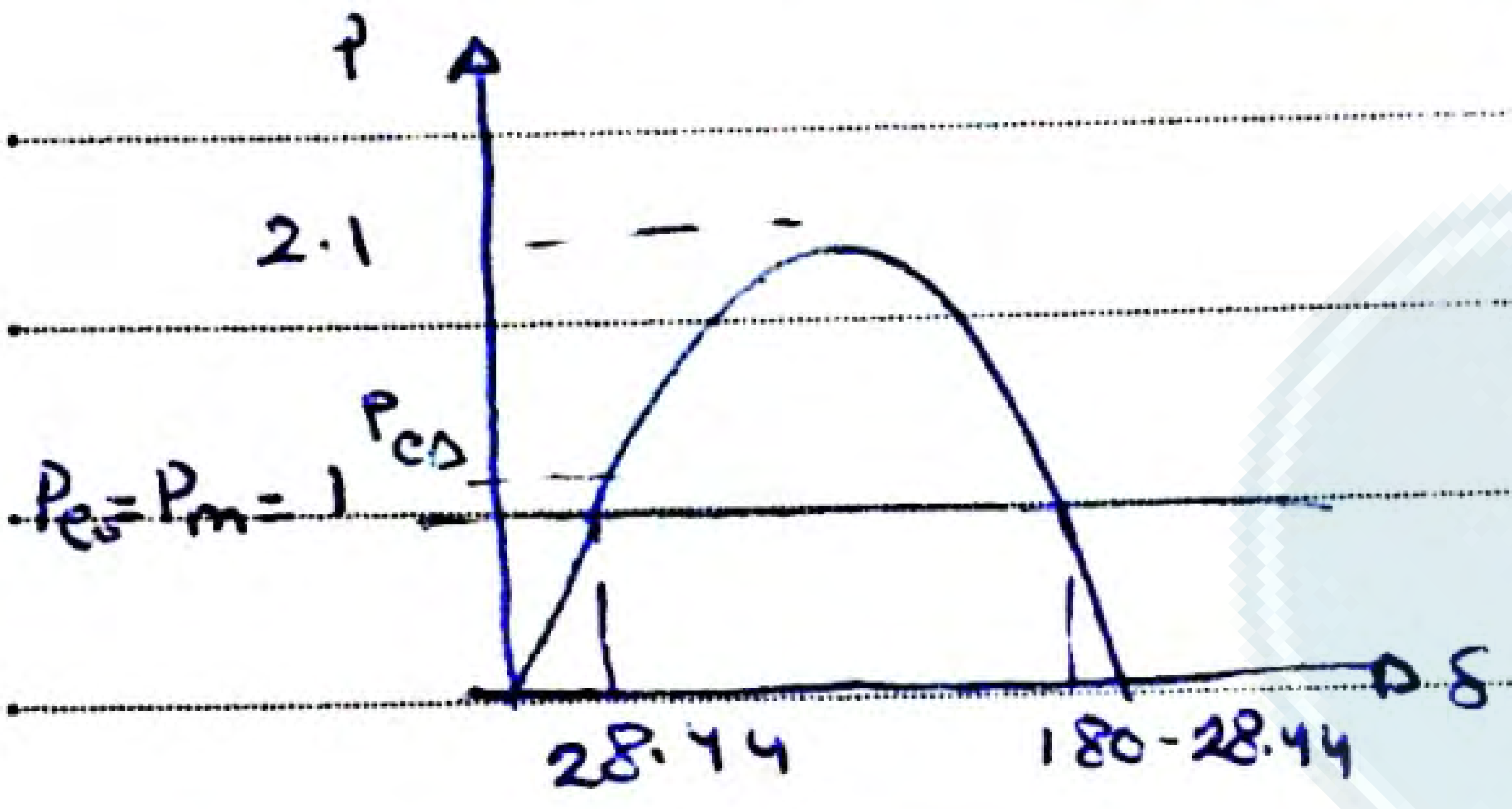


Pre fault : $P_e = 2.1 \sin\delta$

during fault : $P_e = 0.808 \sin\delta$

post Fault : $P_e = 1.5 \sin\delta$





$$\frac{2H}{\omega_s}\frac{d^2\delta}{dt} = P_m - P_e$$

$$\delta = \delta_o + \delta_\Delta$$

$$P_e = P_{eo} + P_{e\Delta}$$

$$P_e = P_{max}\sin(\delta_o + \delta_\Delta) = P_{max}\sin\delta_o\cos\delta_\Delta + P_{max}\cos\delta_o\sin\delta_\Delta$$

$$\sin\delta_\Delta \approx \delta_\Delta$$

$$\cos\delta_\Delta \simeq 1$$

$$P_e = \underbrace{P_{max}\sin\delta_o}_{= P_{eo} = P_m} + P_{max}(\cos\delta_o)\delta_\Delta$$

$$\frac{2H}{\omega_s}\frac{d^2(\delta_o + \delta_\Delta)}{dt^2} = \cancel{P_m} - \cancel{P_{max}\sin\delta_o} - P_{max}(\cos\delta_o)\delta_\Delta$$

$$\frac{2H}{\omega_s}\frac{d^2\delta_\Delta}{dt^2} + \overset{S_p}{\cancel{P_{max}(\cos\delta_o)}}\delta_\Delta = 0$$

$P_{max}\cos\delta_o = S_p$ ( Synchronizing power coefficient )

$$\frac{d^2\delta_\Delta}{dt^2} + \frac{\omega_s S_p}{2H}\delta_\Delta = 0$$

lec # 14

Wednesday

2/4/2014

$(S^2 + \omega_n^2)\, \delta_0(S) = 0$

$S^2 + 2\alpha S + \omega_n^2$

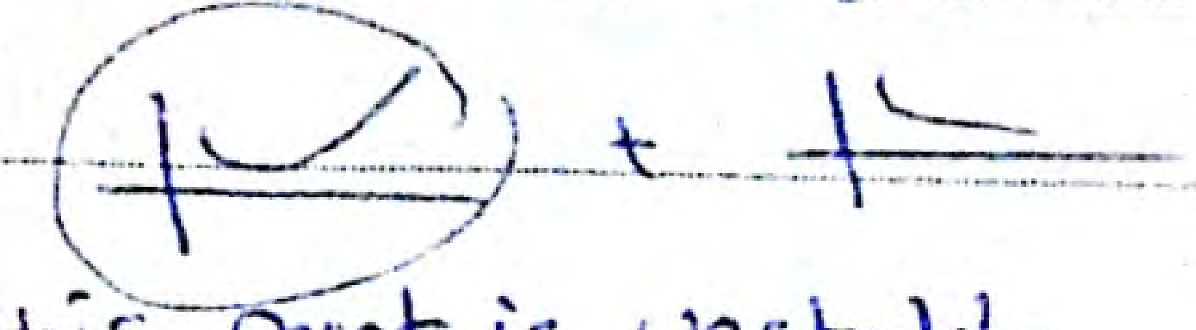
تمثل الـ Damping

Solution: $S^2 = -\omega_n^2$ , if $\omega_n^2 \rightarrow +ve$ , $S_{1,2} = \mp j\omega_n$

$\omega_n^2 \rightarrow -ve$ , $S_{1,2} = \mp \omega_n$

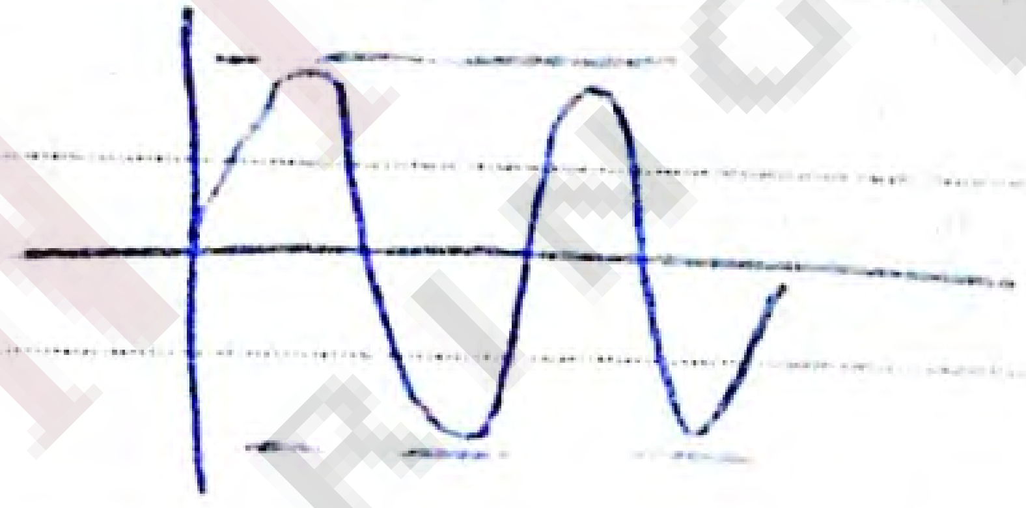
$\omega_n^2$ +ve $= A_1 e^{j\omega_n t} + A_2 e^{-j\omega_n t}$

-ve $= A_1 e^{\omega n t} + A_2 e^{-\omega n t}$ → unstable

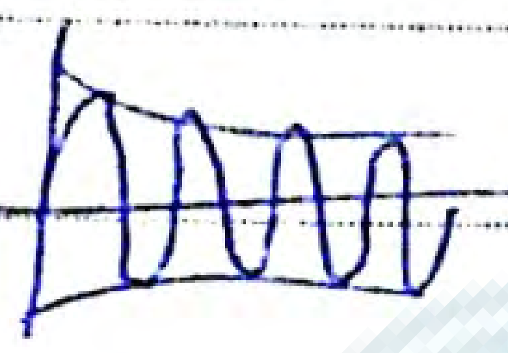


this part is unstable.

$\omega_n$ +ve → $e^{-\alpha t}(A \cos \omega_d t + B \sin \omega_d t)$



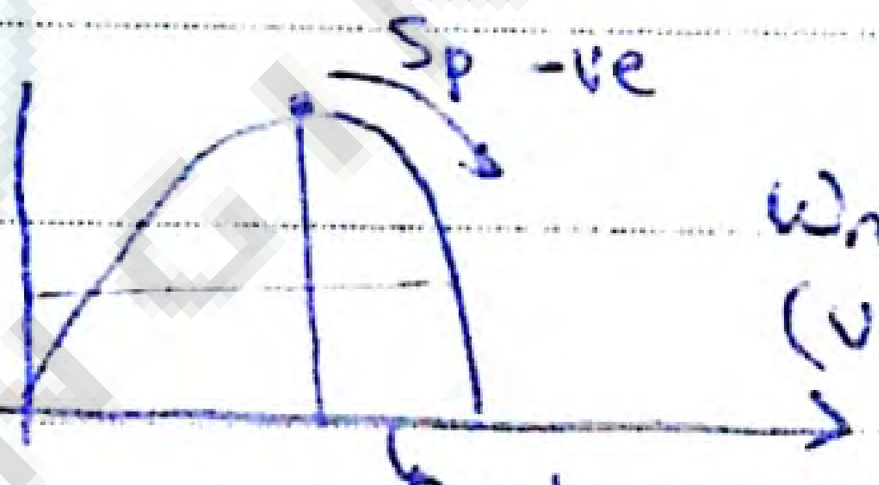
with R



our equation does not have damping → damped sinusoidal

- Friction + Winding

$\omega_n^2 = \frac{\omega_s \boxed{S_P}}{2H}$ متغير



$\omega_n^2 = -ve$
(unstable)

at steady state can't work here.

$2\pi f_n \sim \omega_n = \sqrt{\frac{\omega_s S_p}{2H}}$

oscillation frequency

1 ~ 3 HZ

$\omega_s + \omega_n$ → when in same direction

$\omega_s - \omega_n$ → when in opposite direction

Same Example:

$S_p = P_{max} \cos \delta_0$

$= 2.1 * \cos(28.44) = 1.8466$

$\omega_n = \sqrt{\frac{\omega_s S_p}{2H}} = \sqrt{\frac{377 \times 18466}{2 \times 5}} = 8.343$ rad/s $= 1.33$ HZ

oscillation freq.

good → 1 ~ 3 HZ

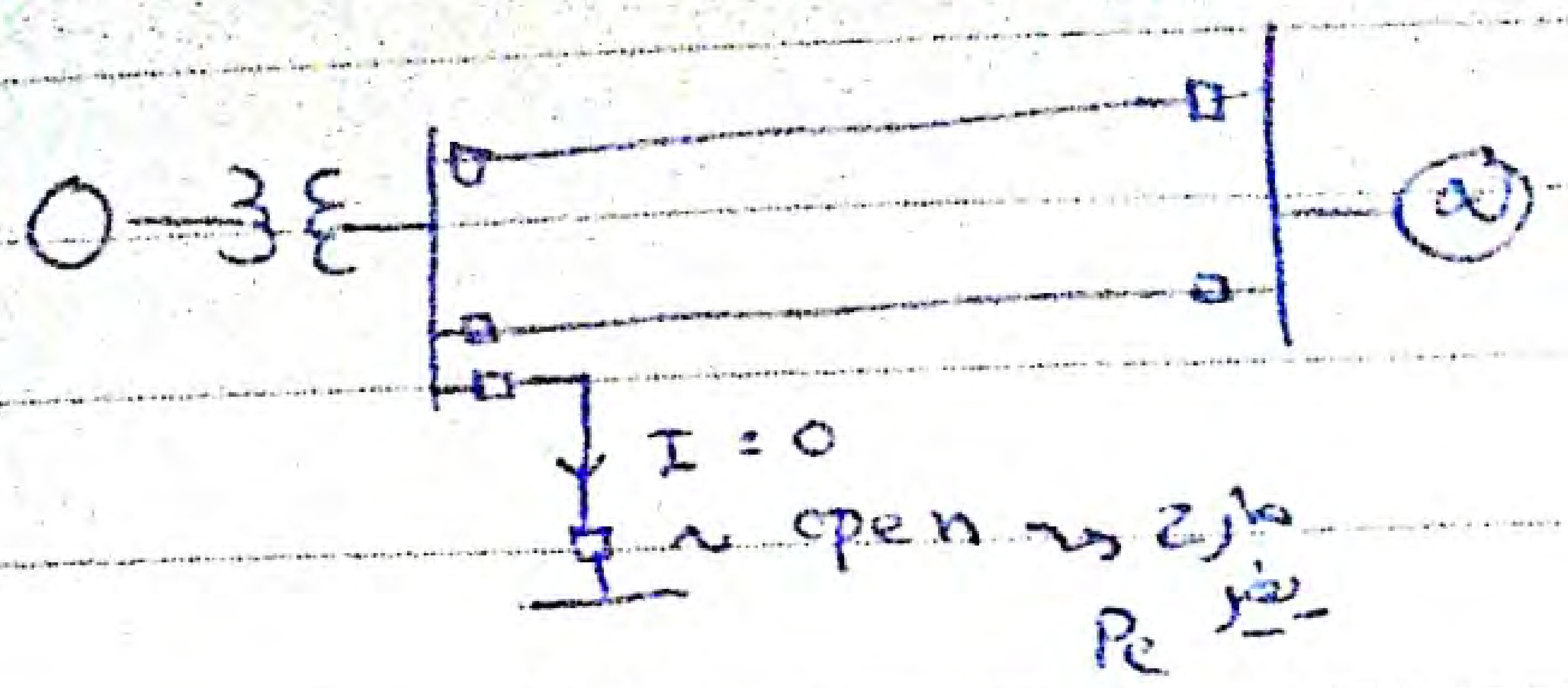
$\omega_s = 314$ , $f = 50$ HZ

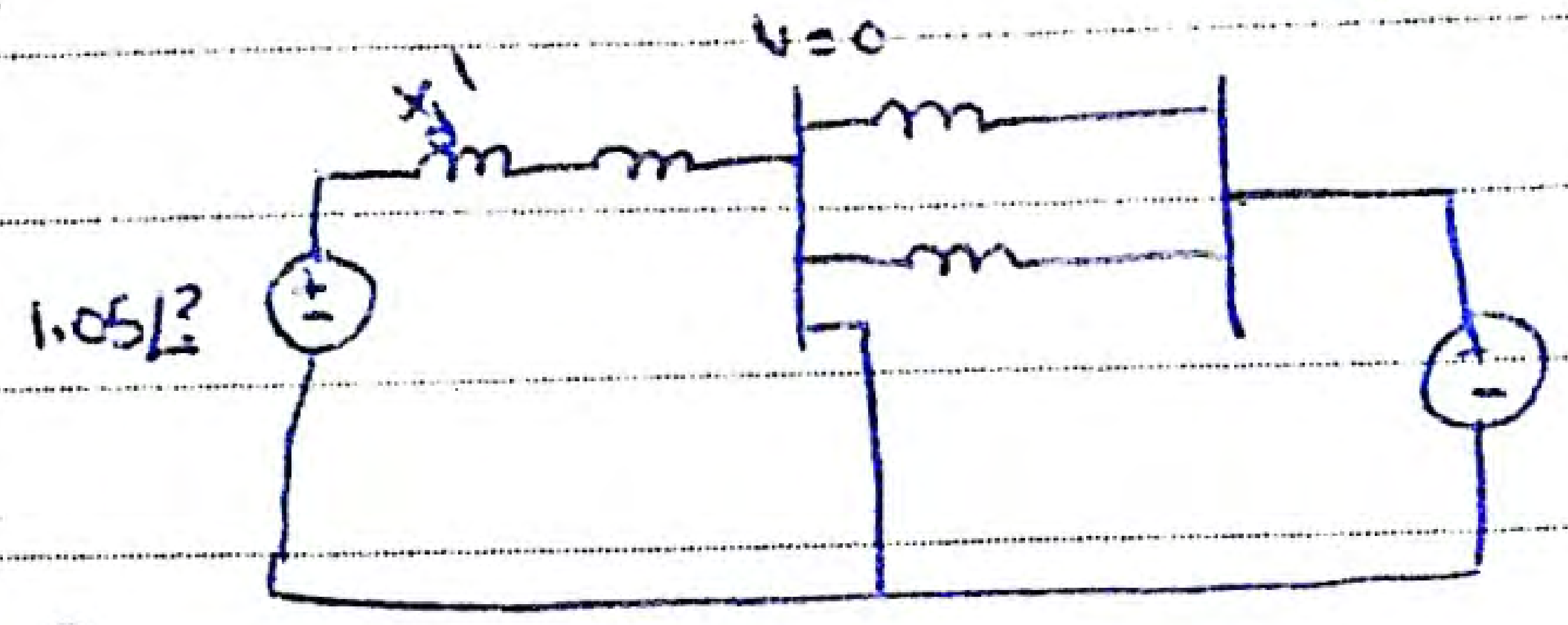
$\omega_s$ 377 , $f = 60$ HZ

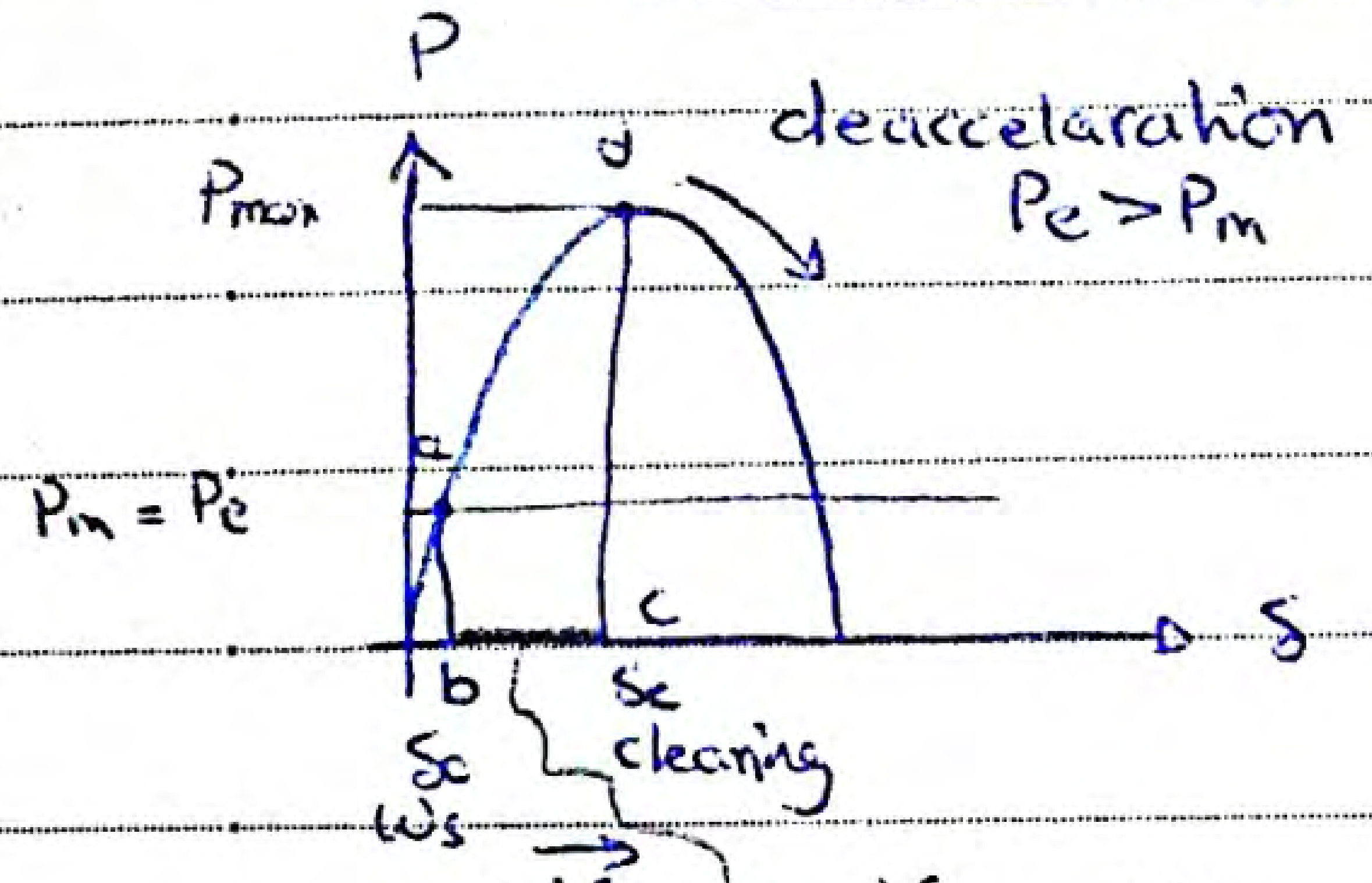
wednesday
2/4/2014

lec # 14

## Equal Area Criterion of Stability







بتسارع → $\frac{d\delta}{dt} = +ve$

$\frac{d^2\delta}{dt} = +ve$

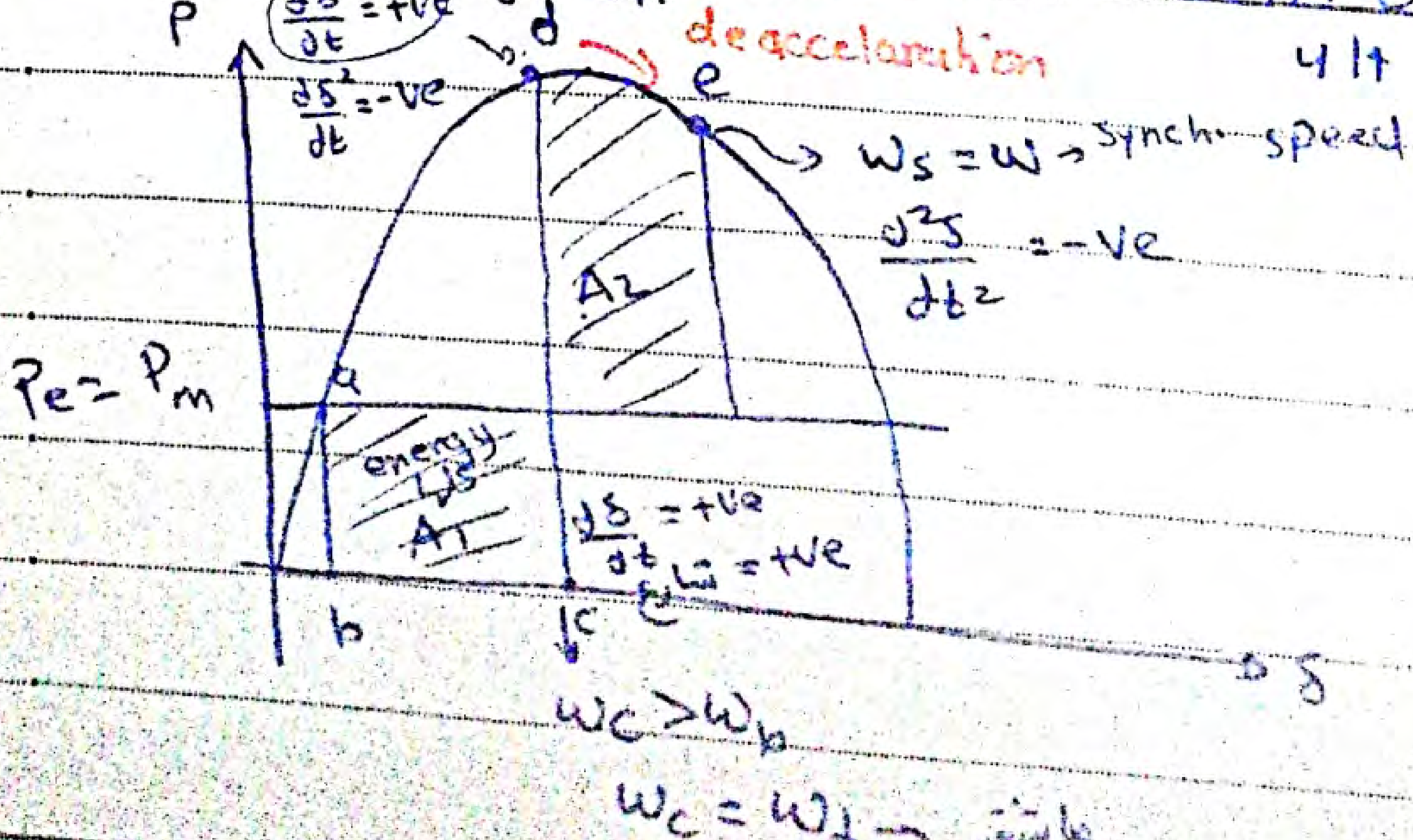
during fault: $\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} = P_m - \cancel{P_e}^{0}$

$$\frac{d^2\delta}{dt} = \frac{\omega_s}{2H} P_m$$

$$\omega - \omega_s = \frac{d\delta}{dt} \rightarrow \text{change in speed} = \int_0^0 \frac{\omega_s}{2H} P_m dt$$

$$= \frac{\omega_s}{2H} t P_m + 0$$

يعني δ بتزيد ← $\delta = \int_0^t \frac{\omega_s}{2H} P_m t \cdot dt = \frac{\omega_s P_m t^2}{4H} + \delta_0$



$\omega_c > \omega_b$

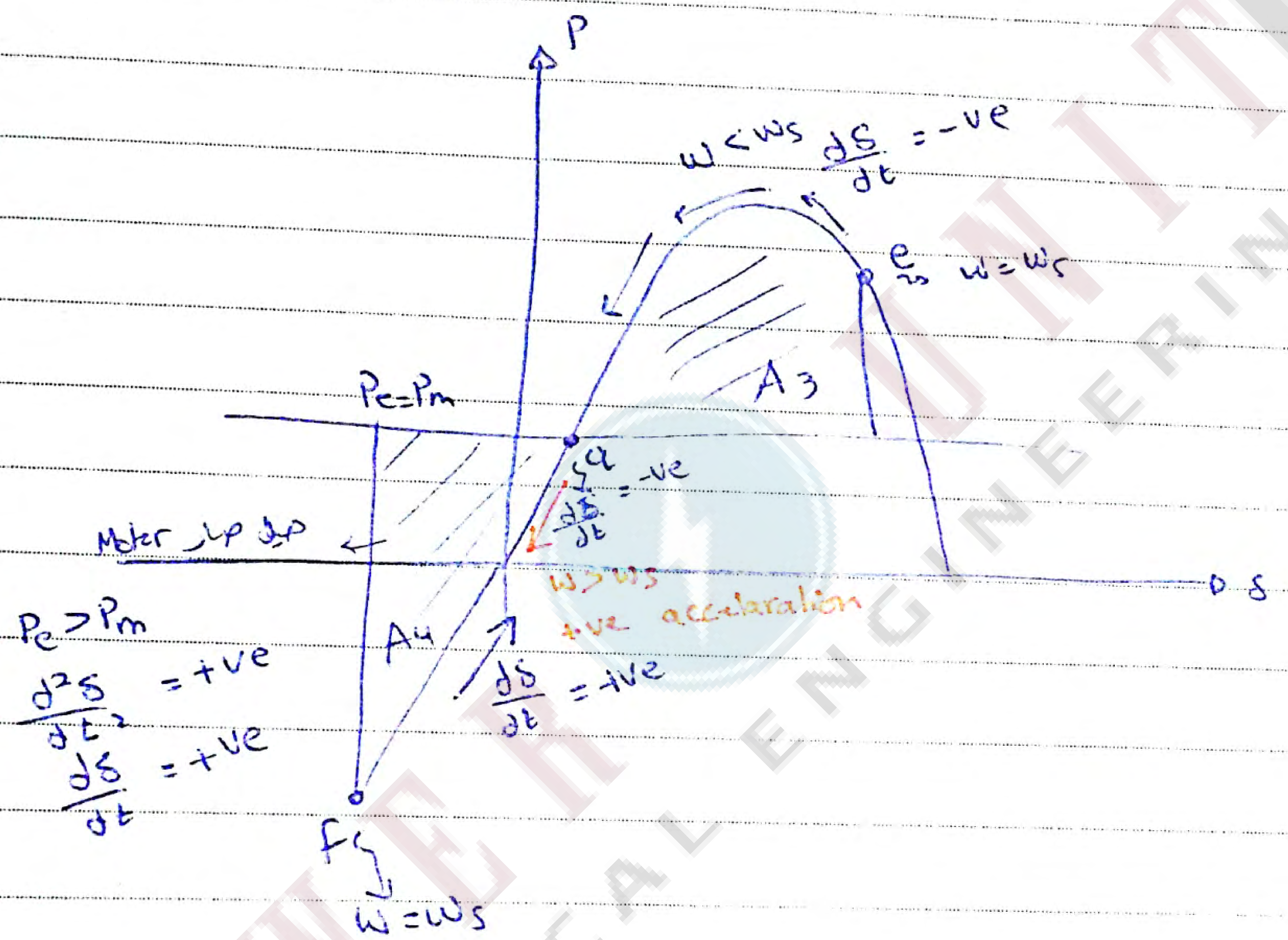
$\omega_c = \omega_d$ → ما بتغير

instantaneous

at d → $\omega > \omega_s$   $\frac{d\delta}{dt} = \omega - \omega_s$

at c → $\frac{d\delta}{dt} = \frac{\omega_s}{2H} P_m t_c$

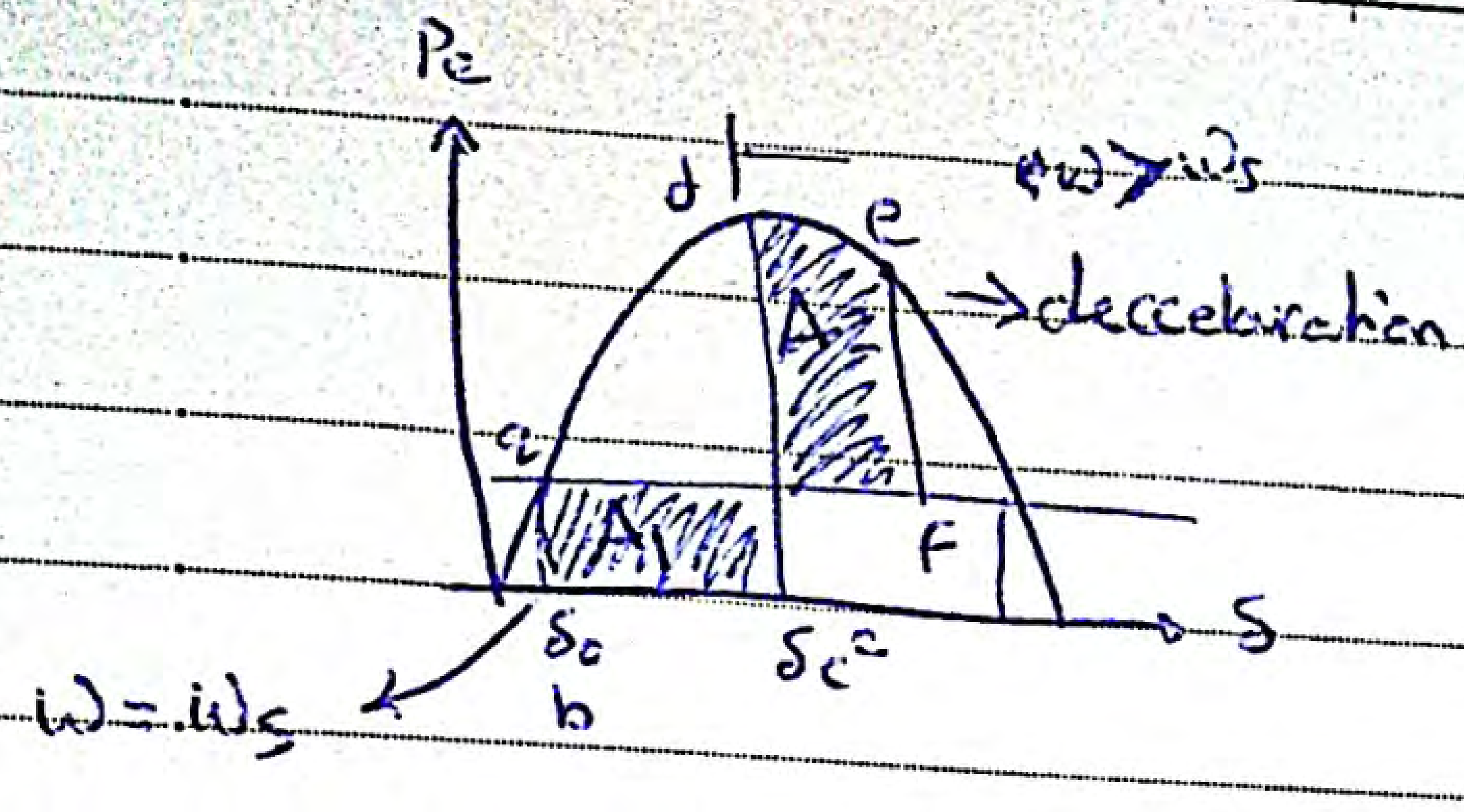
$$\delta = \frac{\omega_s P_m t_c^2}{4H} + \delta_0$$

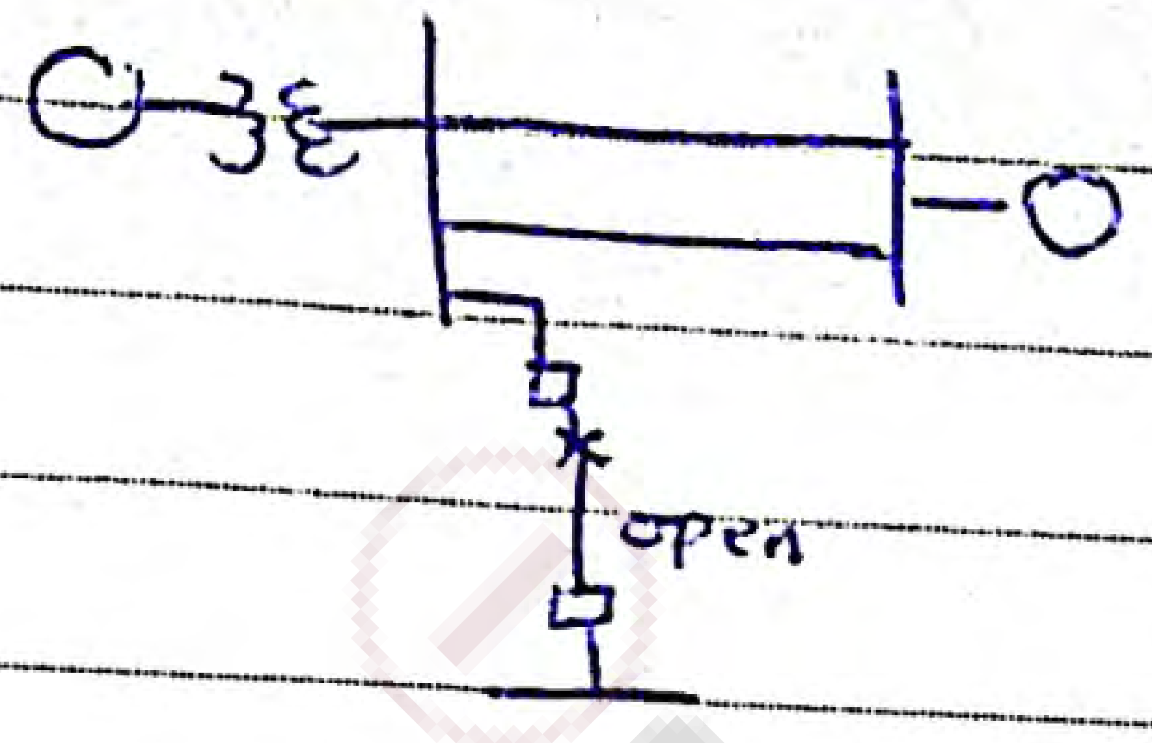


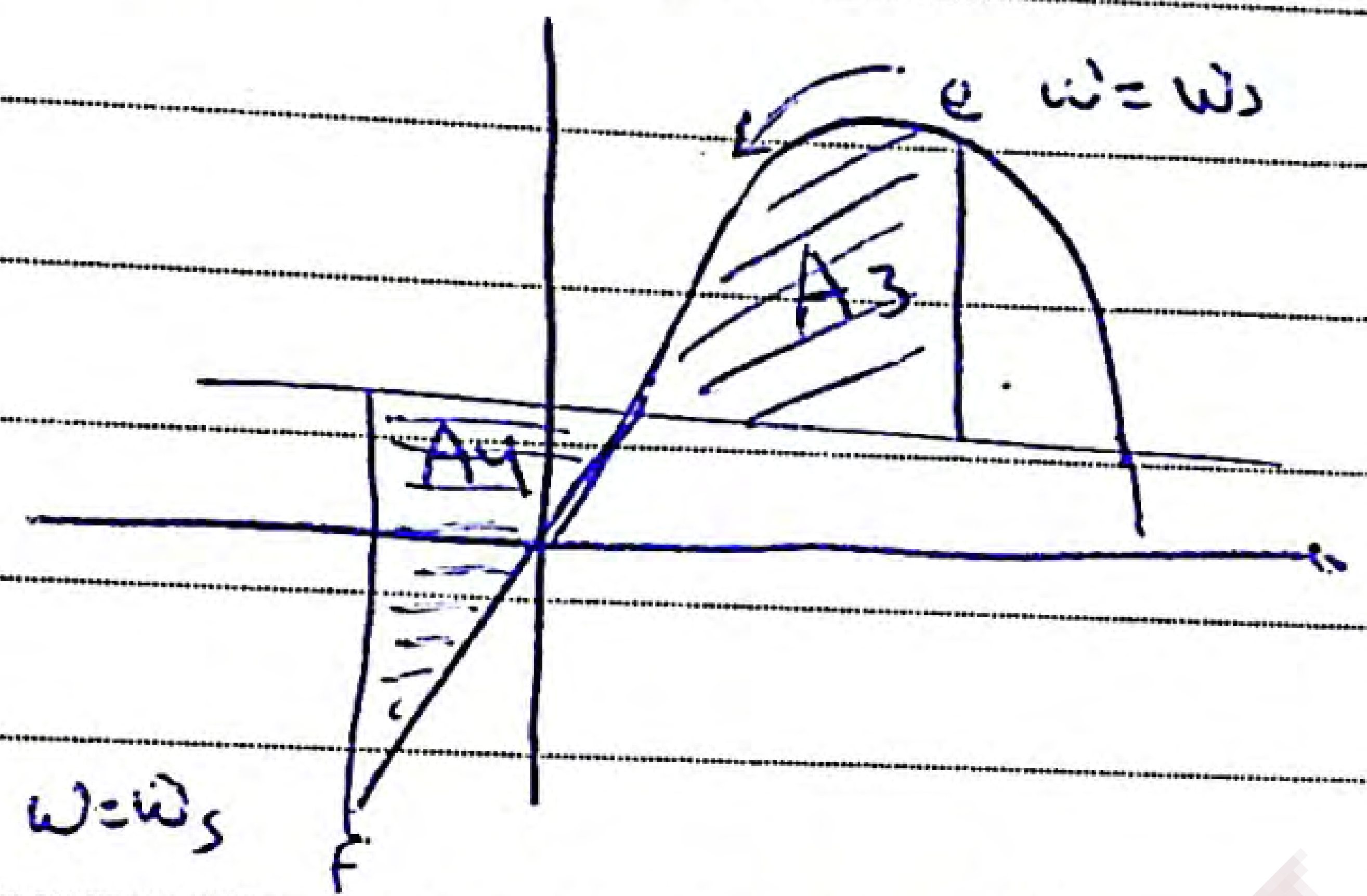
lec # 15

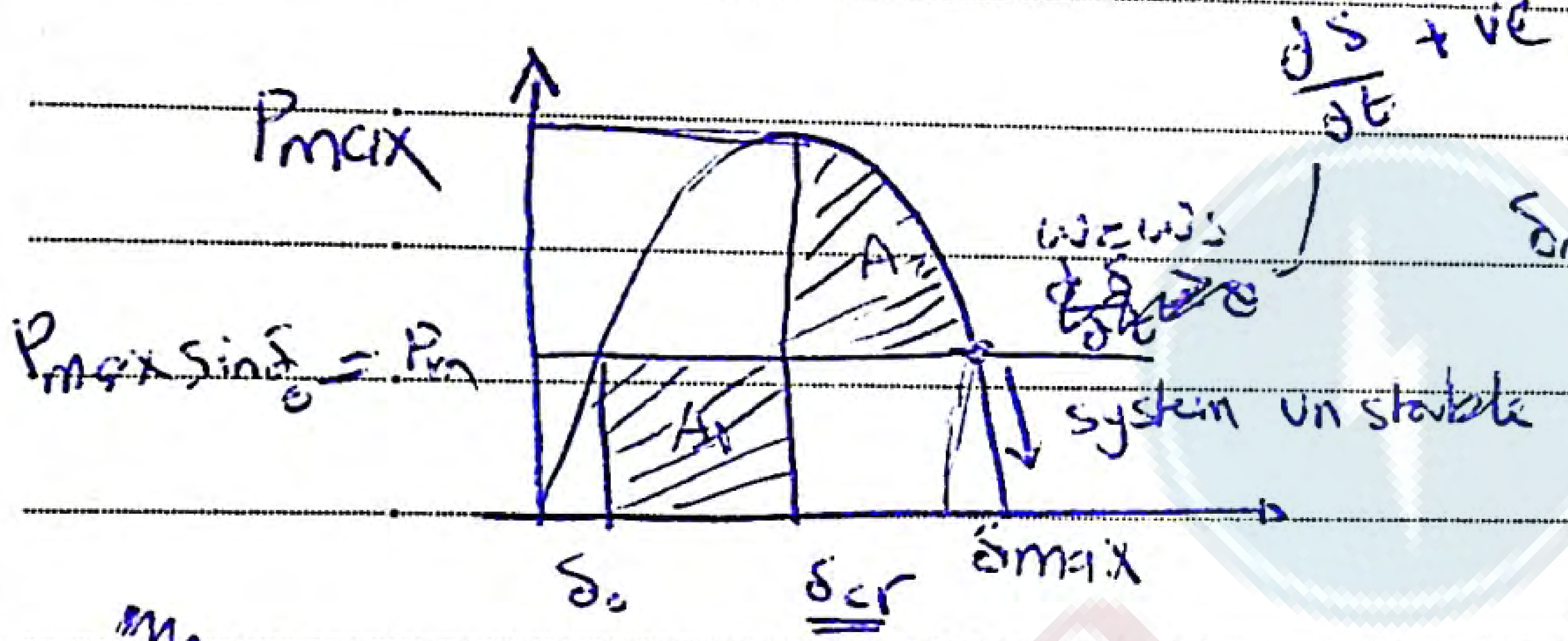
Monday

7/4/2014









$t_c$

$$\delta_c = \frac{\omega_s}{4H} P_m t_c^2 + \delta_o$$

$$A_1 = A_2$$

$$A_1 = \int_{\delta_o}^{\delta_{cr}} (P_m - 0)\, d\delta$$

$$A_2 = \int_{\delta_{cr}}^{\delta_{max}} P_{max}\sin\delta - P_m \, d\delta$$

$$A_1 = P_m(\delta_{cr} - \delta_o) = A_2 = P_{max}(-\cos\delta)\Big|_{\delta_{cr}}^{\delta_{max}} - P_m(\delta_{max} - \delta_{cr})$$

$$\frac{\cancel{P_m\delta_{cr}} - P_m\delta_o}{P_{max}} = \frac{P_{max}\cos\delta_{cr}}{P_{max}} - \frac{P_{max}\cos\delta_{max}}{P_{max}} - \frac{P_m\delta_{max} + \cancel{P_m\delta_{cr}}}{P_{max}}$$

$$\cos\delta_{cr} = \frac{P_m}{P_{max}}(\delta_{max} - \delta_o) + \cos(\delta_{max})$$

$$\cos\delta_{cr} = \sin\delta_o(\pi - 2\delta_o) - \cos\delta_o$$

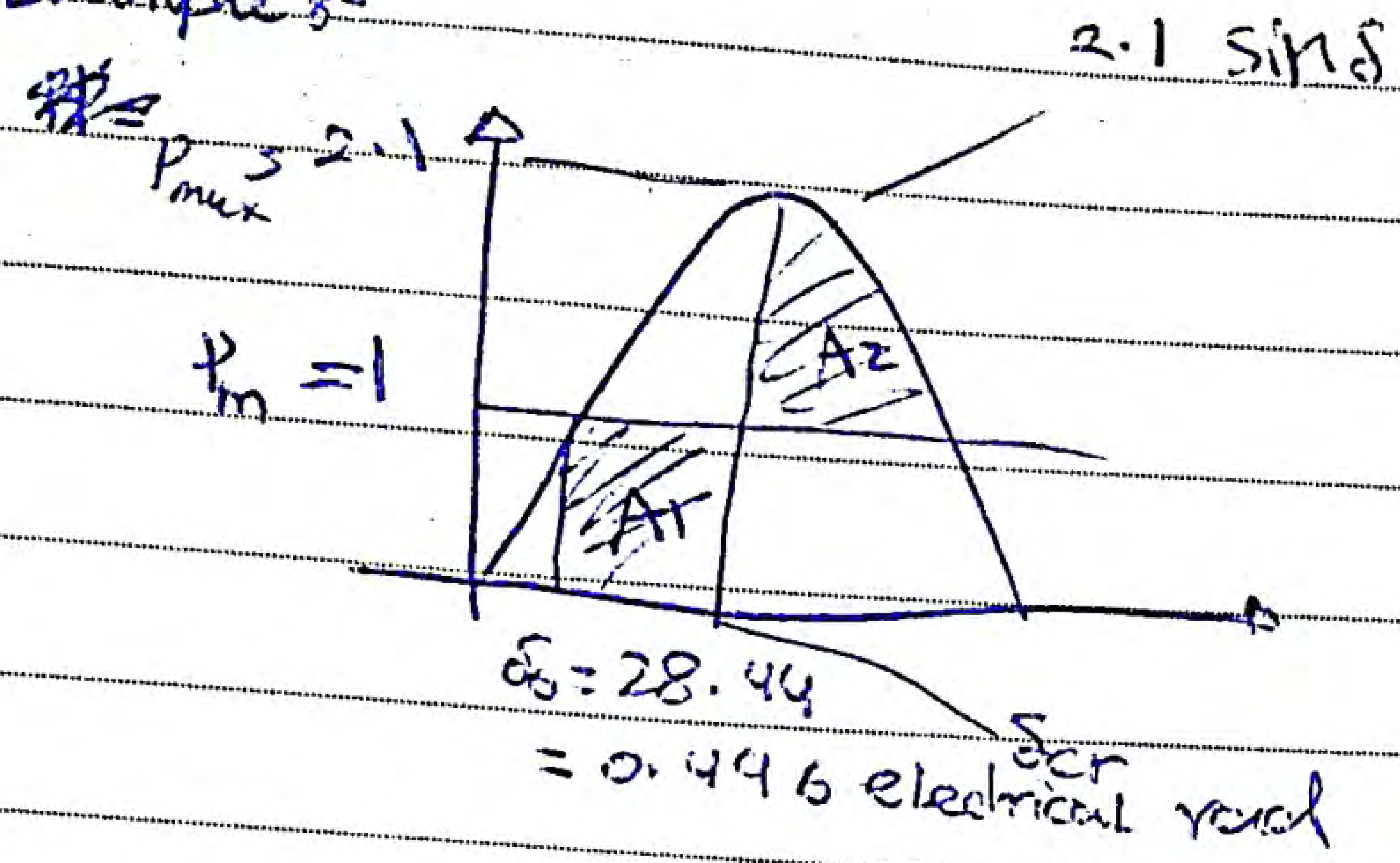
$$\delta_{cr} = \cos^{-1}(\sin\delta_o(\pi - 2\delta_o) - \cos\delta_o)$$

الزاوية التي بحصل عندها الفصل عشان

يضل ال system ← stable

$H = 5$ sec

Example 8:-



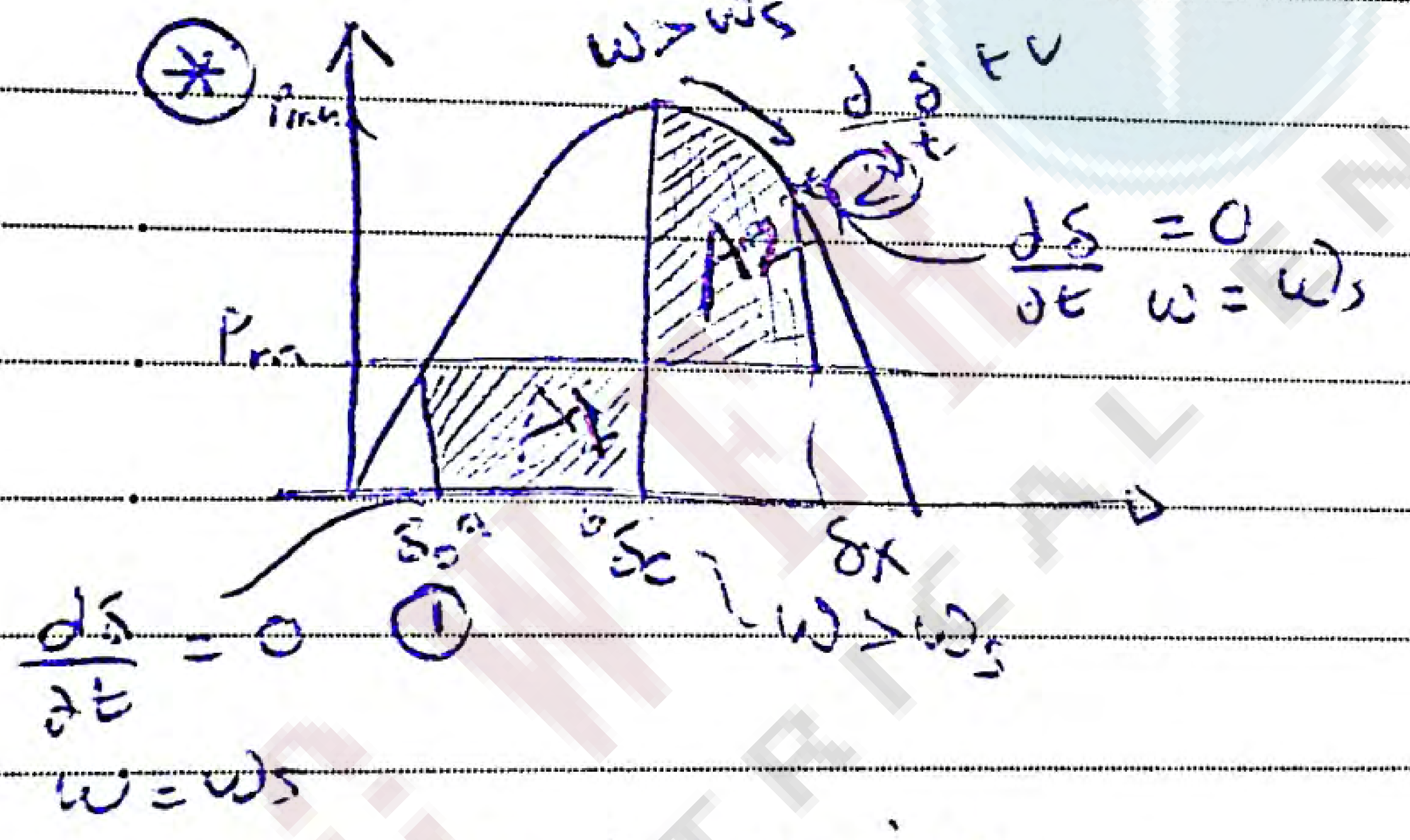
$$\delta_{cr} = \cos^{-1}\left(\sin(28.44)(\pi - 2*0.496) - \cos 28.44\right)$$

$$= 1.426 \text{ elec rad}$$

only when $n=0$

$$t_c = \sqrt{\frac{(\delta_c - \delta_0)\,4H}{\omega_s P_m}} = \sqrt{\frac{(1.426 - 0.496) \times 4 \times 5}{377 \times 1}}$$

$$= 0.222\ S$$



a-b → ω increasing

$$\frac{2H}{\omega_s}\,\frac{d^2\delta}{dt} = P_m - P_e$$

$$\frac{d^2\delta}{dt^2} = \frac{\omega_s}{2H}(P_m - P_e)$$

$$\frac{d\delta}{dt} = \omega - \omega_s = \omega_r$$ deviation on speed

$$\frac{d^2\delta}{dt^2} = \frac{d\omega_r}{dt}$$

Monday

7/4/2014

$$\omega_r \times \frac{2H}{\omega_s}\frac{d\omega_r}{dt} = (P_m - P_e)\frac{d\delta}{dt}$$

$$\frac{H}{\omega_s}\, 2\omega_r \frac{d\omega_r}{dt} = (P_m - P_e)\frac{d\delta}{dt}$$

$$\frac{H}{\omega_s}\frac{d\omega_r^2}{dt} = (P_m - P_e)\frac{d\delta}{dt}$$

$$\frac{H}{\omega_s}\int_{\omega_{r1}}^{\omega_{r2}} d\omega_r^2 = \int_{\delta_1}^{\delta_2} (P_m - P_e)\, d\delta$$

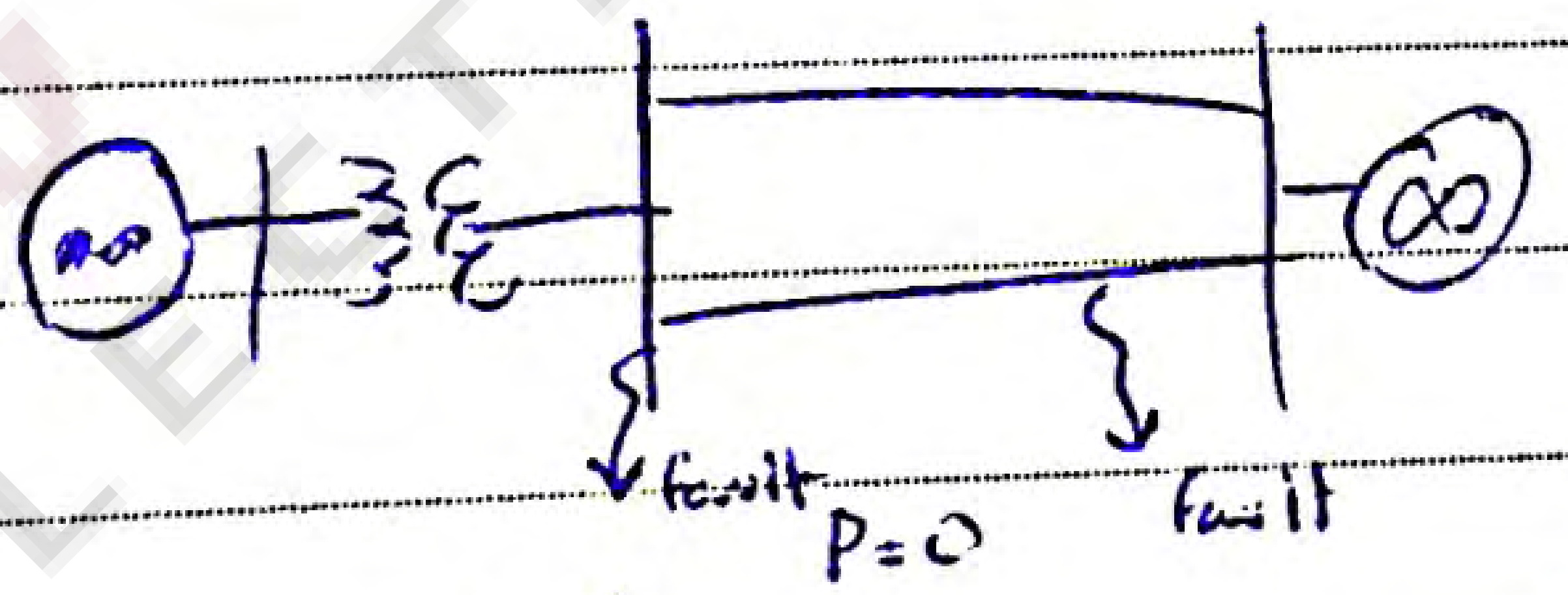
$$0 = \frac{H}{\omega_s}\left(\overset{0}{\cancel{\omega_{r2}}} - \overset{0}{\cancel{\omega_{r1}}}\right) = \int_{\cancel{\delta_1}\ \delta_0}^{\cancel{\delta_2}\ \delta_x} (P_m - P_e)\, d\delta$$

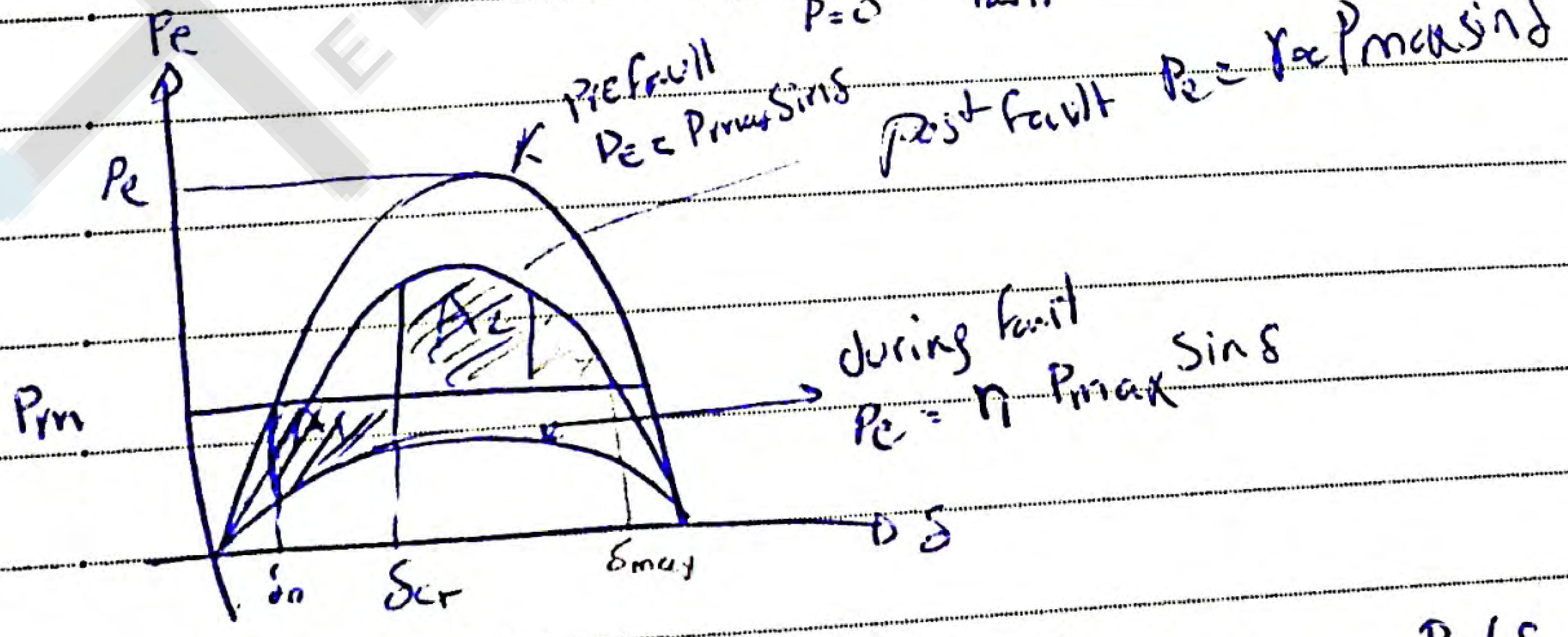
10:05

$$0 = \int_{\delta_0}^{\delta_c} (P_m - P_e)\, d\delta + \int_{\delta_c}^{\delta_x} (P_m - P_e)\, d\delta$$

$$\underbrace{\int_{\delta_c}^{\delta_x} (P_e - P_m)\, d\delta}_{A_2} = \underbrace{\int_{\delta_0}^{\delta_c} (P_m - P_e)\, d\delta}_{A_1}$$

$$A_2 = A_1$$





$$A_1 = \int_{\delta_0}^{\delta_{cr}} (P_m - r_1 P_{max}\sin\delta)\, d\delta = P_m(\delta_{cr} - \delta_0) + r_1 P_{max} (\cos\delta_{cr} - \cos\delta_0)$$

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$$A_2 = \int_{\delta_{cr}}^{\delta_{max}} (r_2 P_{max} \sin\delta - P_m)\, d\delta$$

$$= r_2 P_{max} \left[\cos\delta_{cr} - \cos\delta_{max}\right] - P_m (\delta_{max} - \delta_{cr})$$

$$\cos(\delta_{cr}) = \frac{\cancel{\dfrac{P_m}{P_{max}}}\ \underset{\sin\delta_0}{} (\delta_{max} - \delta_0) + r_2 \cos\delta_{max} - r_1 \cos\delta_0}{\cancel{\dfrac{r/r_2}{r_1}} \quad r_2 - r_1}$$

→ general case.

Lec # 16

Wednesday
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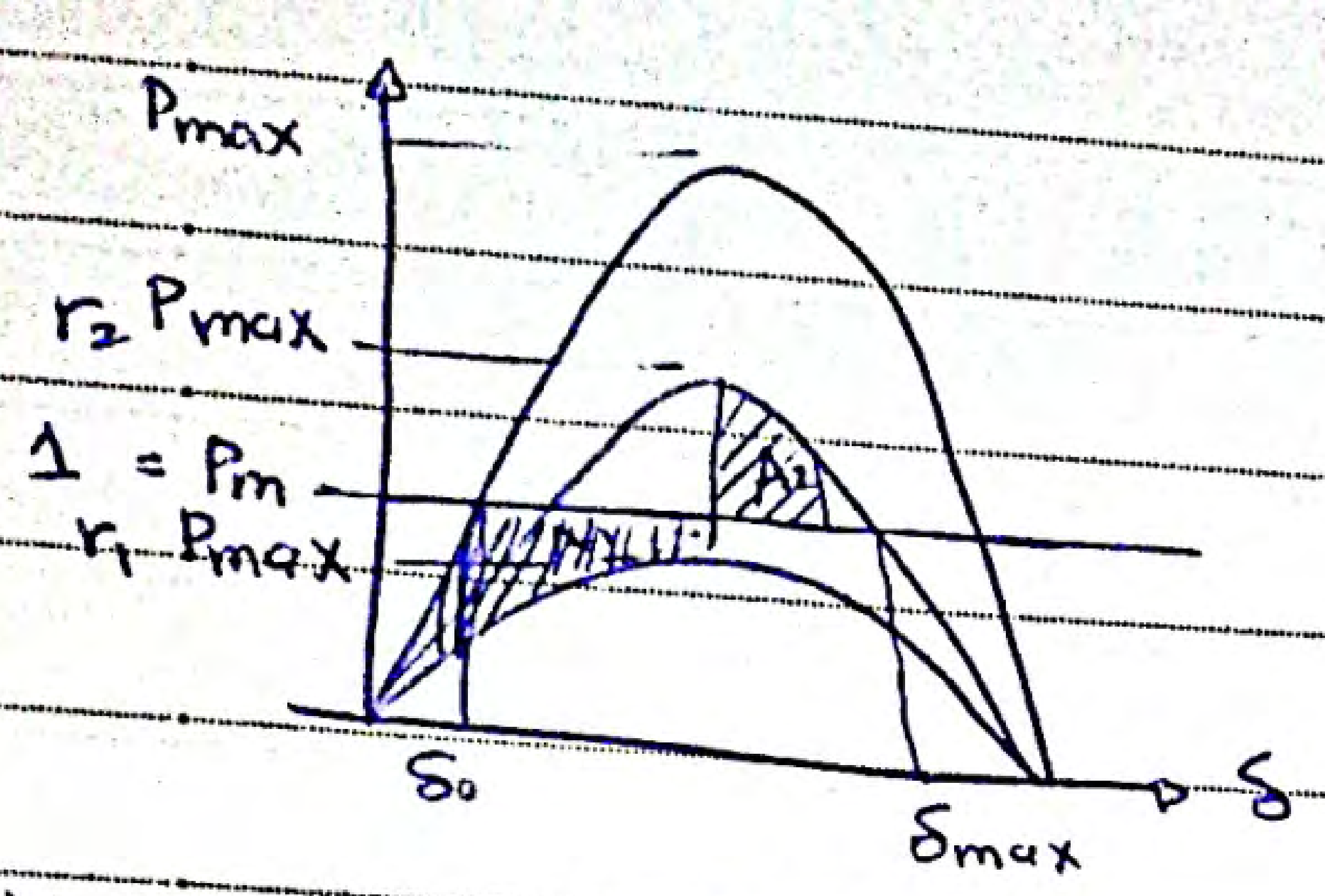
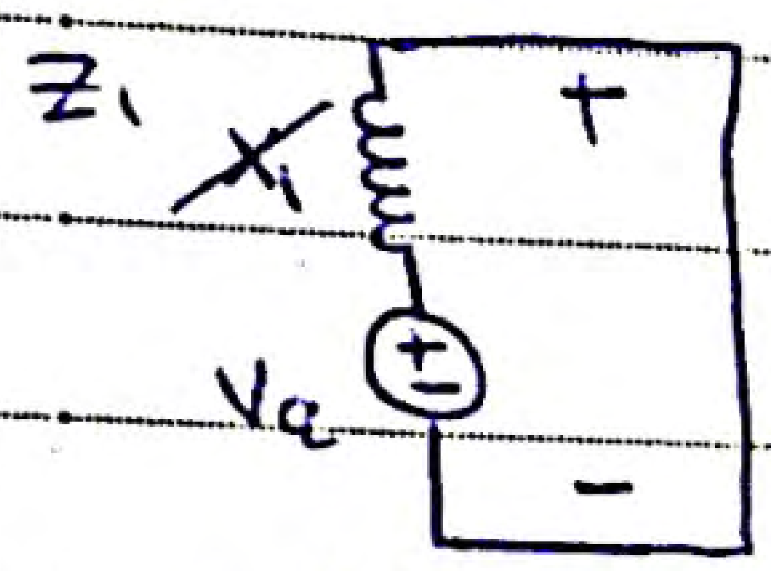


①

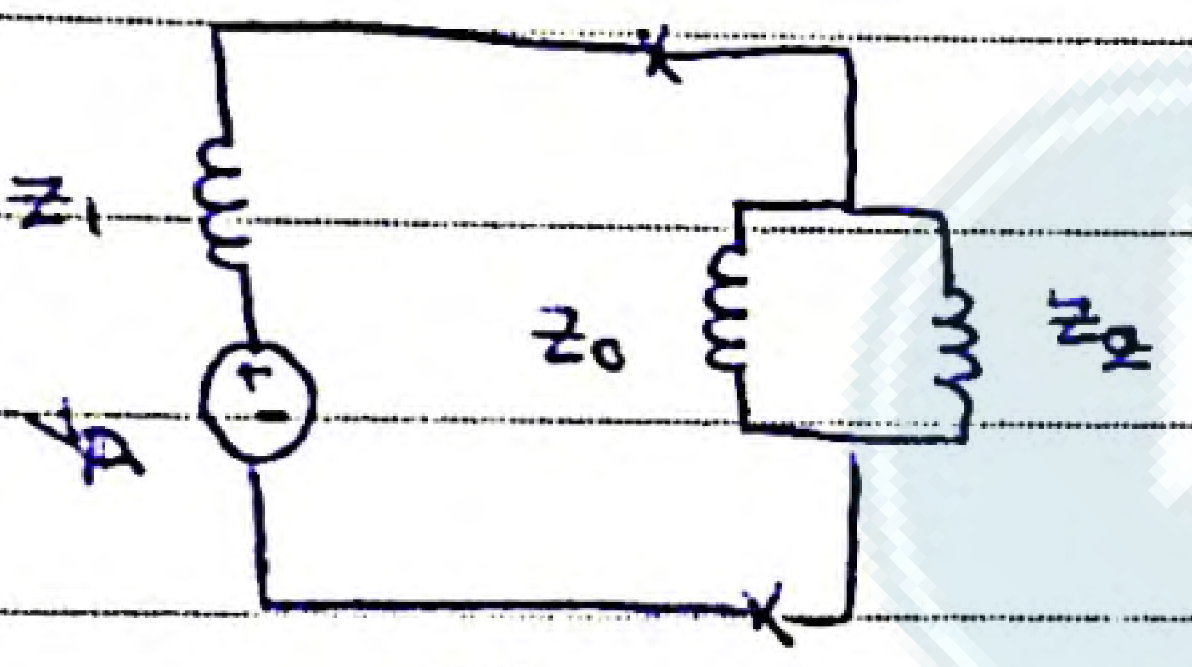
0.1 sec 3-phase fault
0.2 sec if system slow

Fault أشيل



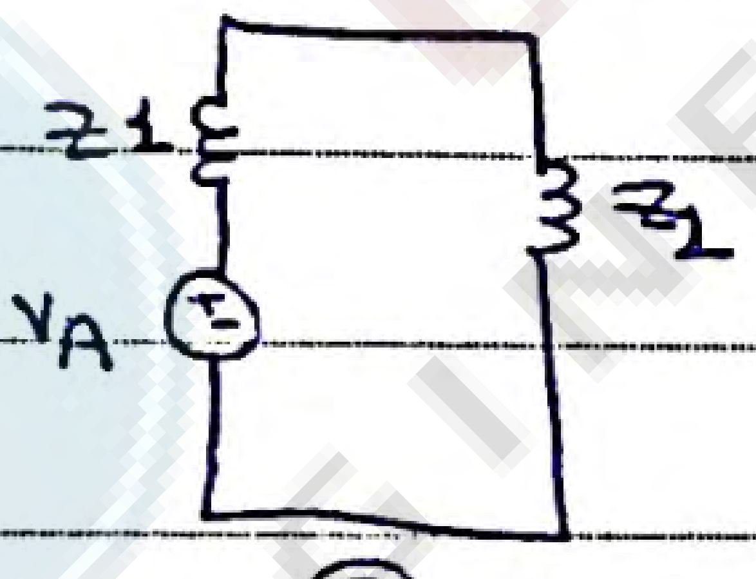
$I_a = \frac{V_a}{jX_{Z_1}}$ @ 3-phase fault

+ve sequence circuit.
L-L-N



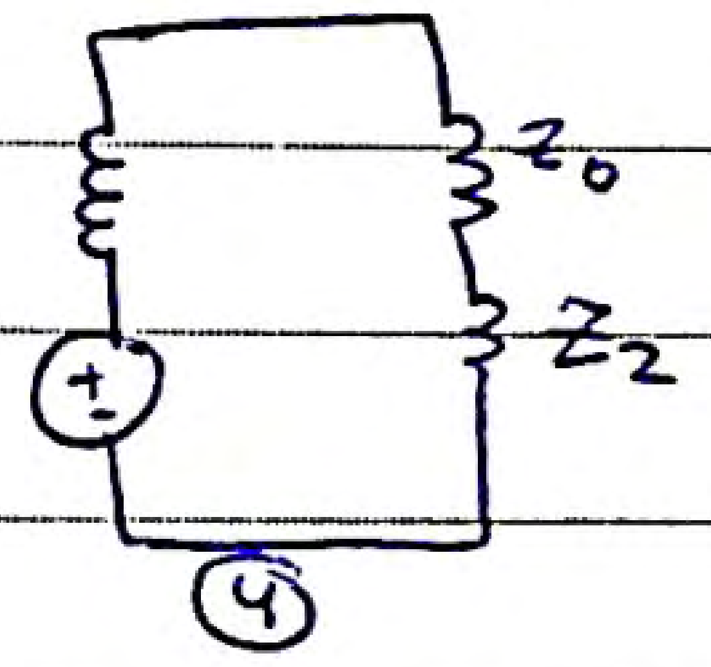
②

L-L



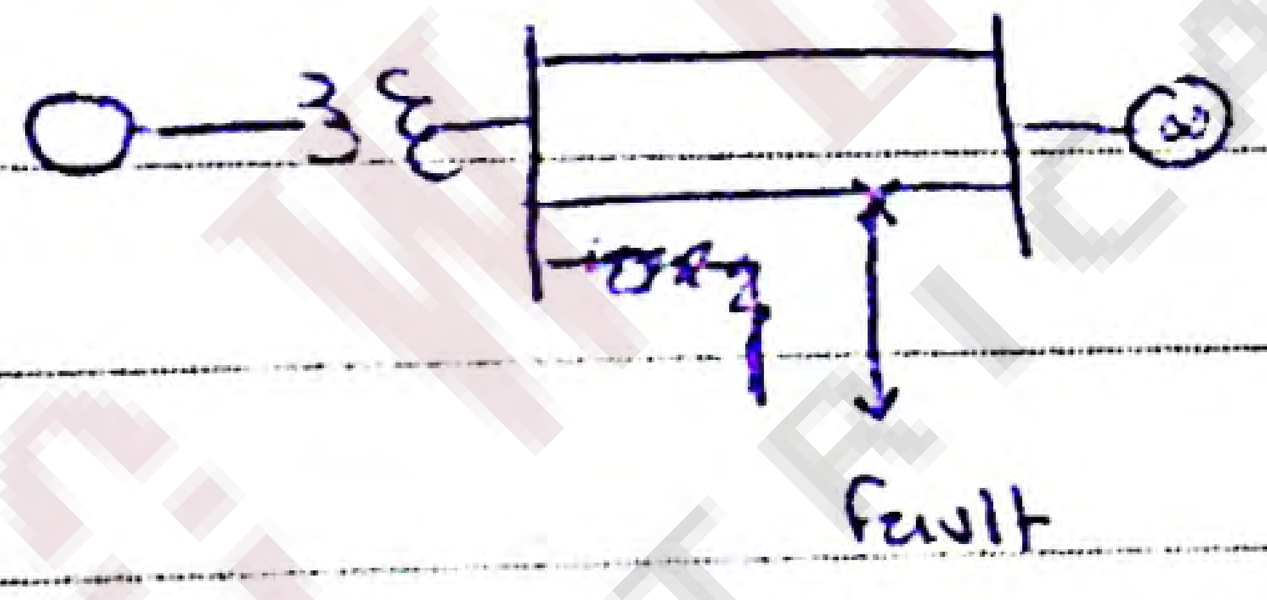
③

L-E



④

Example:



Prefault : $P_e = 2.1 \sin\delta$

during fault : $P_e = 0.808 \sin\delta$

Post fault : $P_e = 1.5 \sin\delta$

$\delta_0 = 28.44° = 0.496$ rad , find $\delta_{cr}$?

$r_1 = \frac{0.808}{2.1} = 0.385$ , $r_2 = \frac{1.5}{2.1} = 0.714$

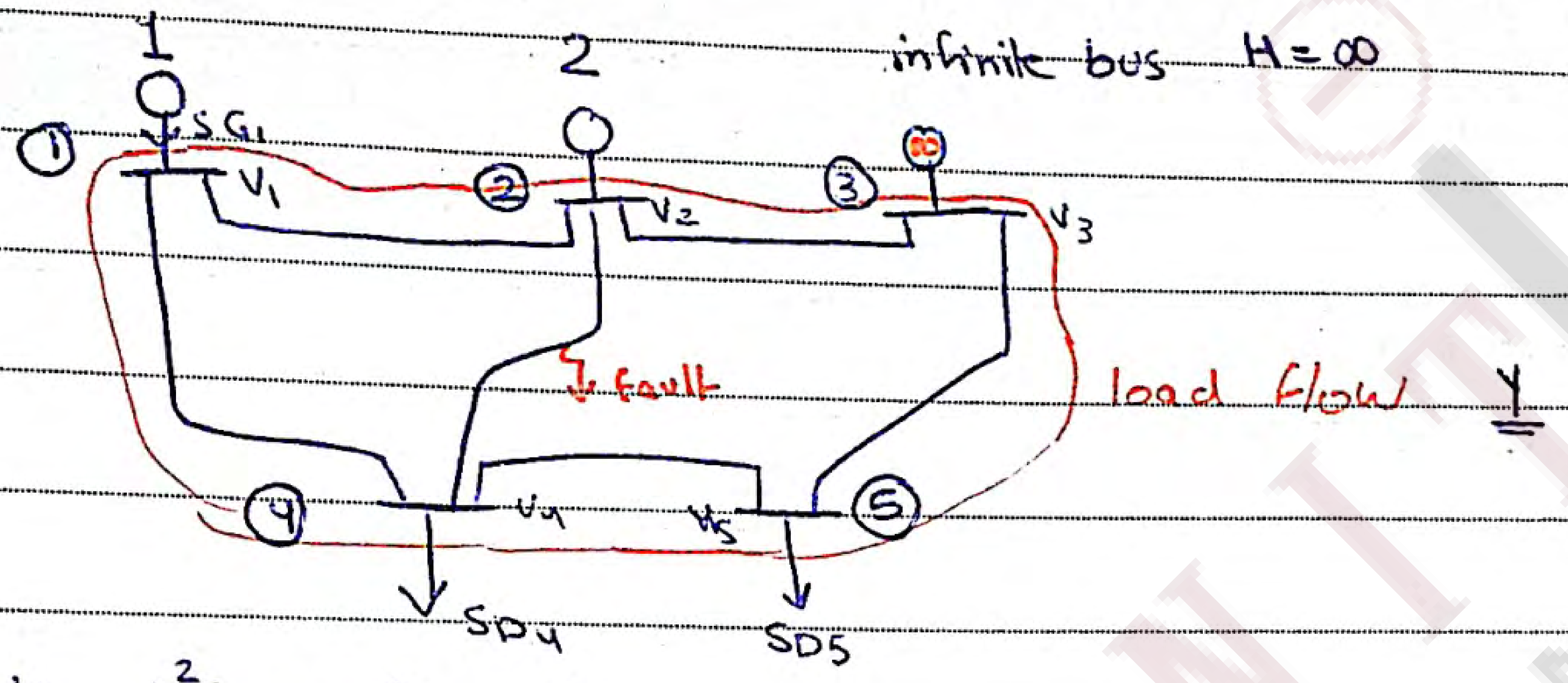
$\delta_0 = 28.44°$

$\delta_{max} = \pi - \sin^{-1}\frac{1}{1.5} =$ ~~N8~~ $138.19° = 2.412$ rad

$$\cos\delta_{cr} = \frac{\frac{1}{2.1}(2.412 - .496) + 0.714\cos(138.19) - 0.385\cos 28.44}{0.714 - 0.385}$$

$= 82.726°$

# Classical Stability Study:
## (multi-machine study):



$S_i = V_i \sum Y_{ik}^* V_k^*$

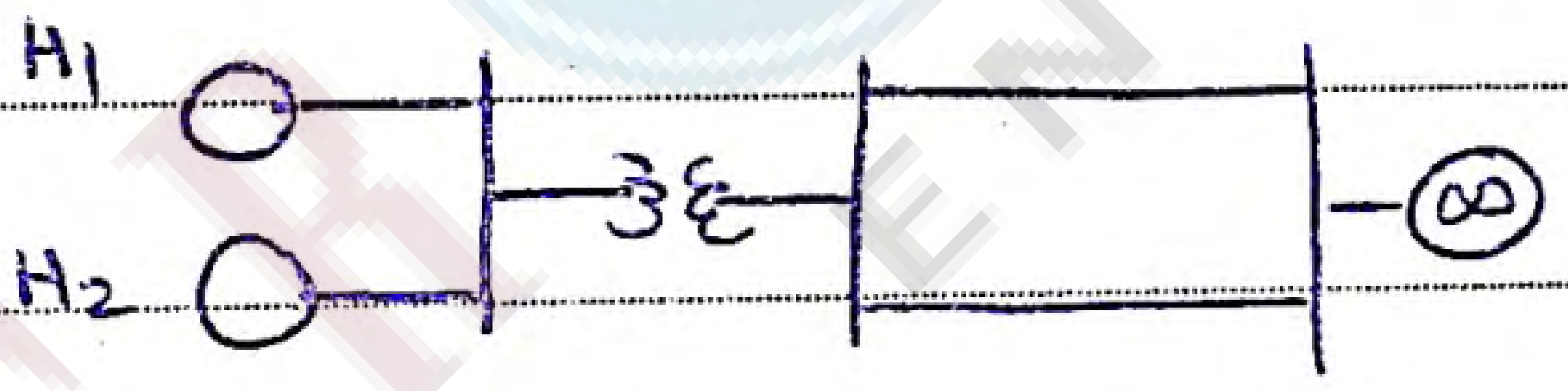
$$\frac{2H}{\omega_s} \frac{d^2\delta}{dt^2} = P_m - P_e$$

$$\frac{d^2\delta}{dt^2} = \frac{\omega_s}{2H}(P_m - P_e)$$

@ infinite bus $H = \infty$ then $\frac{d^2\delta}{dt^2} = 0$

ما بهتز

* * * *



$$\frac{2H_1}{\omega_s} \frac{d^2\delta_1}{dt^2} = P_{m_1} - P_{e_1}$$

$$\frac{2H_2}{\omega_s} \frac{d^2\delta_2}{dt^2} = P_{m_2} - P_{e_2}$$

$$\frac{d^2\delta_1}{dt^2} = \frac{d^2\delta_2}{dt^2} = \frac{d^2\delta}{dt^2}$$

$$\frac{2(H_1 + H_2)}{\omega_s} \frac{d^2\delta}{dt^2} = (P_{m1} + P_{m2}) - (P_{e1} + P_{e2})$$

this machine called Coherent machines

equivelant $H = H_1 + H_2$

* * * *

lec # 15

Wednesday

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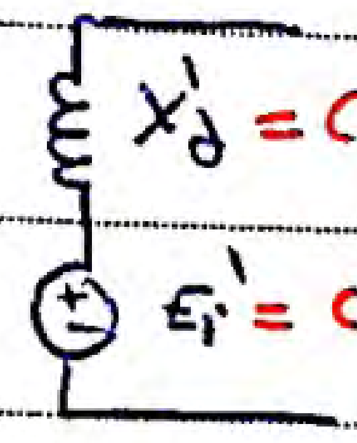
1- $P_m$ For all machines is constant

2- damping is neglected $(\underset{\downarrow \frac{d^2\delta}{dt^2}}{s^2} + \underset{\downarrow \frac{d\delta}{dt}}{2\alpha s} + \omega_n^2)\,\delta_\Delta(s)$

3-



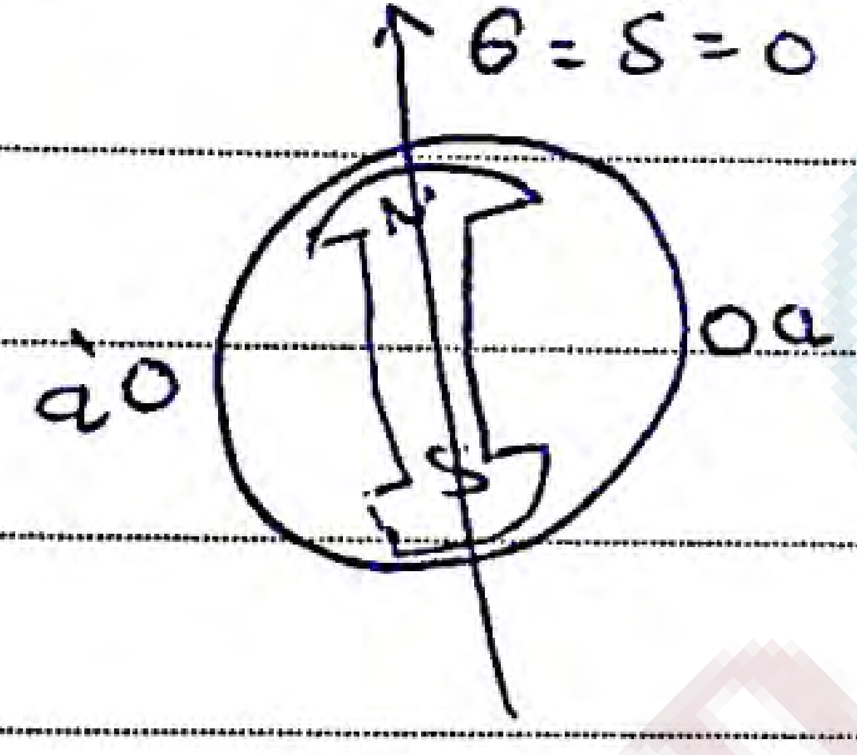
$X'_d$ = Constant

$E'_i$ = constant

$x'_d$ function in $\omega \rightarrow \omega$ constant then $X'_d$ constant

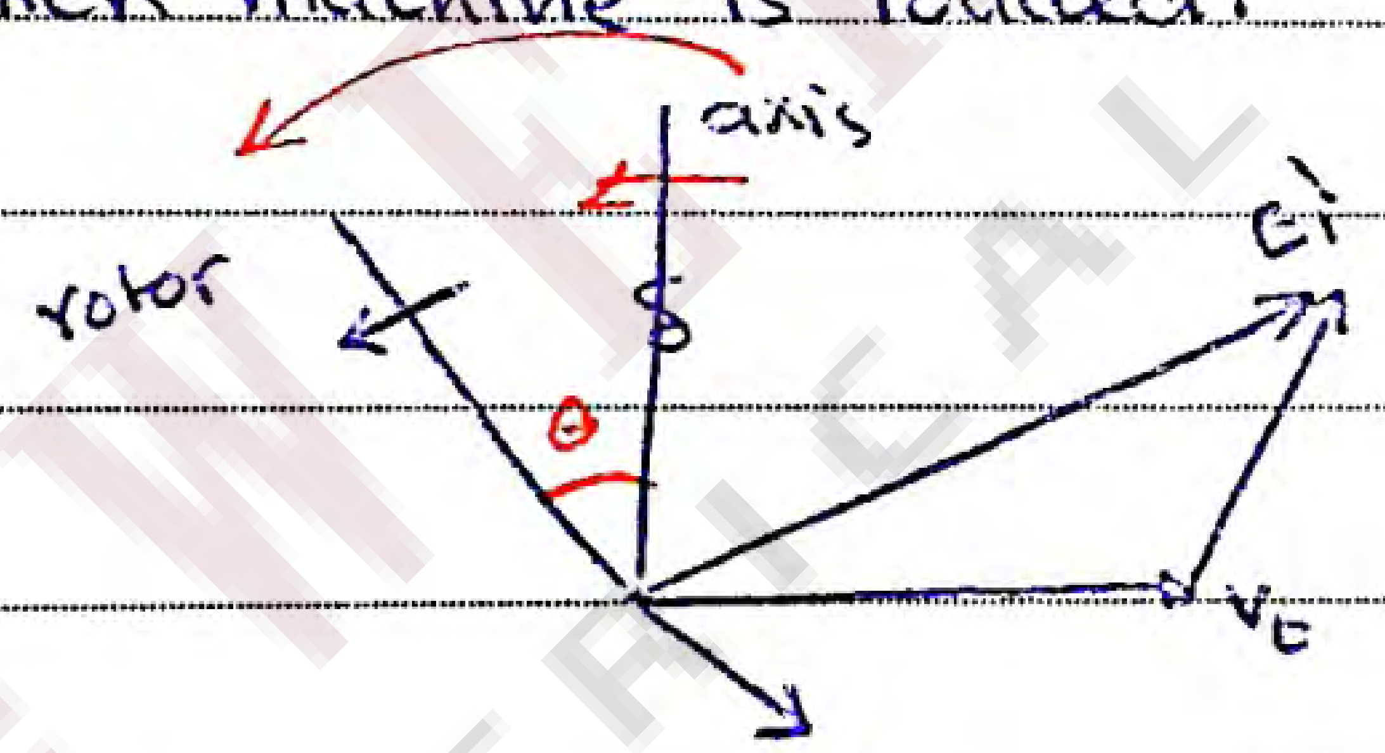
4- $\theta_m = \delta_m + \omega_{sm} t$

$\theta = \delta + \omega_s t$ → electrical



in this case the machine is unloaded.

when machine is loaded:

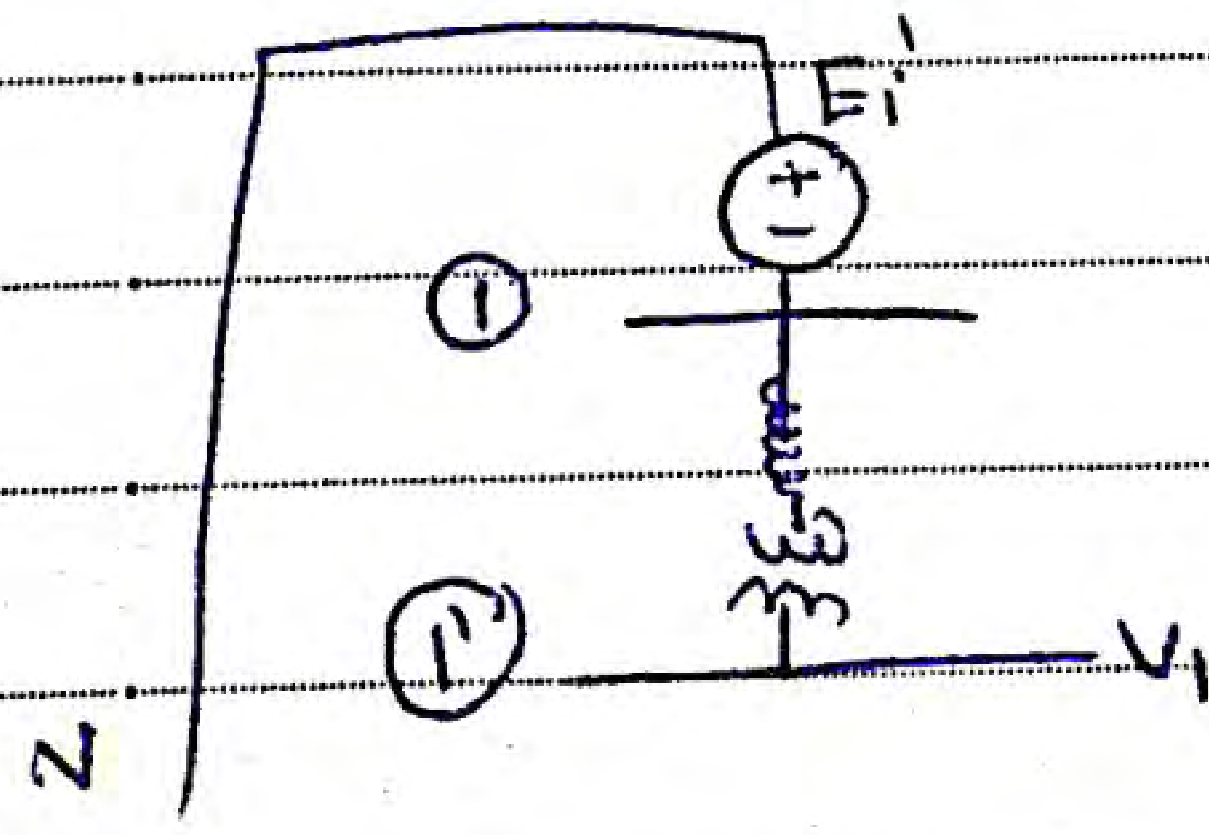


$\delta$ → measured at rotated axis

$\theta$ → measured at stationary axis

5- loads are represented by its admittance.

## 1. load Flow Study:



$S_{G1}, V_1$

$S = V I^*$

$$E'_i = V_1 + I\,(jx'_d + jX_{tran})$$

lec # 16

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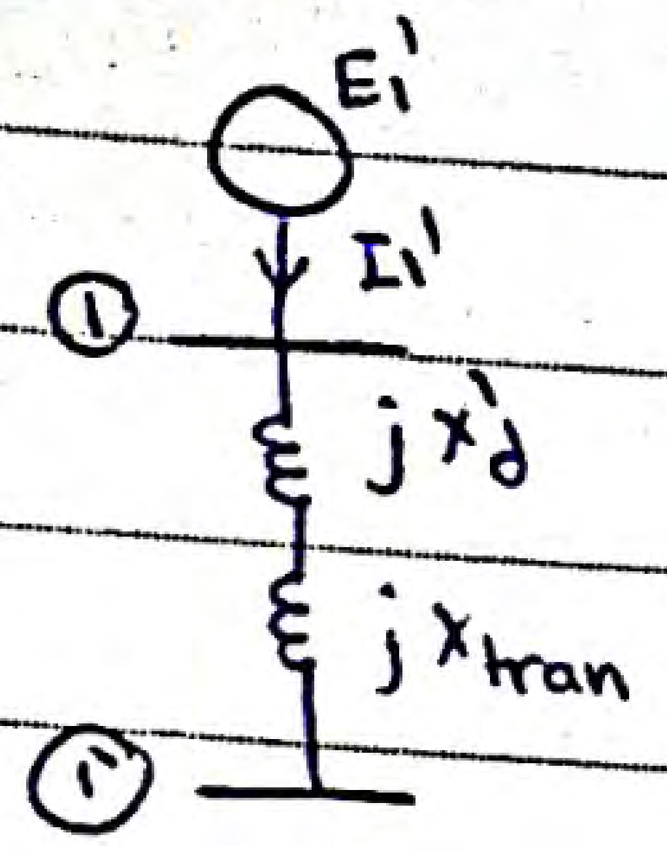


we will make 3 Y matrix ?

1) augmented ( $\overset{\text{prefault}}{Y}$ matrix : load Flow + general transforme reactor

+ gen. trans. react.

5 x 5

$\downarrow$ By cron

3 x 3

$$\left[\begin{array}{c|c} K & L \\ & 3\times3 \\ \hline L^T & M \end{array}\right] 5\times5$$

2. Y matrix during fault.

3. Y-matrix post fault.

$$P_{e1} = |E_1'|^2 G_{11} + |E_1'||E_2'||Y_{12}| \sin(\delta_1 - \delta_2 - \theta_{12}) + |E_1'||E_3'||Y_{13}| \sin(\delta_1 - \delta_3 - \theta_{13})$$

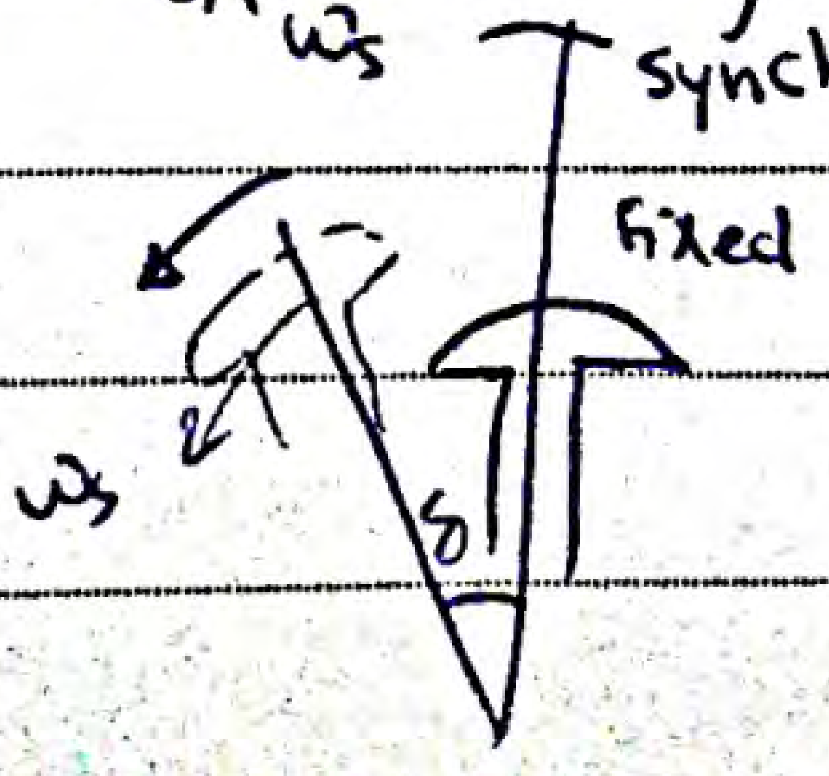
to find Y for $S_{D4}$ :

$S = VI^*$

$I = \frac{S^*}{V^*}$ , $I = YV$

$$Y = \frac{I}{V} = \frac{S^*}{V \times V^*} = \frac{S^*}{|V|^2}$$

if $S_{G1} = 1.8 + j0.9$ then $P_m = 1.8$ p.u.



synchronously rotating frame of refrence.

$\delta$

بتتغير مع ال fault

lec # 16

wednesday
9/4/2014

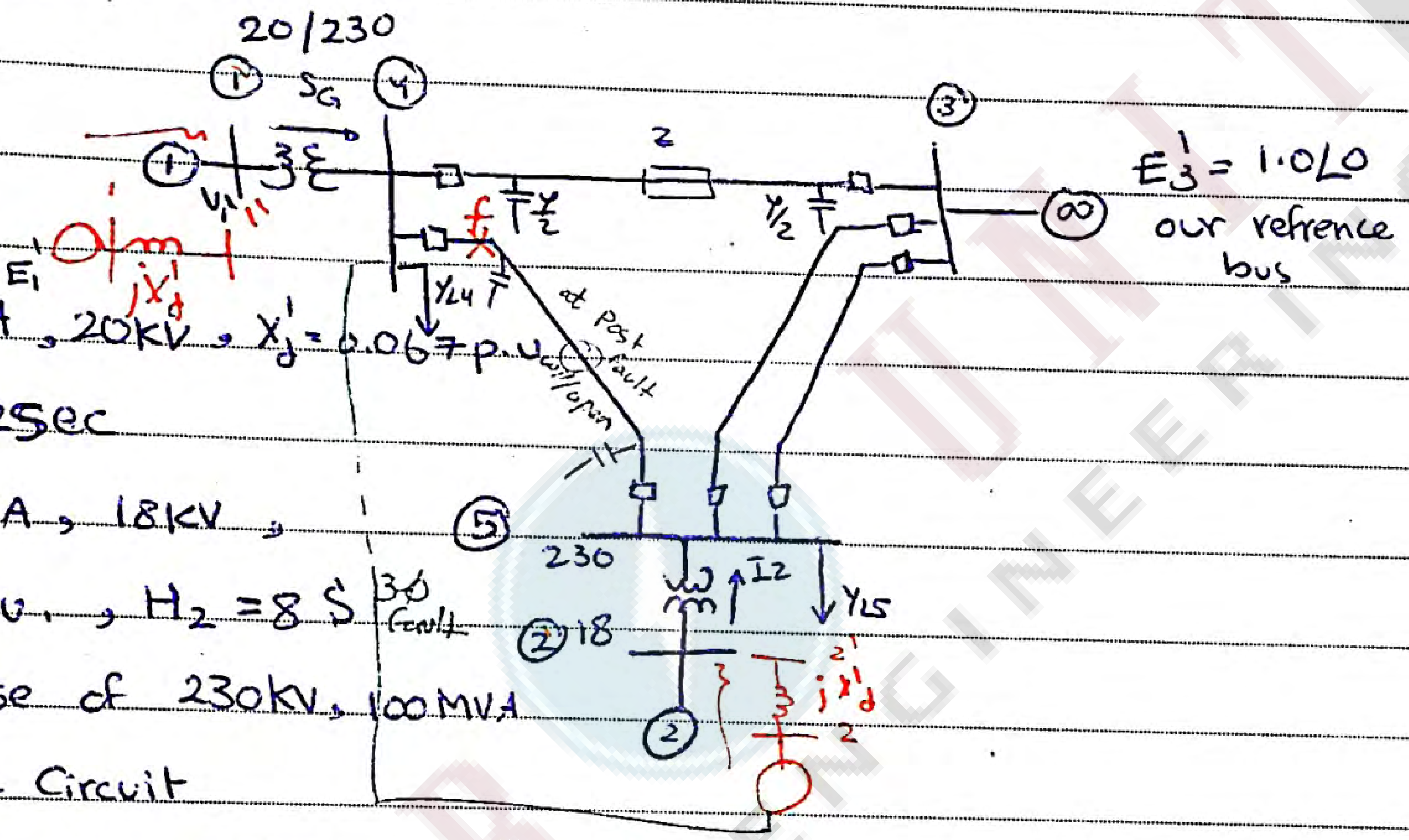
Example:

in next lecture.

lec #17

Monday
14/4/2014

Example:



$G_1$ : 400 MVA, 20kV, $X_d' = 0.067$ p.u

$H_1 = 11.25$ sec

$G_2$: 250 MVA, 18kV,

$X_d' = 0.1$ p.u, $H_2 = 8$ S

given on base of 230kV, 100MVA

TL Circuit

From load flow study:

| bus | Voltage | P, Q gen. | | P, Q load | |
|---|---|---|---|---|---|
| 1' | $1.03\angle 8.88°$ | 3.5 | 0.71 | — | — |
| 2' | $1.02\angle 6.38°$ | 1.85 | 0.98 | — | — |
| 3 | $1.0\angle 0$ | — | — | — | — |
| 4 | $1.018\angle 4.68°$ | — | — | 1.0 | 0.44 |
| 5 | $1.011\angle 2.27°$ | — | — | 0.5 | 0.1 |

Trans 1' : 4 $x = 0.022$ p.u

Trans 2' : 5 $x = 0.04$ p.u

Line 3-4 : $Z = 0.007 + j0.04$, $Y = 0.082$

Line 3-5 : $Z = 0.008 + j0.047$, $Y = 0.098$

Line 4-5 : $Z = 0.018 + j0.11$, $Y = 0.226$

on base 230 kV, 100 MVA

lec # 17

Monday 10:09

14/4/2014

$I_1 = \frac{S_1^*}{V_1^*} = \frac{3.5 - j0.71}{1.03 \angle -8.88^\circ} = 3.486 \angle -2.619$ p.u.

$E_1' = 1.03 \angle 8.88 + j0.067 I_1$

$= 1.1 \angle 20.82$

$I_2 = \frac{S_2^*}{V_2^*} = \frac{1.85 - j0.298}{1.02 \angle -6.38^\circ} = 1.837 \angle -2.771^\circ$

$E_2' = 1.02 \angle 6.38 + j0.1 I_2 = 1.065 \angle 16.19^\circ$

$P_{m1} = P_{E1}$ Before the fault.

$P_{m1} = 3.5$ p.u. $= P_{e10}$

$P_{m2} = 1.85$ p.u. $= P_{e20}$

$Y_{L4} = \frac{S_4^*}{|V_4|^2} = \frac{1.0 - j0.44}{(1.018)^2} = 0.9649 - j0.4246$

$Y_{L5} = \frac{S_5^*}{|V_5|^2} = \frac{0.5 - j0.16}{(1.011)^2} = 0.4892 - j0.1565$

row 1

$Y_{11} = \frac{1}{j0.067 + j0.22}$

$Y_{12} = 0$

$Y_{13} = 0$

$Y_{14} = \frac{-1}{j0.067 + j0.22}$

$Y_{15} = 0$

row 4

$Y_{41} = Y_{14}$

$Y_{42} = 0$

$Y_{43} = \frac{-1}{0.007 + j0.4}$

$Y_{44} = \frac{1}{j0.067 + j0.22} + j0.041 + \frac{1}{0.007 + j0.4} + \frac{1}{0.018 + j0.11} + j0.113$

$+ 0.9649 - j0.4246$

augmented Y-matrix → get matrix 5x5

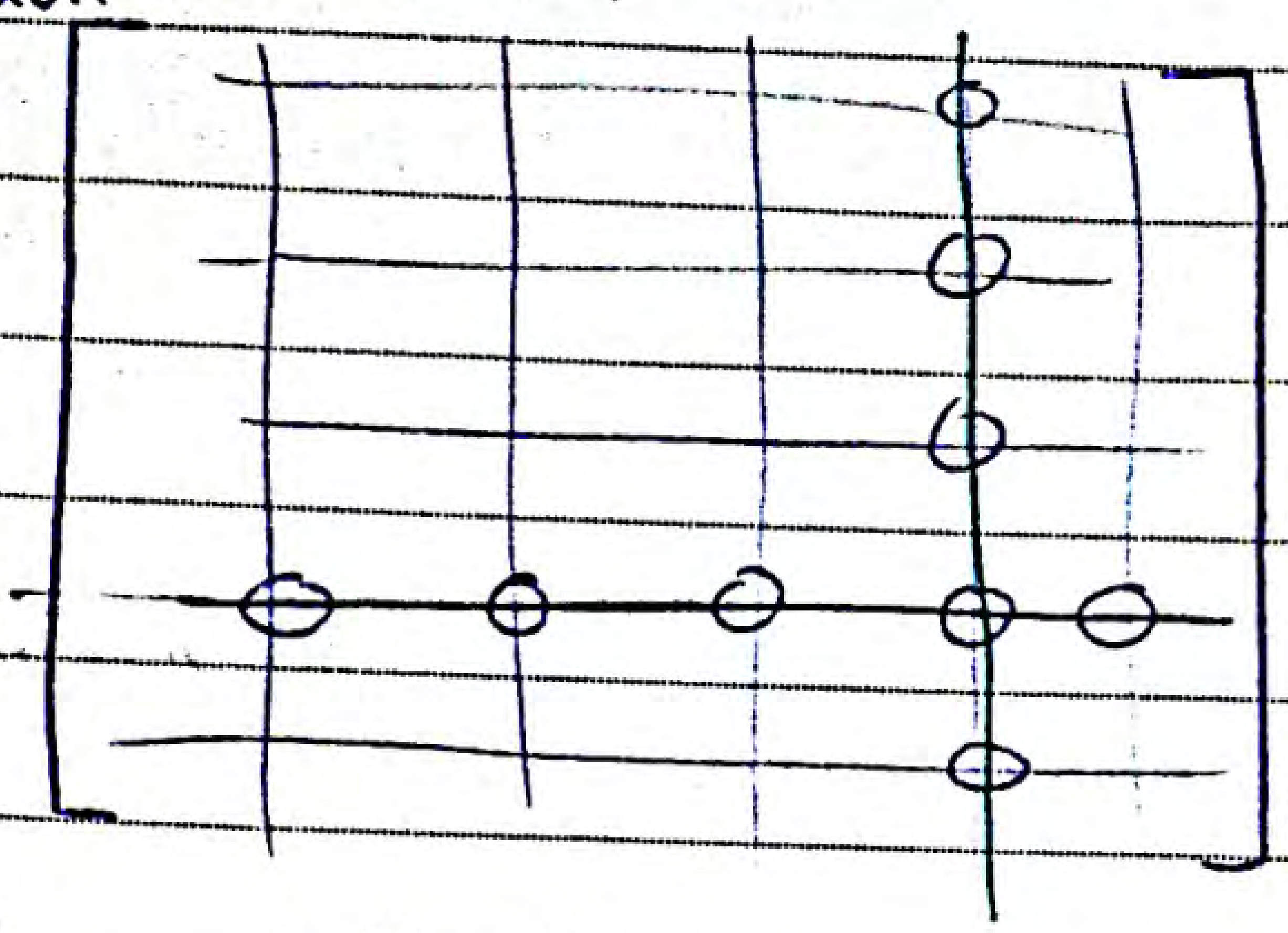
$Y_{45} = \frac{-1}{0.618 + j0.11}$

lec # 17

Monday

14/4/2014

## during fault:



eliminate row 4 & Column 4

and we will get 4x4 matrix

$P_{e1} = 0$ , $V_4 = 0$

$$\begin{bmatrix} 0-j11.236 & 0 & 0 \\ 0 & \overset{6.2752\angle -88.756}{0.1362-j6.2737} & Y_{23} \\ 0 & & \end{bmatrix}_{3\times3}$$

$Y_{23} = 5.1665 \angle 90.7752^{\circ}$

eliminated bus matrix during fault.

$$P_{e1} = |E_1'|^2 \underset{0}{\underline{\underline{G_{11}}}} + |E_1'||E_2'| \underset{0}{Y_{12}} \sin(\quad) + |E_1'||E_2'| \underset{0}{\cancel{Y_{23}}} \sin(\quad)$$

$$P_{e2} = \cancel{|E_1'||E_2'|} \overset{0}{Y_{21}} \cancel{\cos} + \overset{1.065^2 \times 0.1362}{|E_2'|^2 G_{22}} + \overset{1.065 * 1 * 5.165}{|E_2'||E_3'||Y_{23}|} \underset{\cos(\delta_2 - \delta_3 - 90.755}{\sin(\delta_2 - \delta_3 - .755)}$$

$$P_{e2} = 0.1545 + 5.5023 \sin(\delta_2 - 0.755)$$

swing equation.

$$P_{e1} \rightarrow \frac{H_1}{180f} \frac{d^2\delta_1}{dt^2} = 3.5 - 0$$

$$P_{e2} \longrightarrow \frac{H_2}{180f} \frac{d^2\delta_2}{dt^2} = 1.85 - P_{e2}$$

## during Post fault :

augmented prefault matrix

$$\begin{bmatrix} & & \\ & & \\ & & \end{bmatrix}_{5\times5}$$

$Y_{45} = 0$

$Y_{54} = 0$

$Y_{44} = Y_{44old} - \frac{1}{Z_{45}} - j0.113$

$Y_{55} = Y_{55old} - \frac{1}{Z_{54}} - j0.113$

and it will be 3x3

lec # 18

Wednesday

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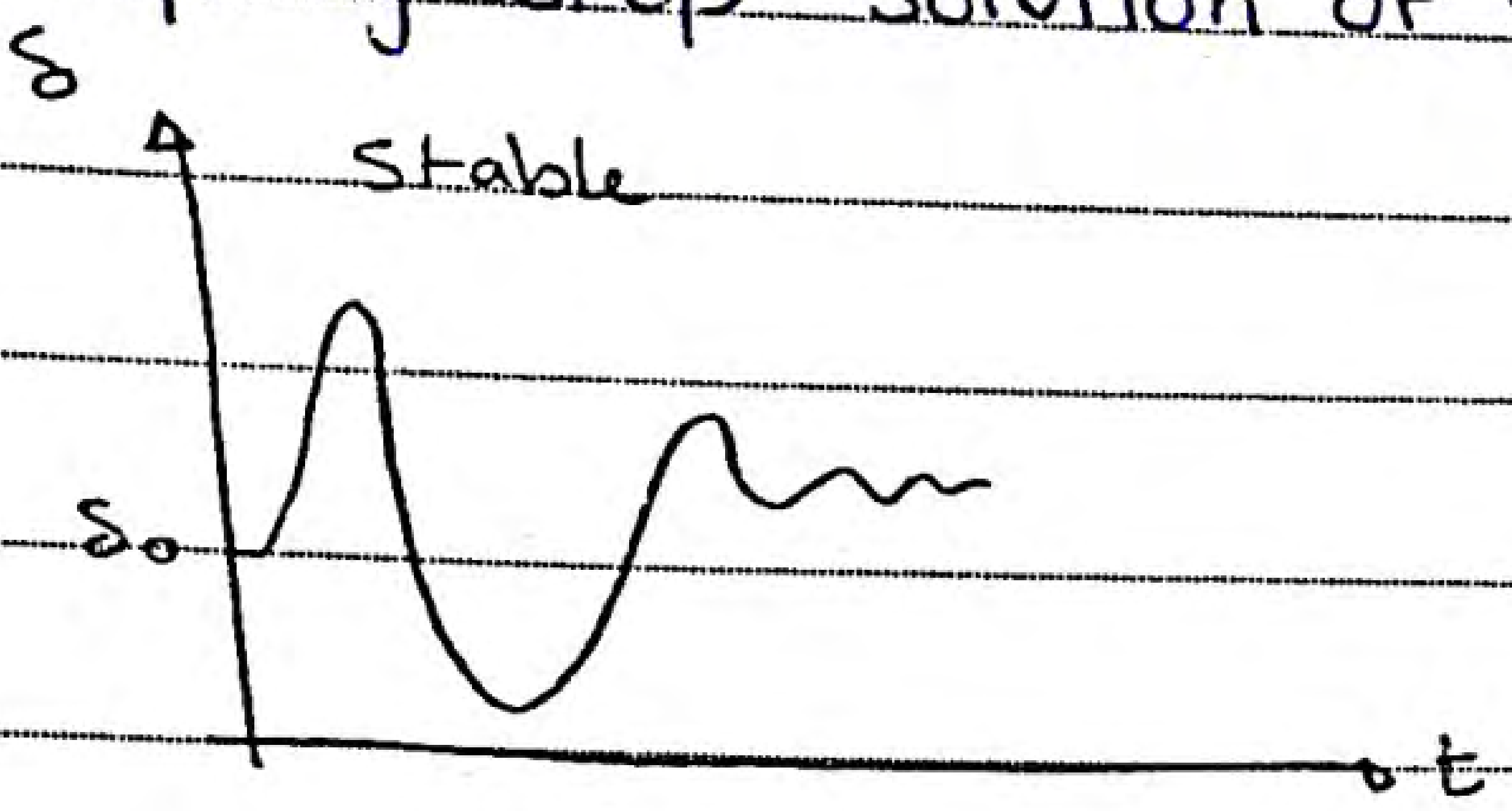
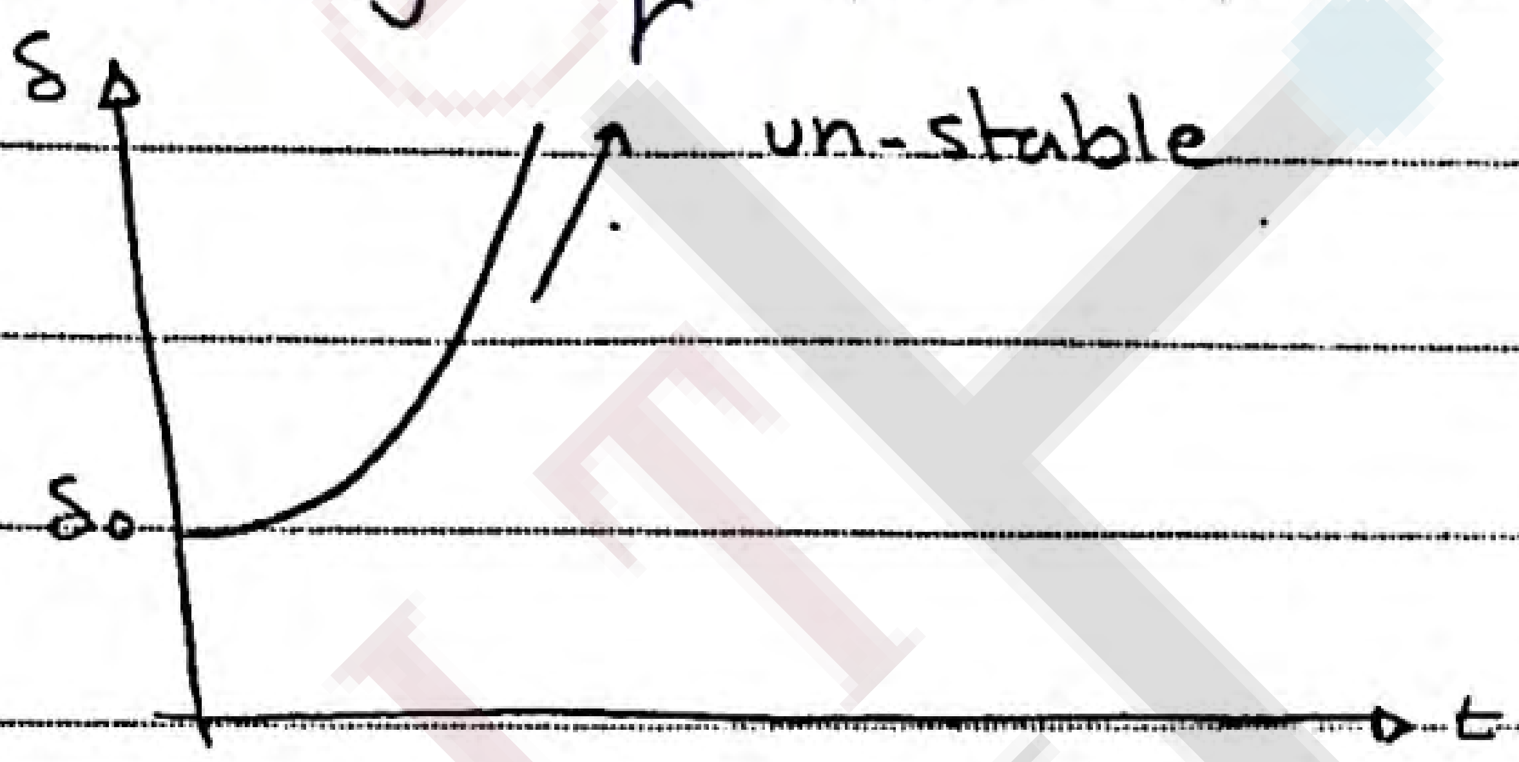
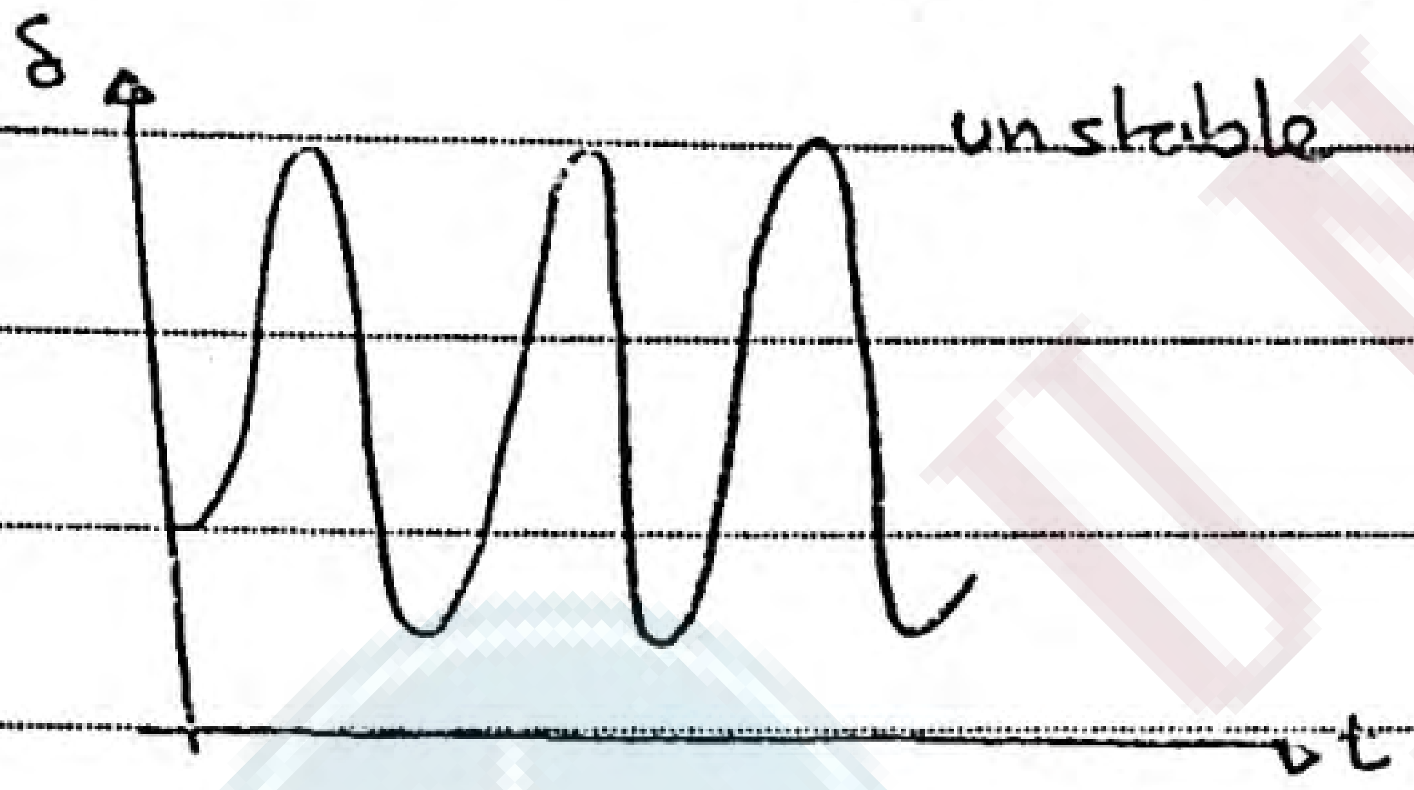
$$\frac{H}{180f}\frac{d^2\delta}{dt^2} = P_m - P_e = P_a$$

## Step by step solution of the swing equation :







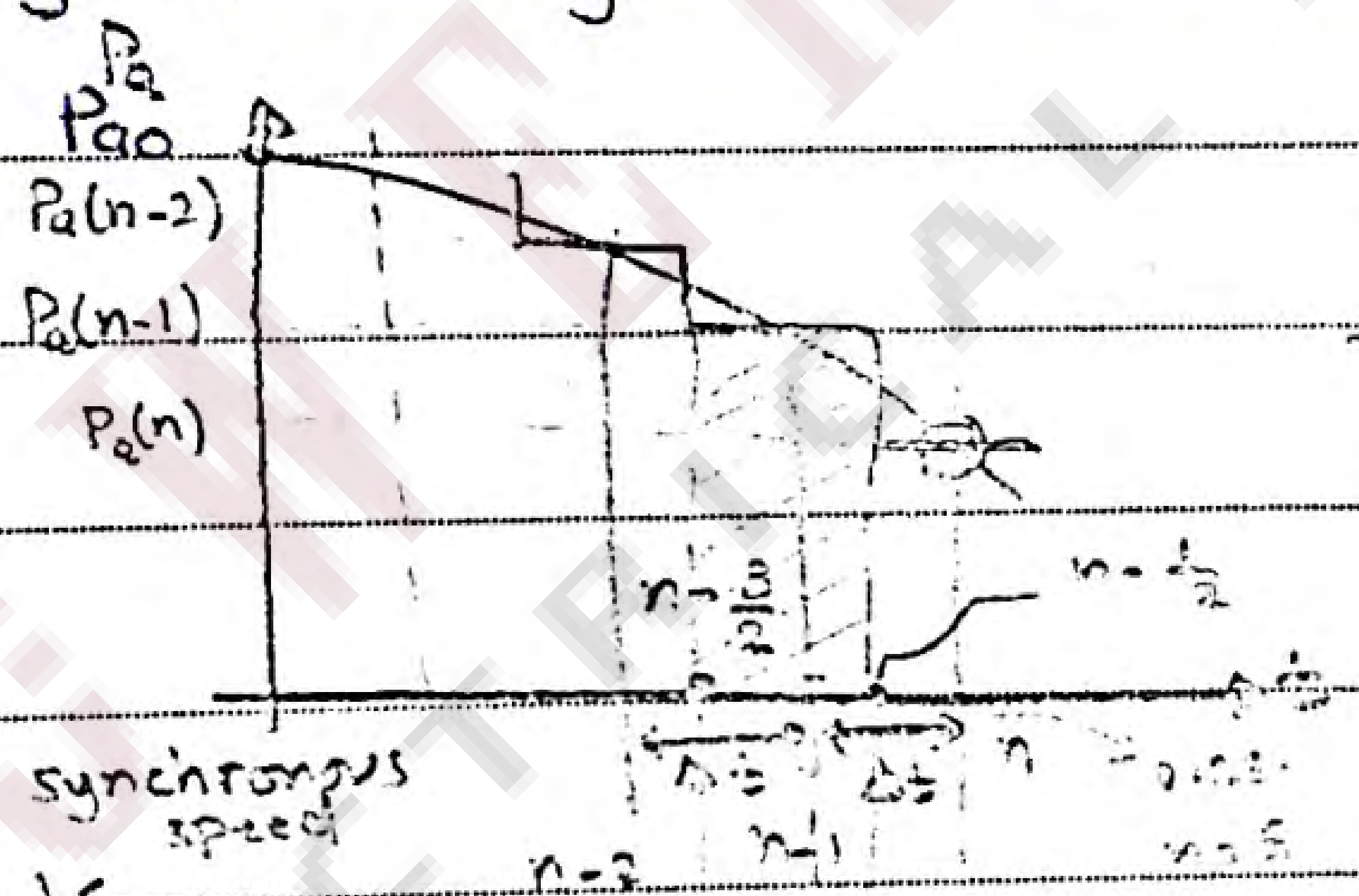
- Fault at most severe ~~condition~~ position
- Fault time 0.1 sec 0.2 sec

(relay operating 50msec time + Circuit Breaker 50 msec clearing time)

$P_a^{0^-} = 0$

$P_a^{0^+} = P_{a0}$

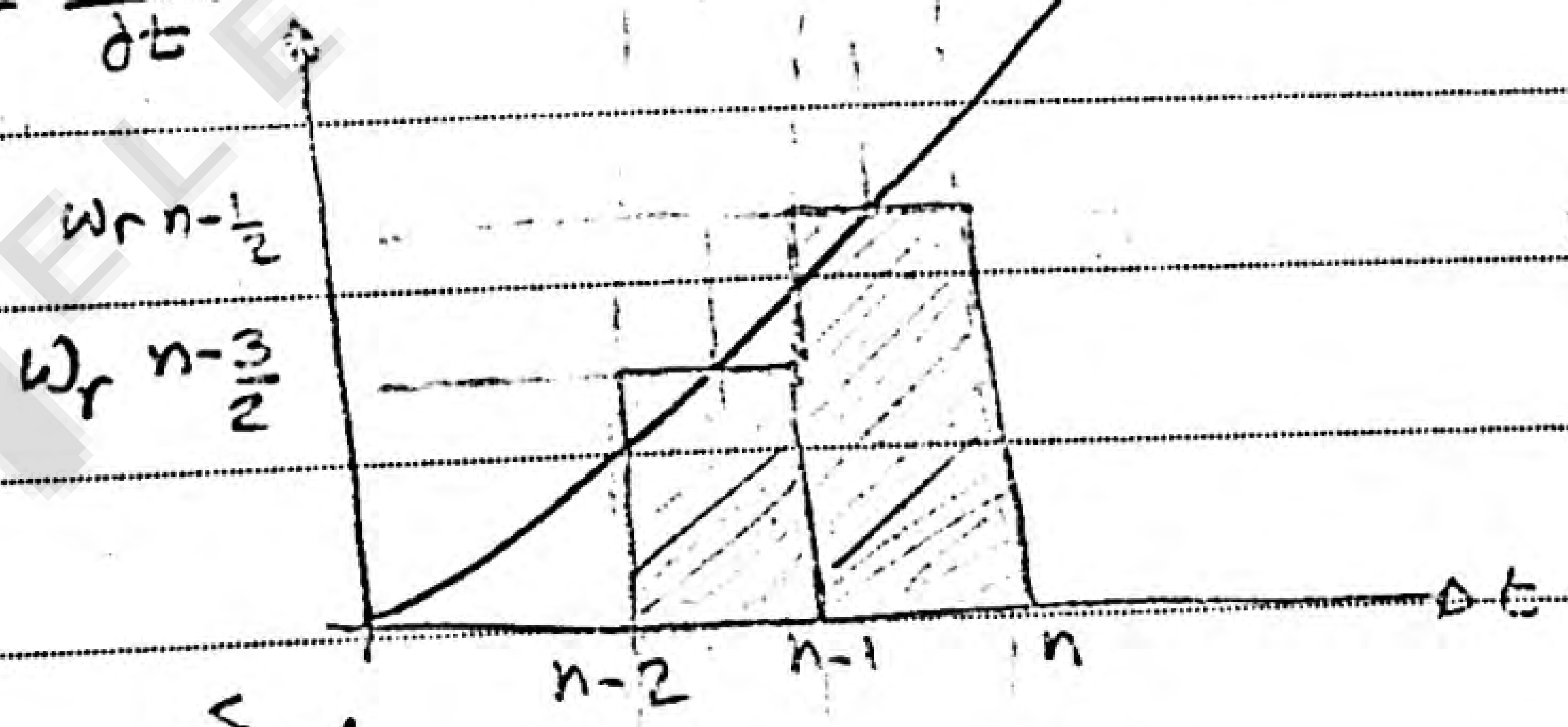
take average.



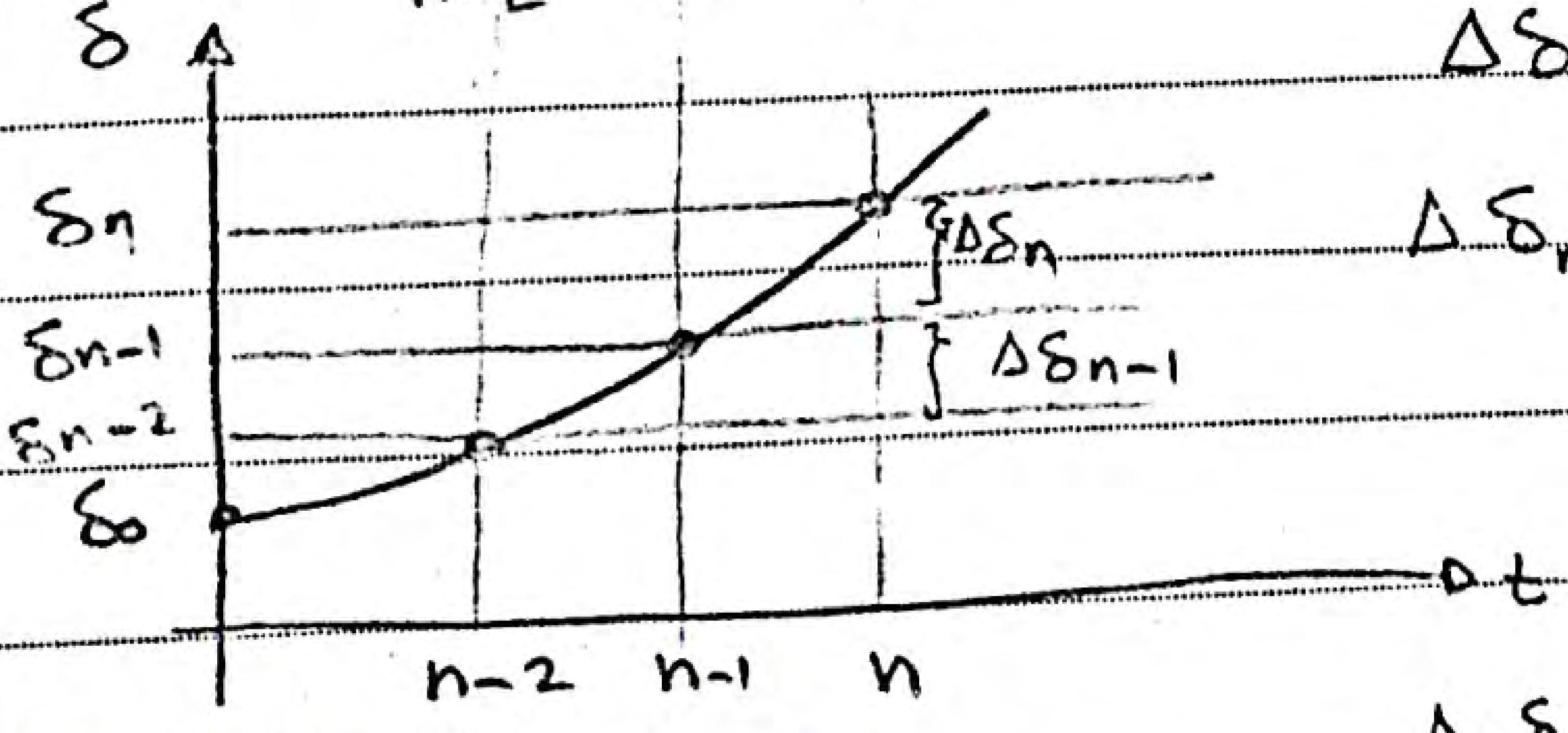
$\frac{d^2\delta}{dt^2} = P_a \times \frac{180f}{H}$

deviation synchronous speed

$\omega_r = \frac{d\delta}{dt}$



$$\omega_{r\,n-\frac{1}{2}} - \omega_{r\,n-\frac{3}{2}} = \frac{180f}{H} P_{a\,n-1} \cdot \Delta t$$



This called swing curve

$$\Delta\delta_n = \delta_n - \delta_{n-1} = \omega_{r\,n-\frac{1}{2}}\Delta t$$

$$\Delta\delta_{n-1} = \delta_{n-1} - \delta_{n-2} = \omega_{r\,n-\frac{3}{2}} \cdot \Delta t$$

$$\Delta\delta_n - \Delta\delta_{n-1} = \left(\omega_{r\,n-\frac{1}{2}} - \omega_{r\,n-\frac{3}{2}}\right)\Delta t$$

$$\Delta\delta_n - \Delta\delta_{n-1} = \frac{180f}{H}(\Delta t)^2 P_{a\,n-1}$$

lec # 10

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$$\Delta\delta_n = \Delta\delta_{n-1} + K P_{a_{n-1}}$$

K → electrical degree

Example :

machine 2

$$\frac{H}{180f}\frac{d^2\delta}{dt^2} = 1.6955 - 5.5023 \sin(\delta_2 - 0.755)$$

$t_{clearnig} = 0.225$ sec

~~$\Delta t = 0.25$ sec~~

$\Delta t = 0.05$ sec

$H = 8$ S

$E_2 = 1.065 \angle 16.19°$

✳ it $t_{clearing} = 0.25$ — $0.25^-$ @ fault, $0.25^+$ @ Post, $0.25_{avg}$

$$K = \frac{180f}{H}\Delta t^2 = \frac{180*60}{8} * 0.05 = 3.375° \text{ electric}$$

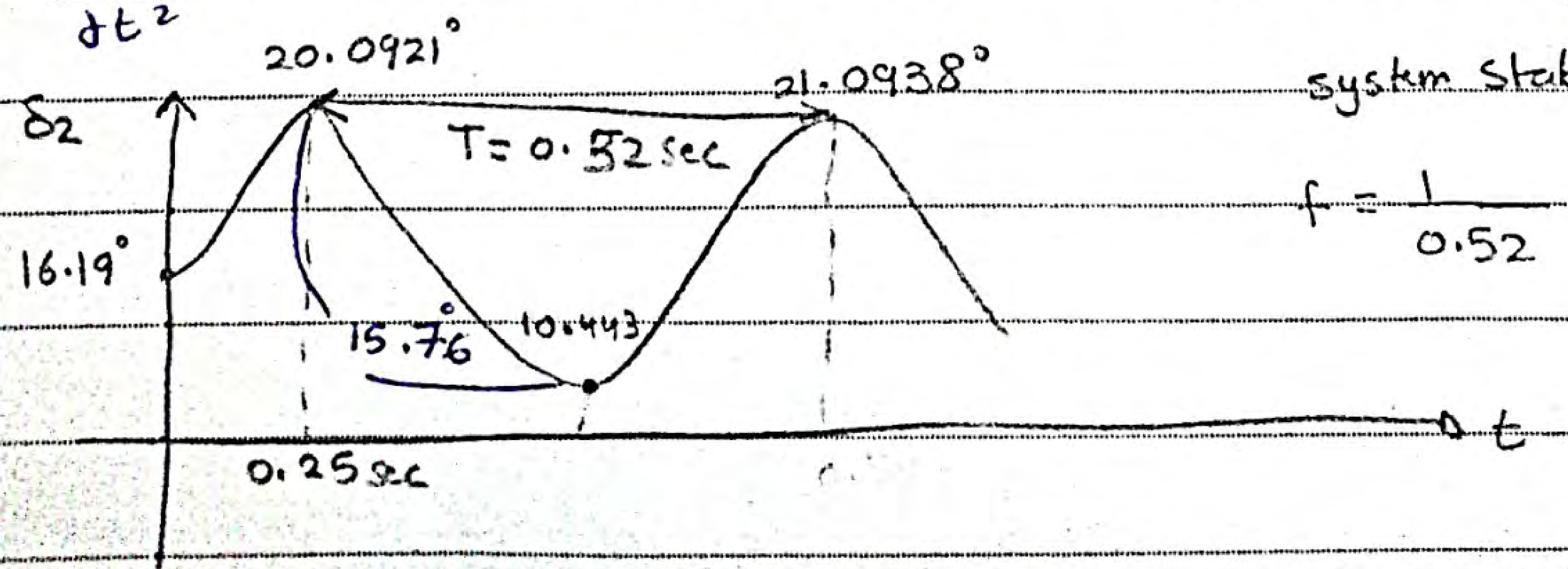
| t,S | $(\delta_2-\gamma)°$ | $P_{max}\sin(\delta_2-\gamma)$ | $P_a$ | $K P_{a_{n-1}}°$ | $\Delta\delta_n$ | $\delta_n$ |
|---|---|---|---|---|---|---|
| $0^-$ | | | 0 | | | 16.19° |
| $0^+$ | 15.435 | 1.4644 | 0.231 | | | 16.19° |
| $0_{av}$ | | | 0.1155 | 0.389 | 0.389 | 16.19° |
| 0.05 | 15.824 | 1.5 | 0.1955 | 0.658 | 1.05 | 16.579° |
| 0.1 | 16.87 | | | | | 17.627° |
| 0.2 | | | | | 0.7976 | [illegible] |
| 0.25 | 20.24~~8~~ | 2.247 | -0.5774 | -1.95 | -1.15 | 21.0921 |
| | | | | | | 19.94 |

post fault

0.275

After post fault :

$$\frac{d^2\delta}{dt^2} = 1.85 - 0.1804 - 6.4934 \sin(\delta_2 - 0.847)$$



system stable.

$$f = \frac{1}{0.52}$$

lec # 18

Wednesday

16/4/2014

$$f_n = \frac{1}{2\pi}\sqrt{\frac{\overset{377}{\omega_s} \cdot S_P}{\cancel{2H}/16}} = 1.935 \text{ Hz} \rightarrow T = \frac{1}{F} = 0.517^{\circ}$$

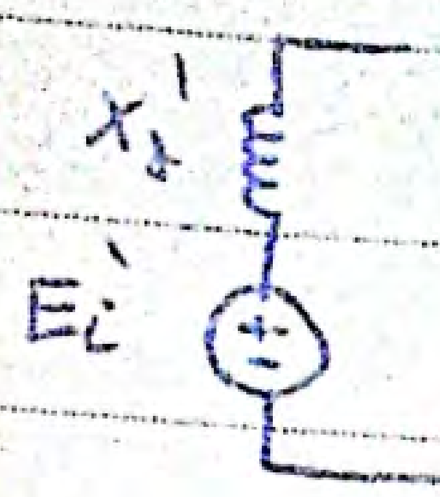
$$S_P = \frac{dP_e}{d\delta} = \frac{d}{d\delta}\left(0.1804 + 6.4934 \sin(\delta_2 - 0.847)\right)$$

23/3/2014

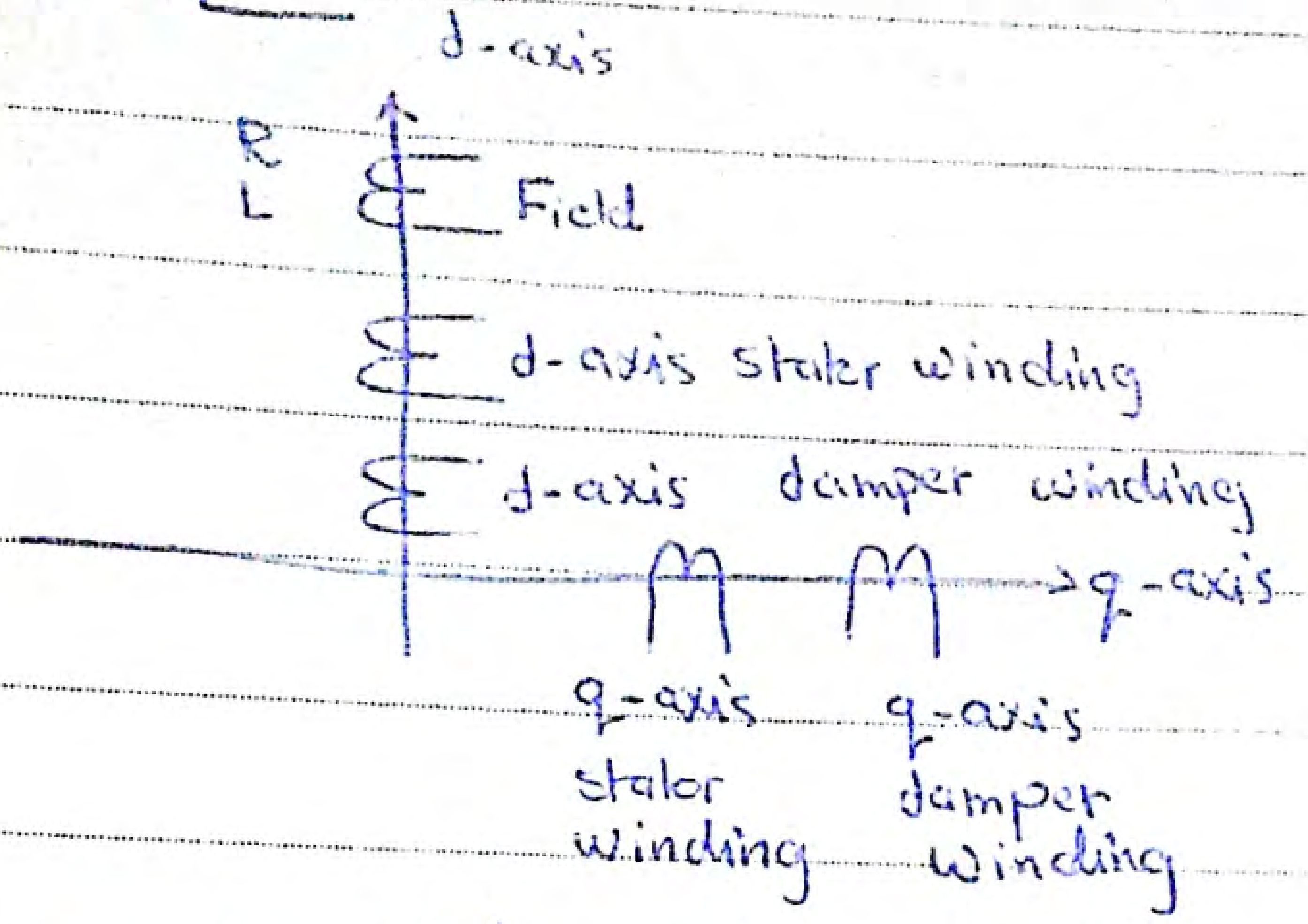
## Computer Programs for Transient Stability Studies:

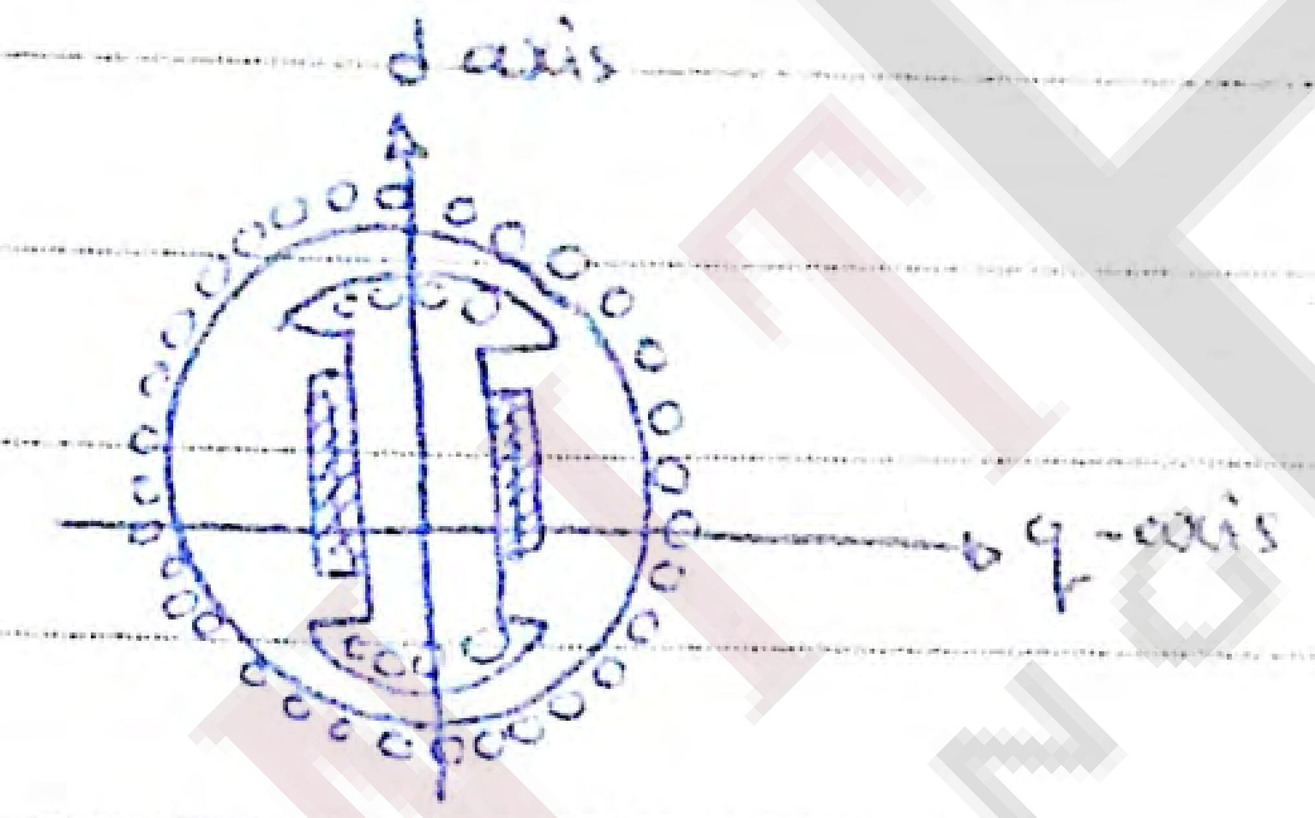
- very large Number of machines

-

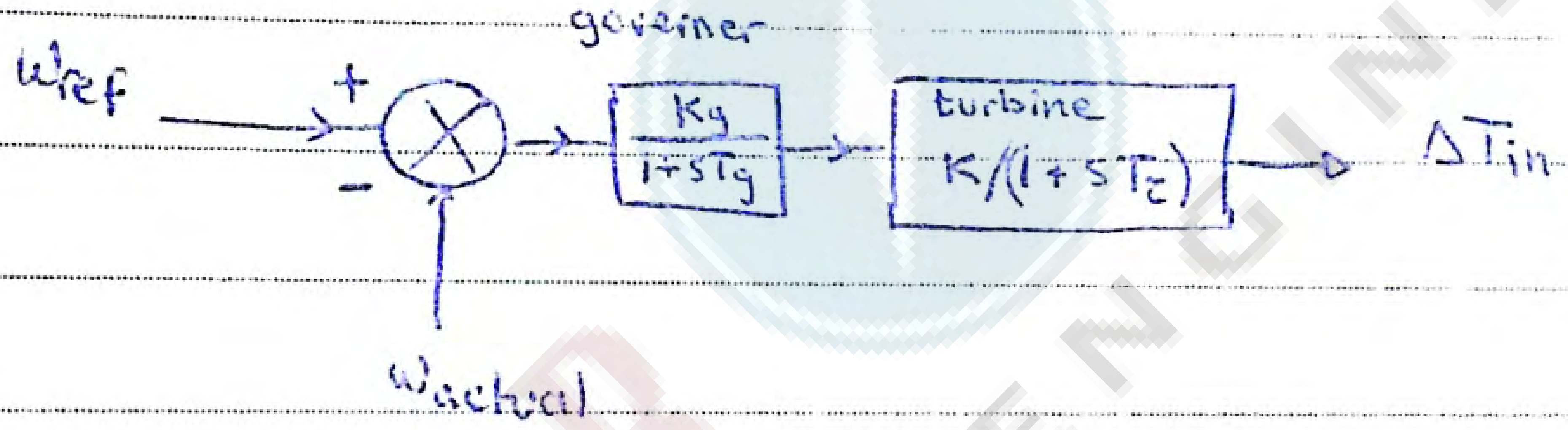


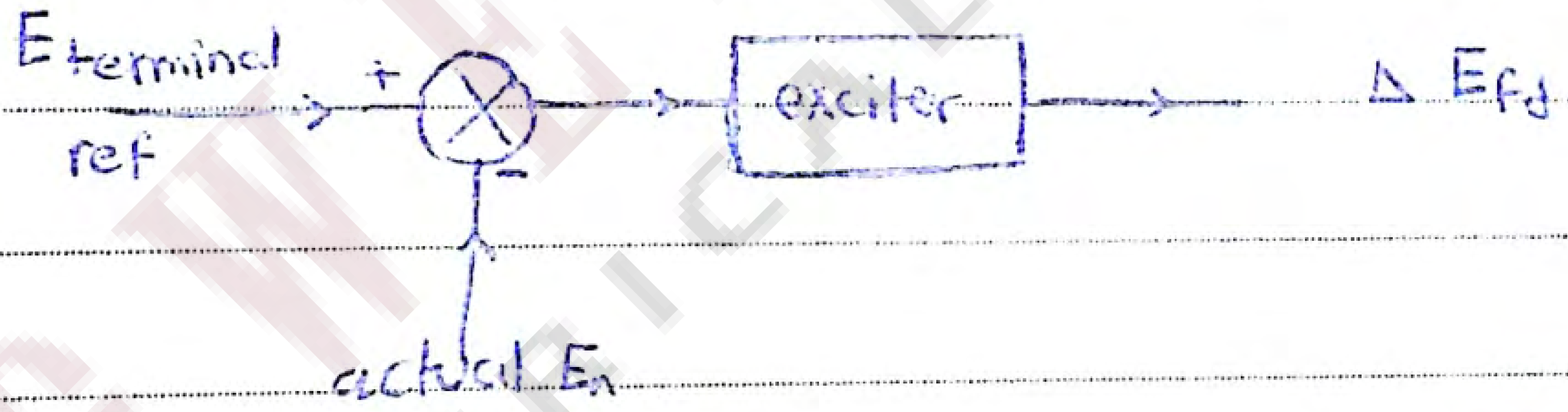
detailed representation of synchronous machine.





- representation of controllers





| | classical study | Computer study |
|---|---|---|
| t = 0.25 | $\delta = 21.09°$ | $\delta = 20.9°$ |
| t = 0.75 | $\delta = 21.09°$ | $\delta = 20.8°$ |

## Factors Affecting Transient Stability:

$$\underbrace{\frac{H}{180f}}_{\text{constant}} \frac{d^2\delta}{dt^2} = \underbrace{P_m}_{\text{constant}} - P_e$$

⇒ H↑ , accelaration ↓

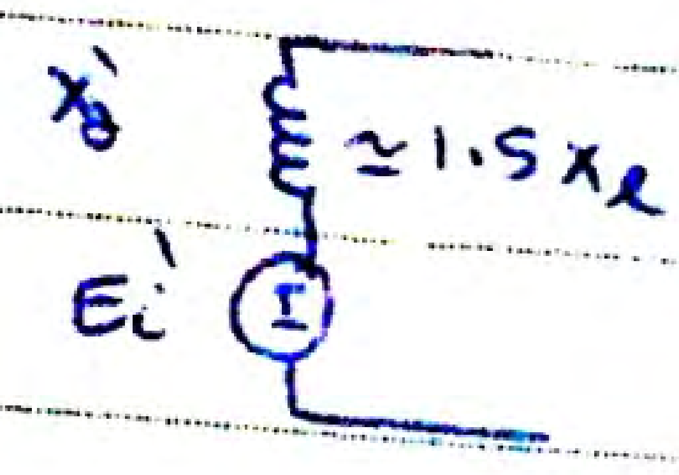
$$\Delta\delta_n = \Delta\delta_{n-1} + \frac{180f}{H}(\Delta t)^2 P_{a\,n-1}$$

lec # 19

Wednesday

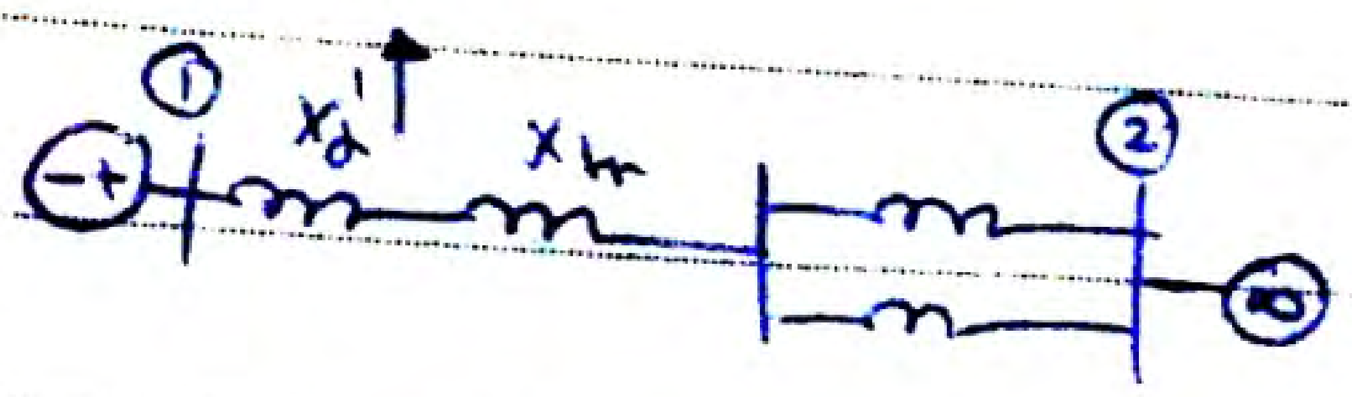
23/4/2014

$$H = \frac{\text{K.E. stored at synchronous speed}}{S_{machine}} = \frac{\frac{1}{2}\overset{\text{mass}}{J}\,\omega_{sm}^2}{S_{machine}}$$



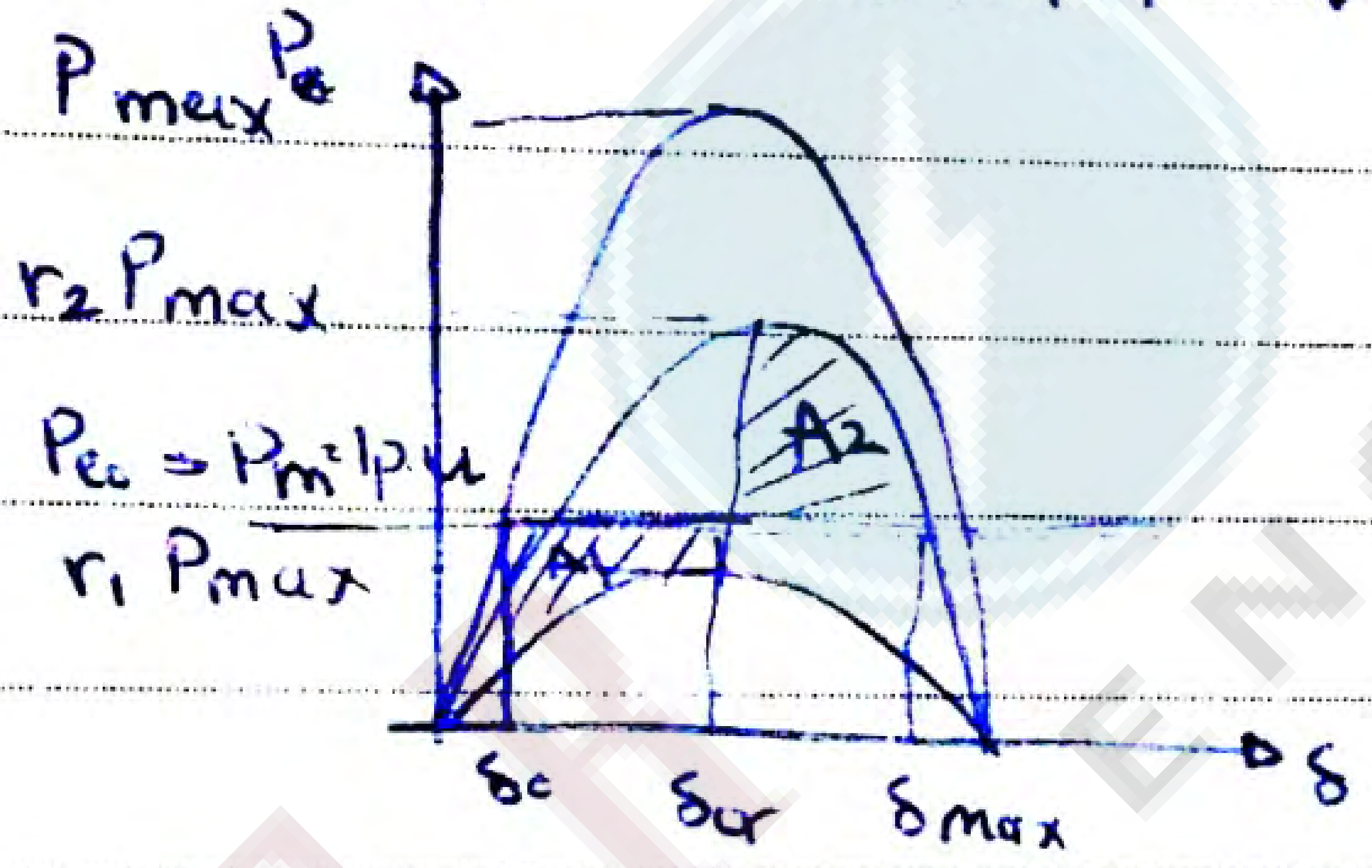
$H \downarrow$ $\underline{\underline{x_d'}} \uparrow$

↳ mass increased



$$\left| \frac{1}{x_d' + x_{tr} + x_{\parallel TL}} \right| = |Y_{12}| \downarrow$$

$P_{max} = E_1' E_2' |Y_{12}| \downarrow$ , $P_e \downarrow$ , accelaration ↑, H ↓



$P_{max} \downarrow$ , $\delta_o$ increase , $\delta_{max}$ decreases ,

$\delta_{cr}$ will decrease.

$\boxed{**}$ we try to increase $P_{max}$.

1. Use of thyristor exciter

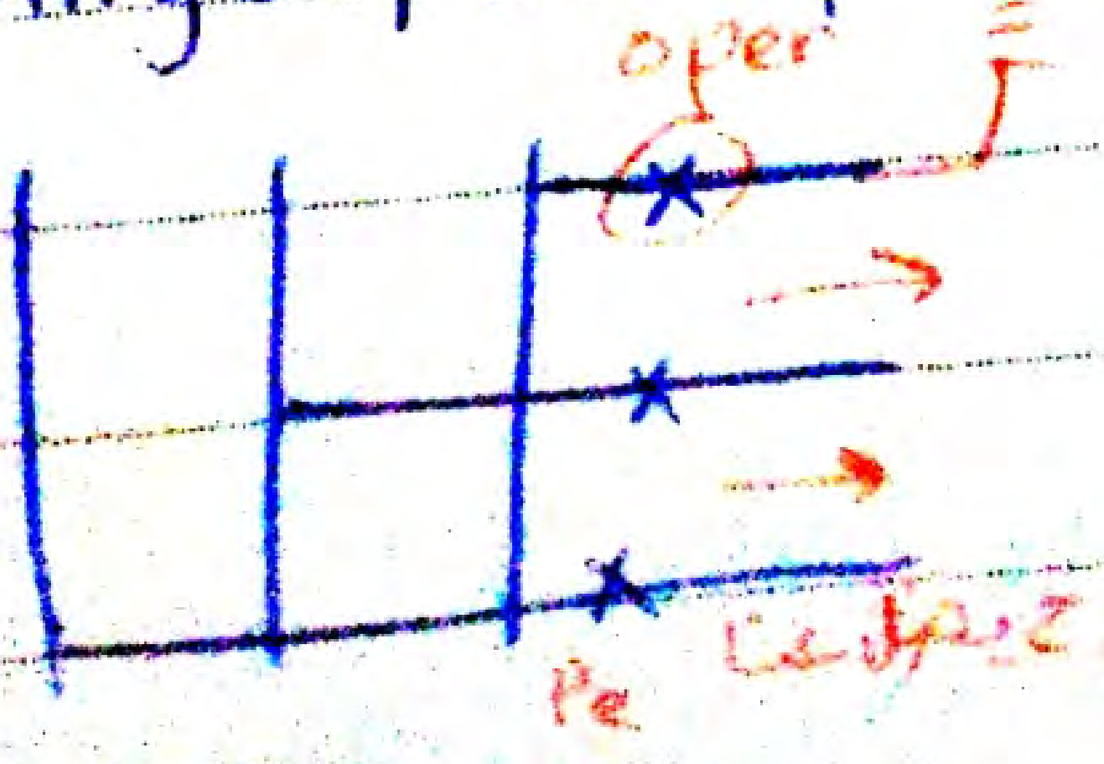
to change

$t_{cr}$ + (0.5 – 1.5 cycle).

2. Use of solenoid valves on turbines

$t_{cr}$ + ( 1 – 2 cycles)

3. Single pole operation



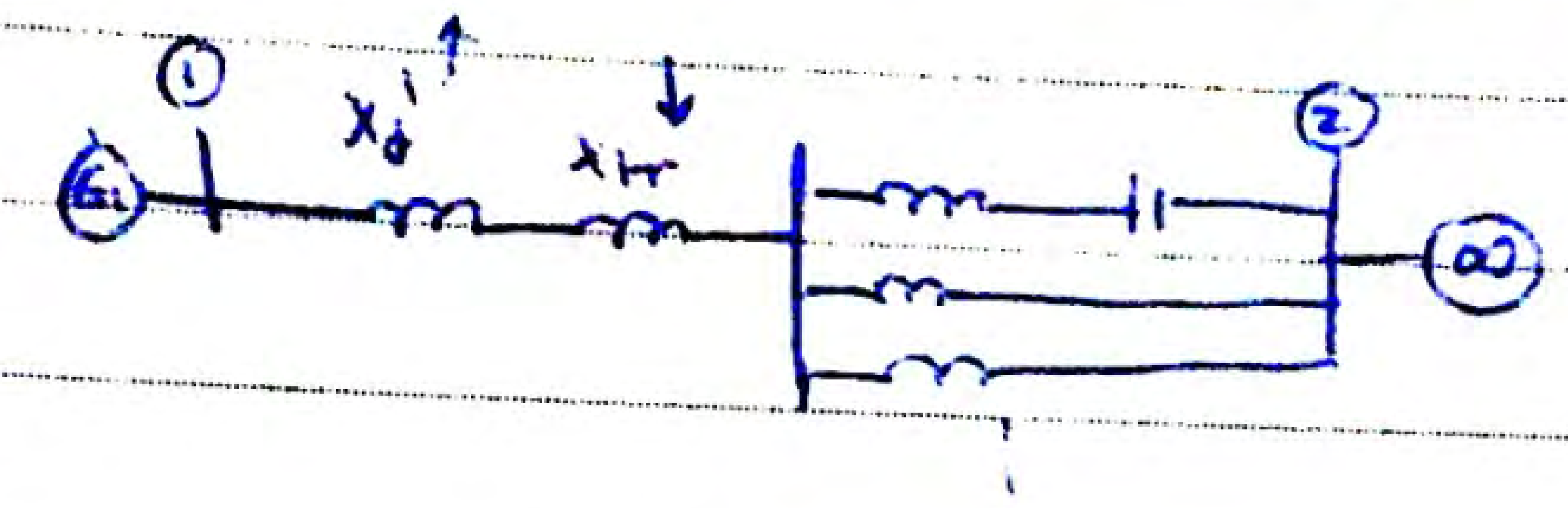
phase اللي
حصل عليه الـ fault
بس هو اللي
يفتح

$t_{cr}$ + ( 2 - 5 cycles)

lec # 19

Wednesday
23/4/2014

4. Fast fault clearing times
- more TL's in //el
- use series compinsation (reduce impedance $Z$ & increase admattence $Y$)
- reduce transformer impedance.

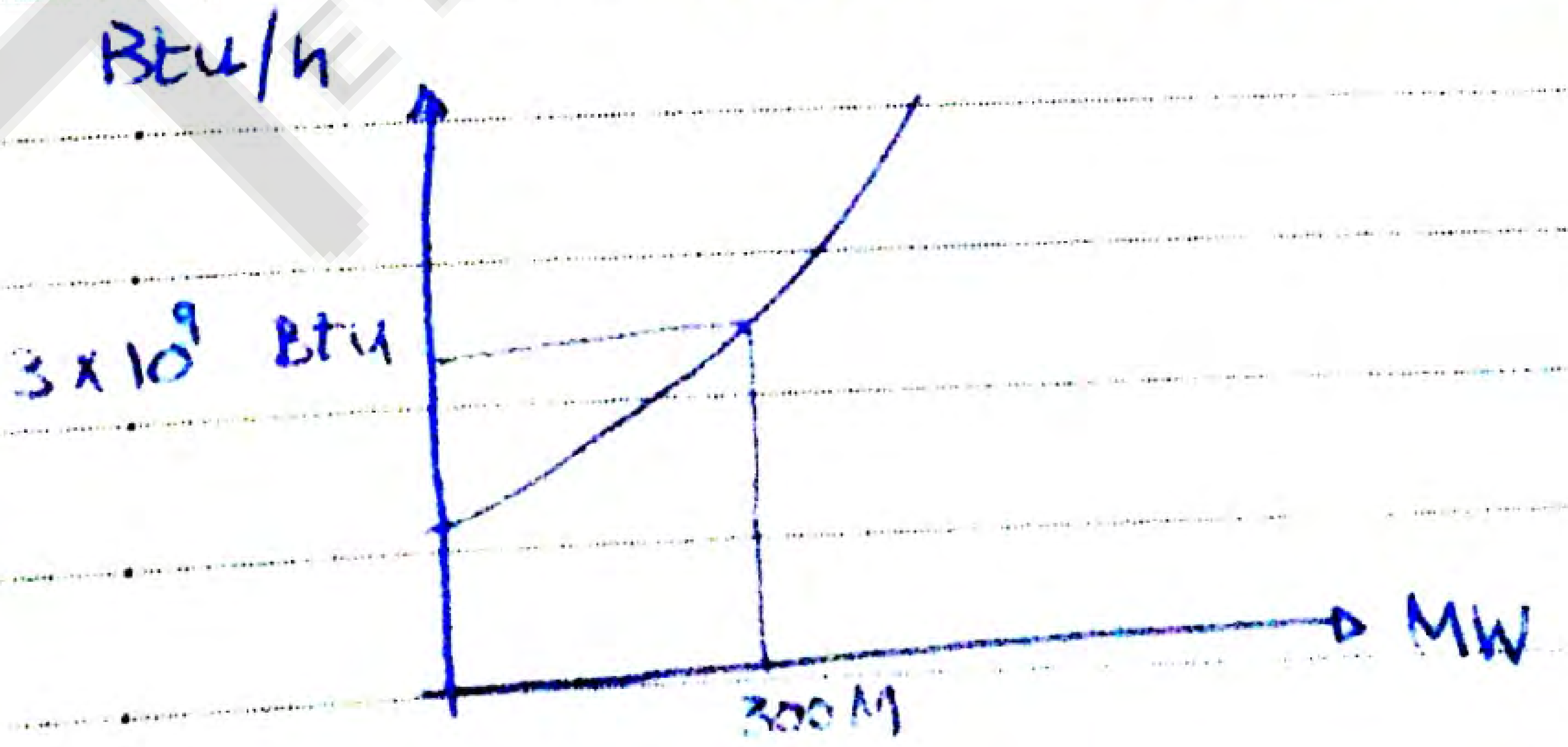


--- ⓔ Seconed

Economic Operation of Power Systems:
supply power
constant V & F
in reliable & <u>economic</u> manner

Regulatory bobies:
- reduce price
- reduce fuel consumption

generation: coal
nuclear
Fuel cost gas (5 $/MBtu)
heavy fuel (12-14 $/MBtu)
Diesal (20 $/MBtu)



lec # 19

wednesday

23/4/2014

$$1\,W = \frac{1\,J}{1\,Sec}$$

$1000\,W\,s = 1\,kJ$

$Btu = 1.055056\,kJ$

$1\,kJ = 0.94782\,Btu$

1kWh

1000W . 3600S

$1\,kW = 3600\,kJ$

$= 3412.152$ Btu

Britsh thermal unit

# Power II

# NoteBook

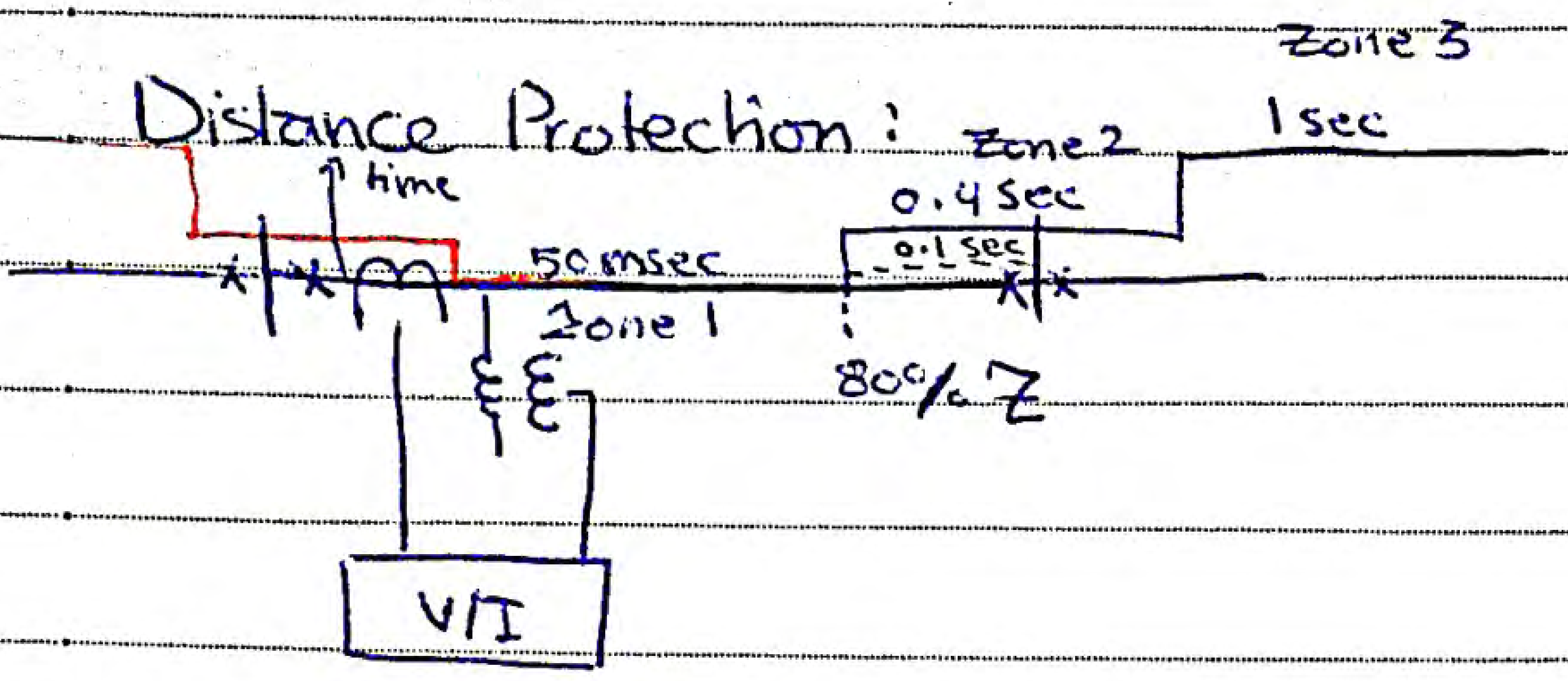
19/3/2014-23/4/2014

POWER UNIT
ELECTRICAL ENGINEERING

Lec # 10

wednesday
19/3/2014

## Distance Protection :



$> \underline{10 - 20 \text{ miles}}$

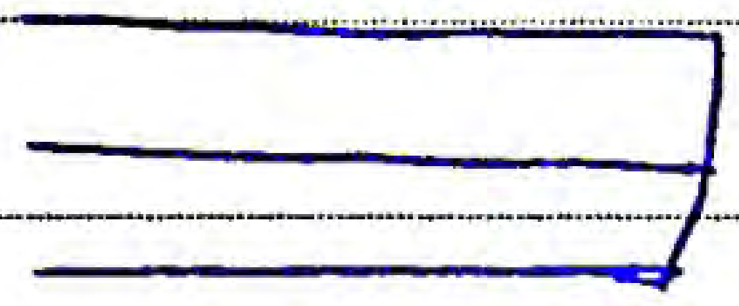
Distance Relay

$Z_1 \Rightarrow$ our refrence. the Relay will measure $Z_1$

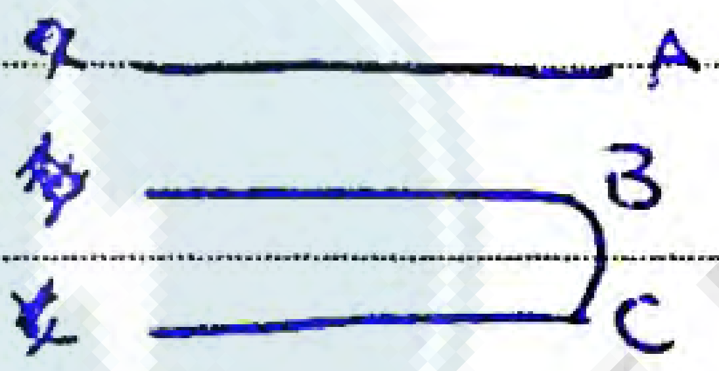
$Z_2$

$Z_0$

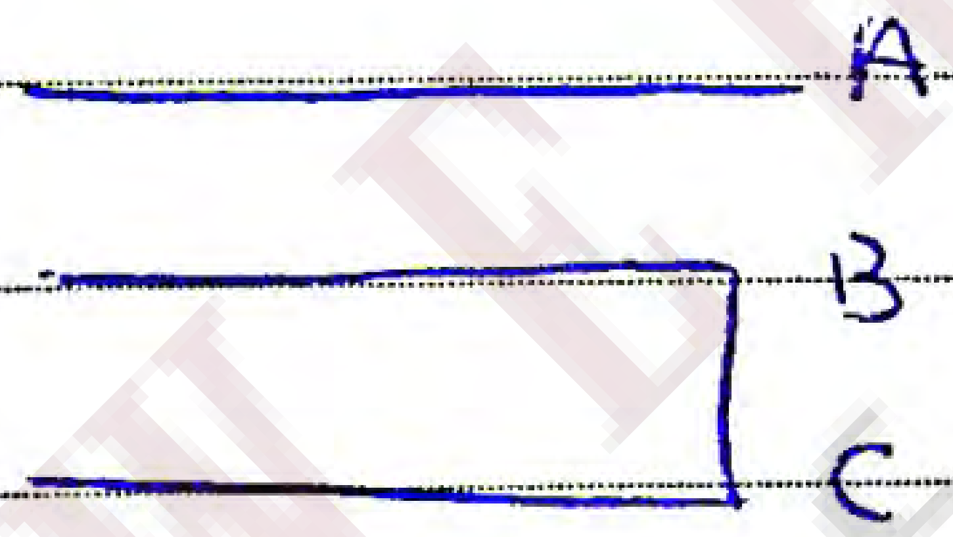
3 $\phi$ fault
Van/Ia

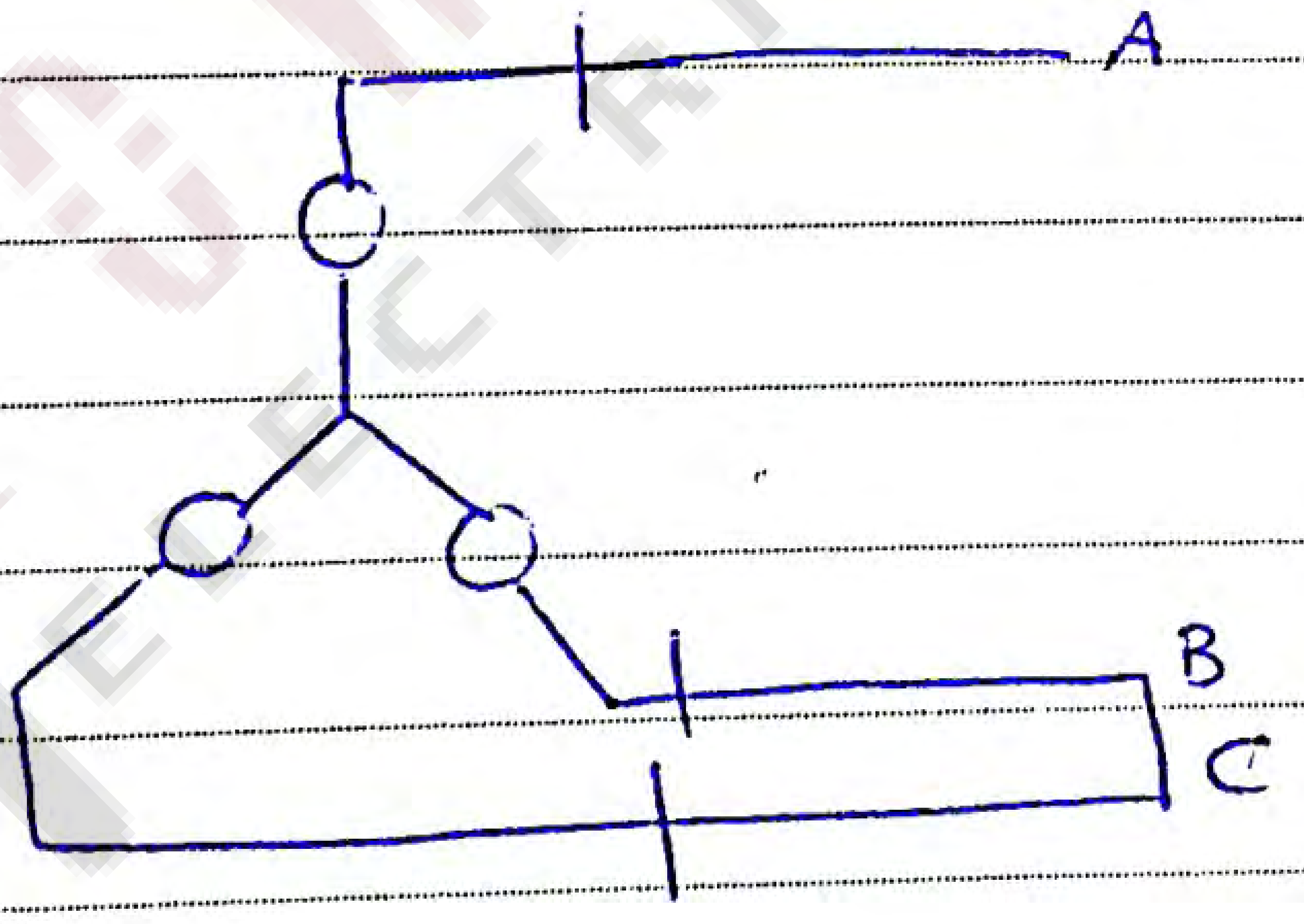


$\phi - \phi$ fault

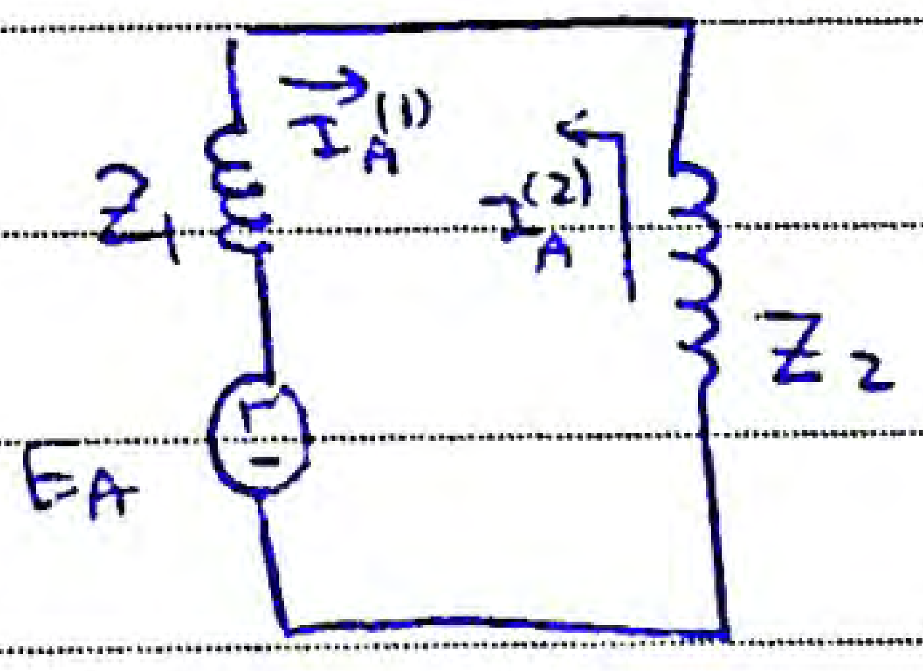


Phase - Phase fault :





+ve and -ve sequence.



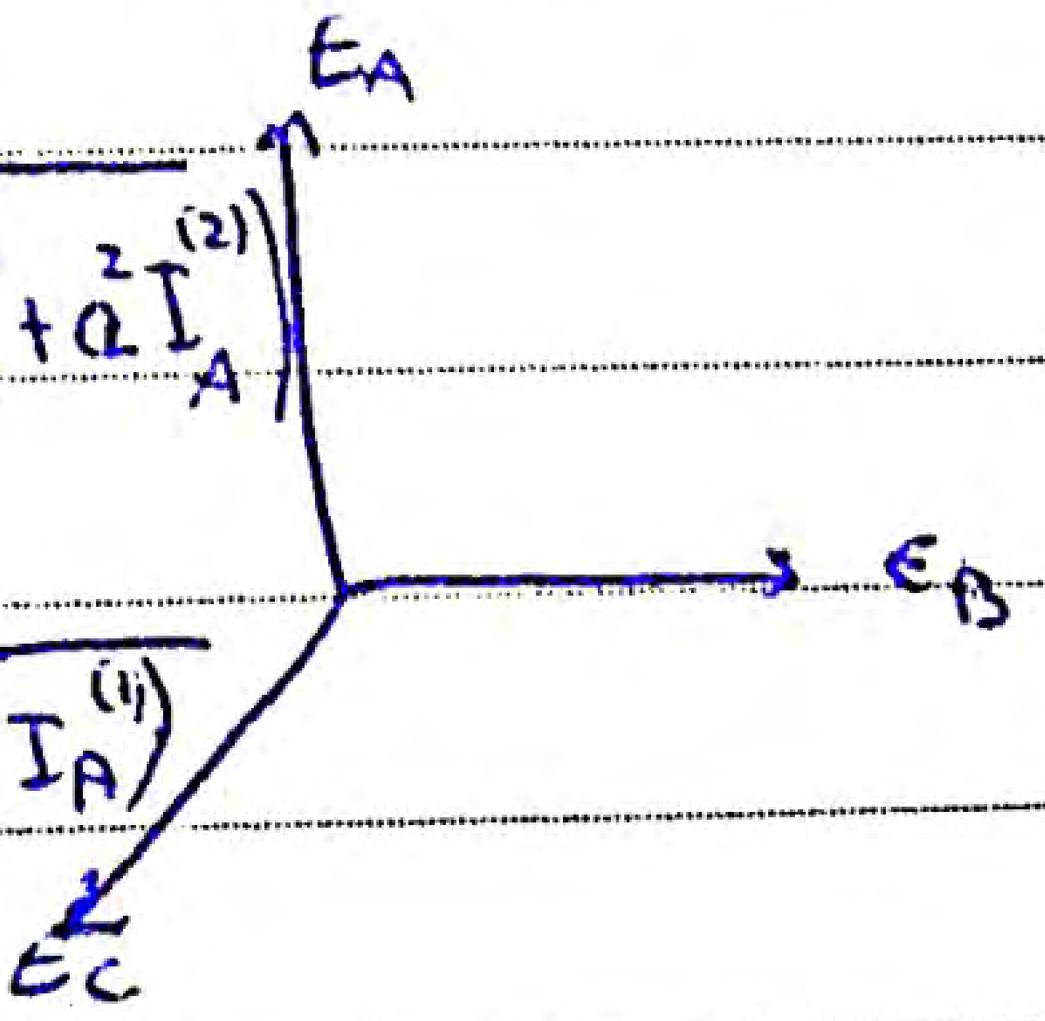
$$I_A^{(1)} = \frac{E_A}{Z_1 + Z_2}$$

$$I_A^{(2)} = -I_A^{(1)} \quad , \quad I_A^{(0)} = 0$$

$$\frac{E_B - E_C}{I_B - I_C} = \frac{a^2 E_A - a E_A}{a^2 I_A^{(1)} + a I_A^{(2)} - \left(a I_A^{(1)} + a^2 I_A^{(2)}\right)}$$

$$= \frac{a^2 E_A - a E_A}{a^2\left(I_A^{(1)} - I_A^{(2)}\right) + a\left(I_A^{(2)} - I_A^{(1)}\right)}$$

$$= \frac{a^2 E_A - a E_A}{(a^2 - a)\,(\underbrace{I_A^{(1)} - I_A^{(2)}}_{2 I_A^{(1)}})}$$



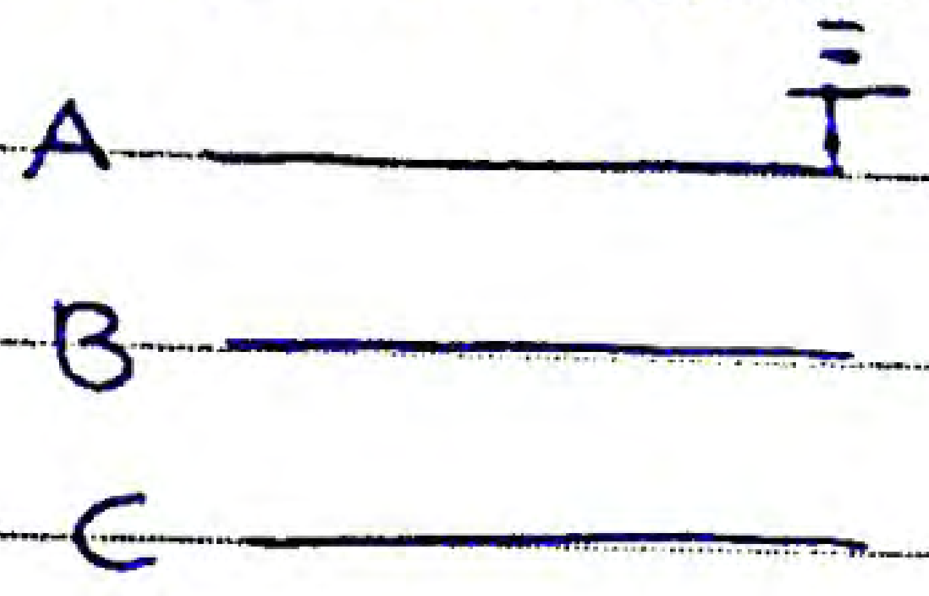
lec # 10

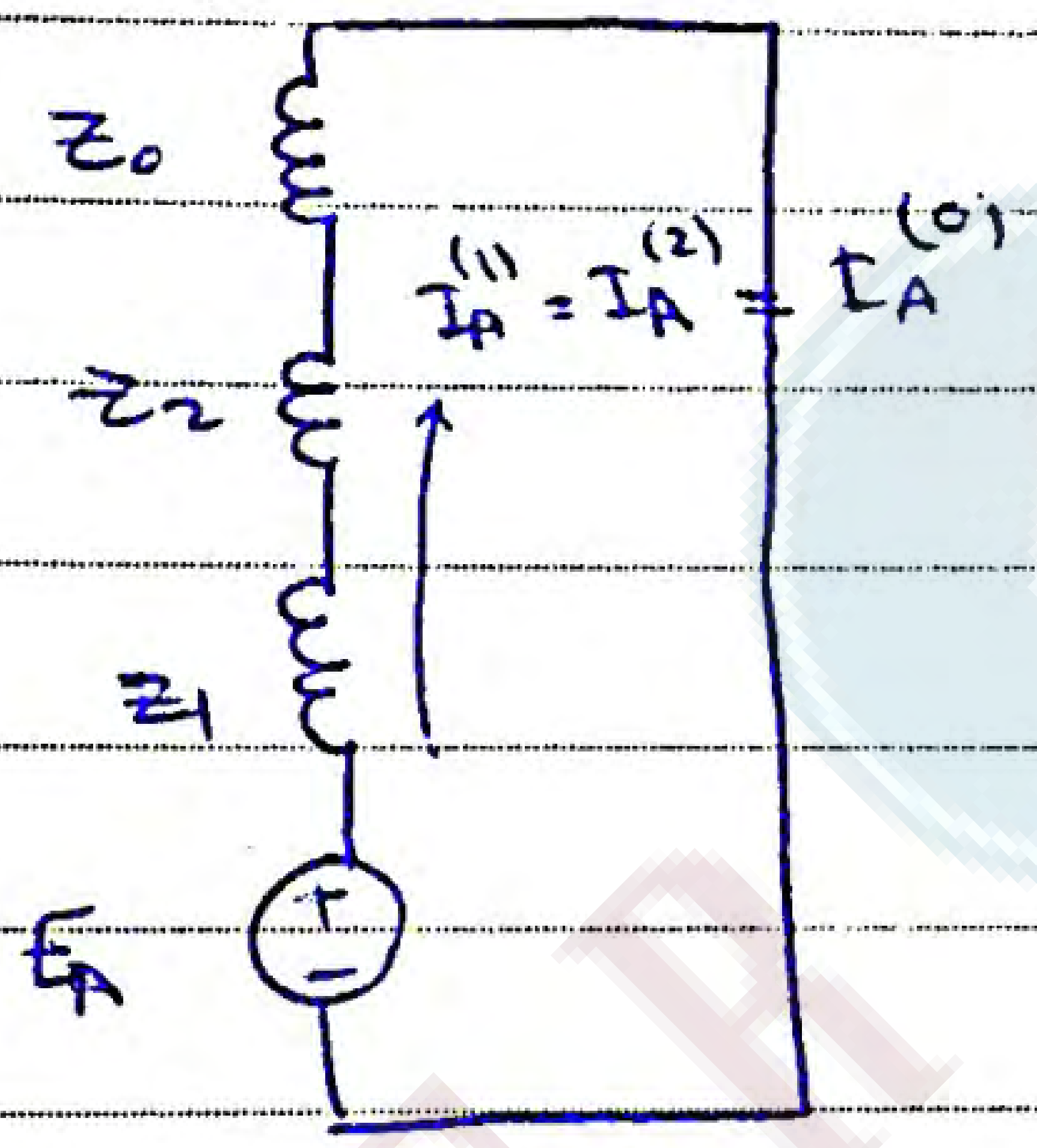
Wednesday
19/3/2014

$$2I_A^{(1)} = \frac{2\;E_A}{Z_1+Z_2} = \frac{E_A}{Z_1}$$

$$\frac{E_B-E_C}{I_B-I_C} = \frac{(a^2-a)E_A}{(a^2-a)\;E_A/Z_1} = Z_1$$

Phase - Earth fault





$$E_A = I_A^{(1)} Z_1 + I_A^{(2)} Z_2 + I_A^{(c)} Z_c$$

$$E_A = I_A^{(1)} Z_1 + I_A^{(2)} Z_2 + I_A^{(0)} Z_c$$

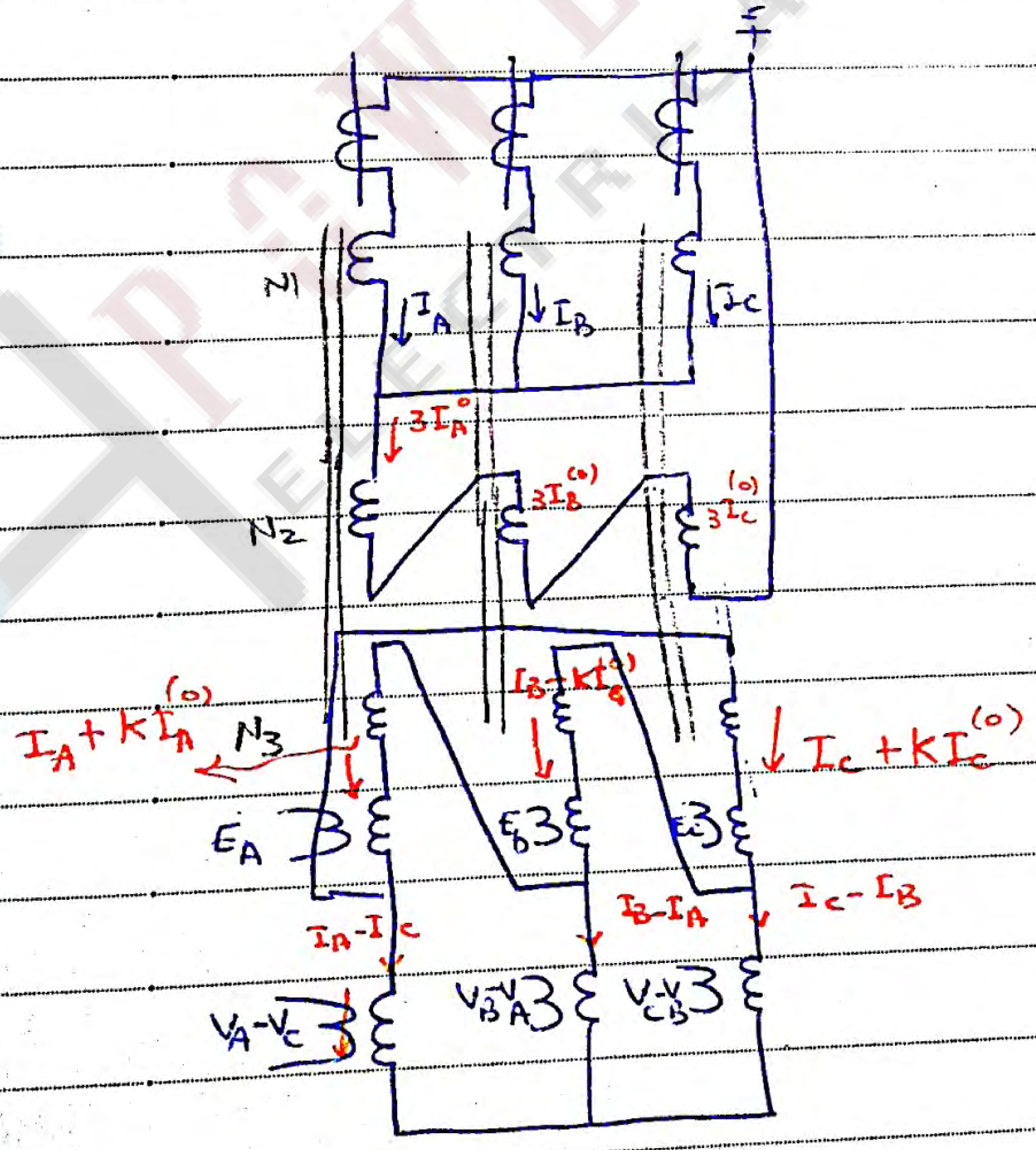
$$E_A = \left(I_A^{(1)} + I_A^{(2)}\right) Z_1 + I_A^{(0)} Z_0$$

$$E_A = \left(I_A - I_A^{(0)}\right) Z_1 + I_A^{(0)} Z_0$$

$$E_A = \left[\left(I_A\right) + \left(I_A^{(0)}\right)\left(\frac{Z_0 - Z_1}{Z_1}\right)\right] Z_1$$

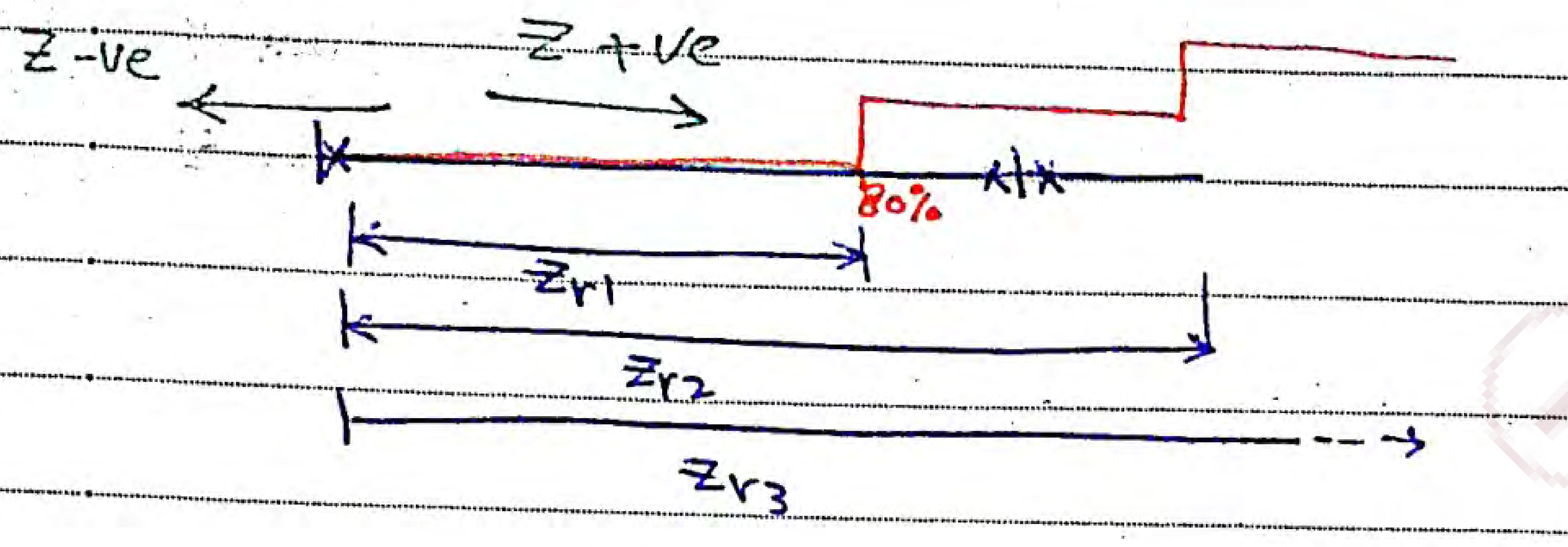
$$Z_1 = \frac{E_A \quad \Rightarrow V}{I_A + I_A^{(0)} \frac{Z_0 - Z_1}{Z_1} \quad \Rightarrow I}$$

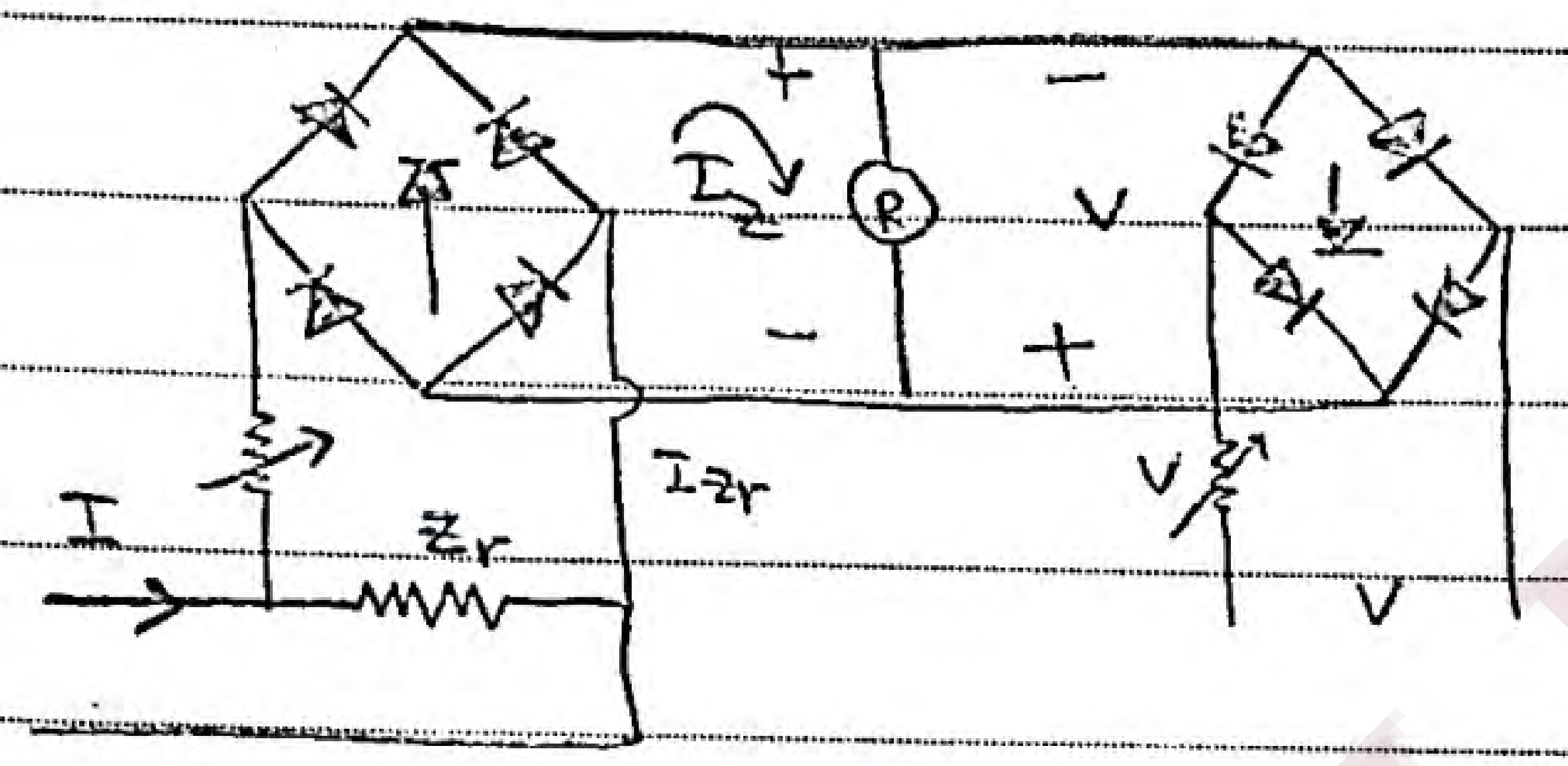
$$I_A^{(0)} = \frac{1}{3}\left(I_A + I_B + I_C\right)$$



lec # 11

24/3/2014
Monday





Type of distance Relays:

1. Directional Relay

$|V + IZ_r|$ operation

$|V + IZ_r|$ operation

$|V - IZ_r|$ restraining

Amplitude comparison:

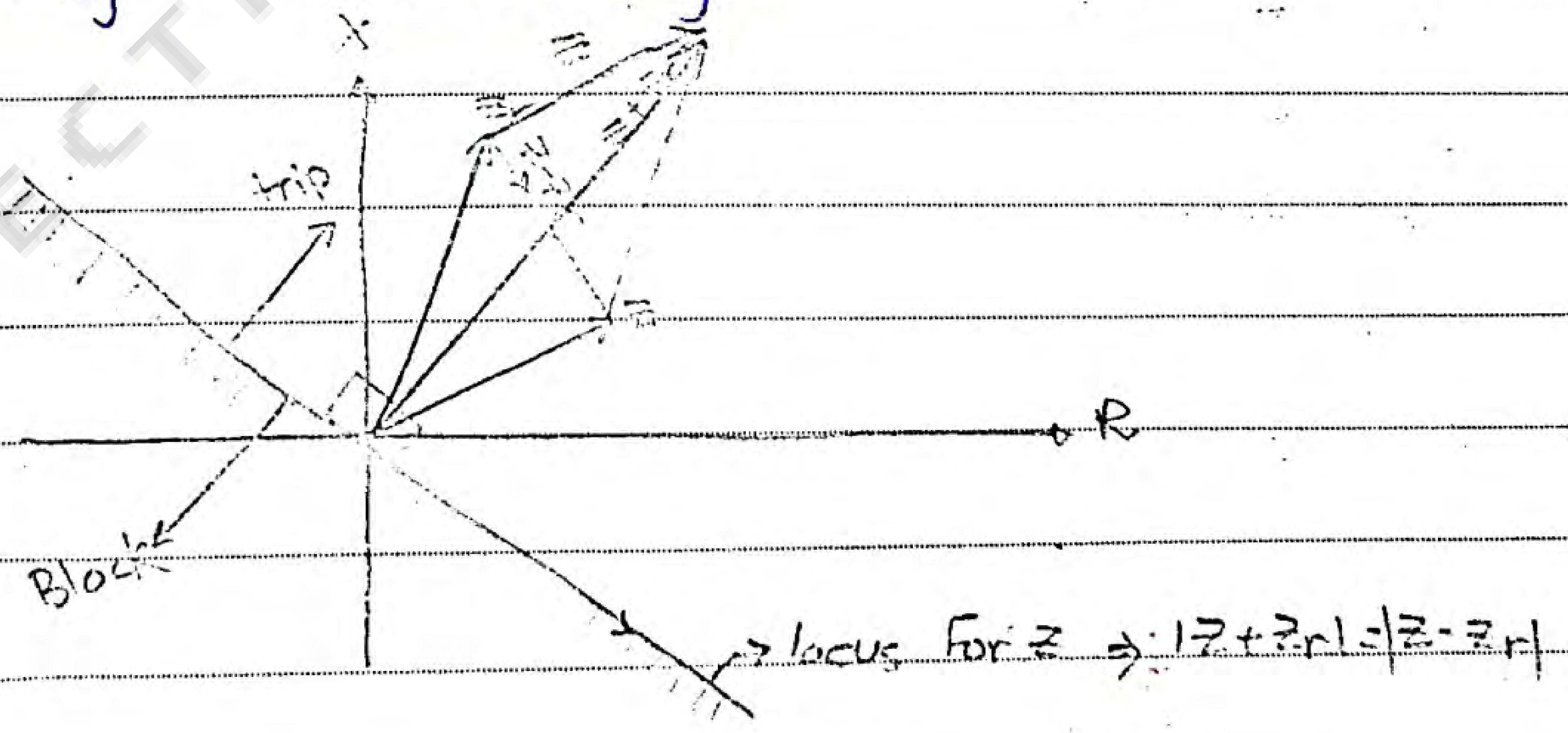
$|V + IZ_r| \longrightarrow |V - IZ_r|$

$\div I$

$Z_r \angle 90° - 60°$

$|Z + Z_r| \longrightarrow |Z - Z_r|$

operating restraining



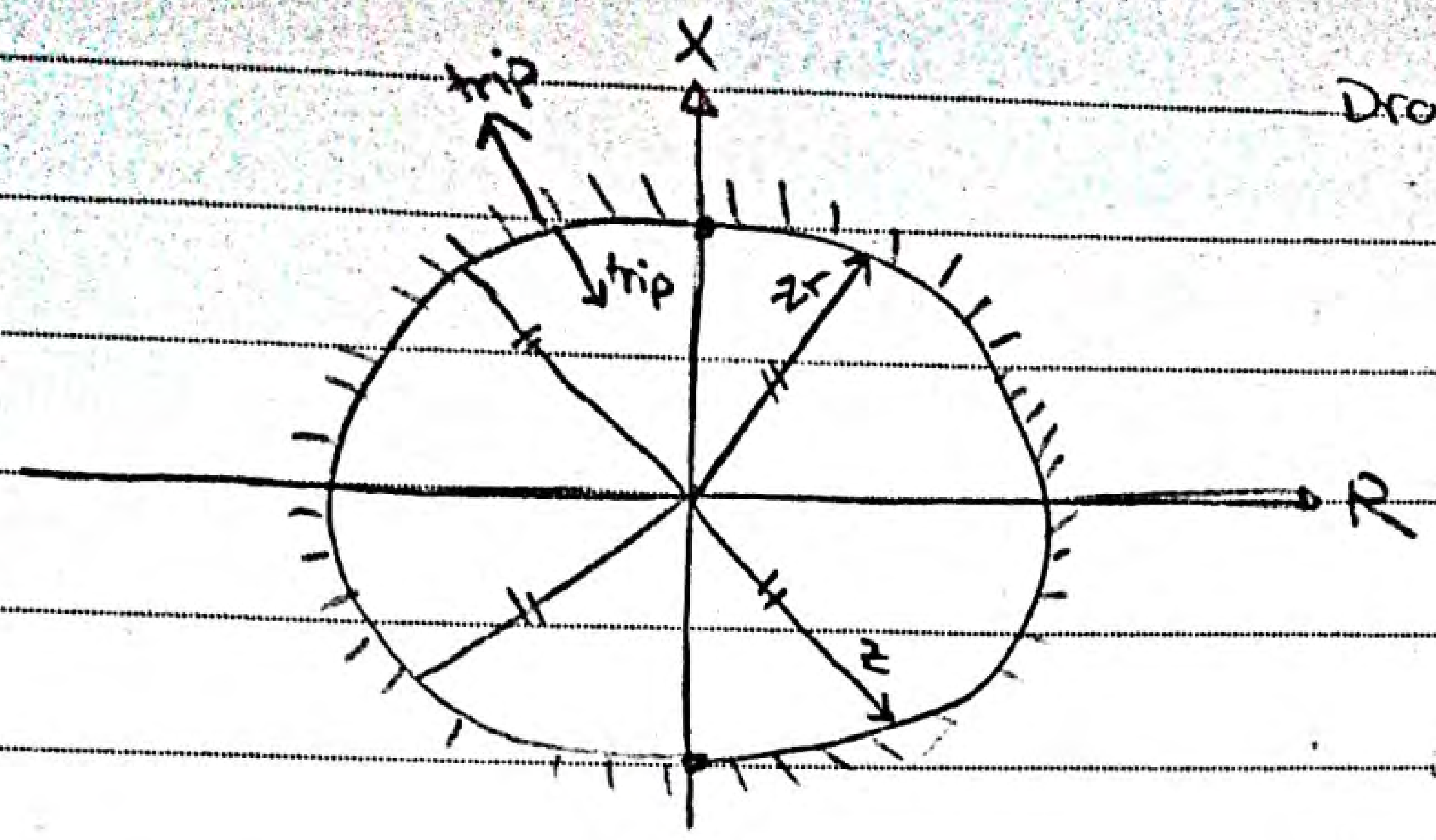
2. Impedance Relay or called ohm Relay

$|IZ_r| \longrightarrow |V|$
op. restraining

$\div I$

$|Z_r| \longrightarrow |Z|$

24/3/2014



DrawBacks : Non-directional relay
it will see $Z_r$ in all direction.

## 3. Reactance Relay

$$|\underbrace{2IZ_r - 2IR_r}_{2IX_R} - V| \longrightarrow |V|$$

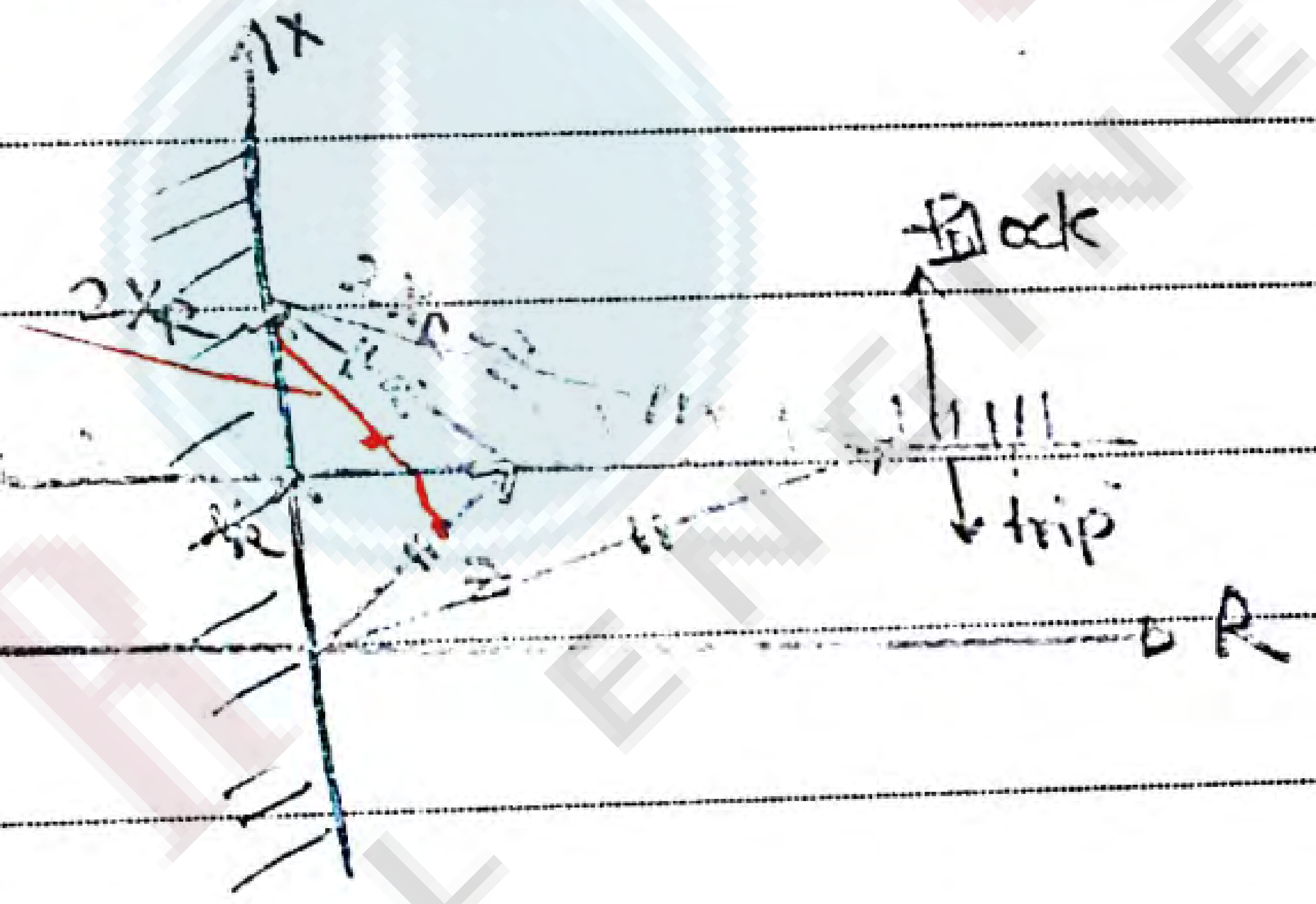
op. restraining

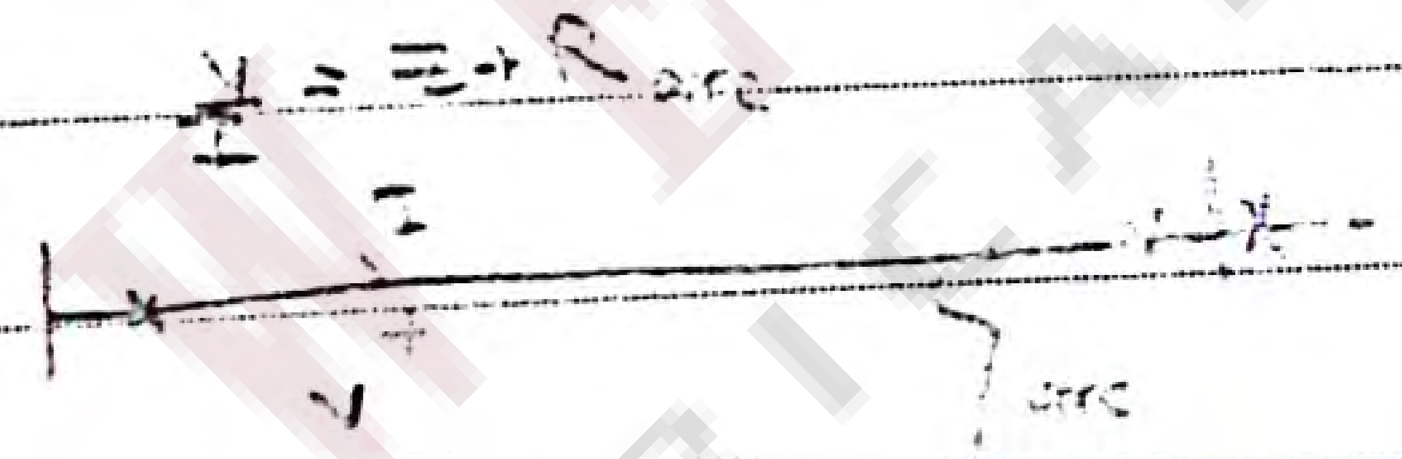
÷ I

$$|2X_R - Z| \longrightarrow |Z|$$

DrawBacks:
not directional relay
to make relay directional
Adv. : not sensitive for $R_{arc}$

will work Z in اكبر





## 4. mho Relay

$$|IZ_r| \longrightarrow |2V - IZ_r|$$

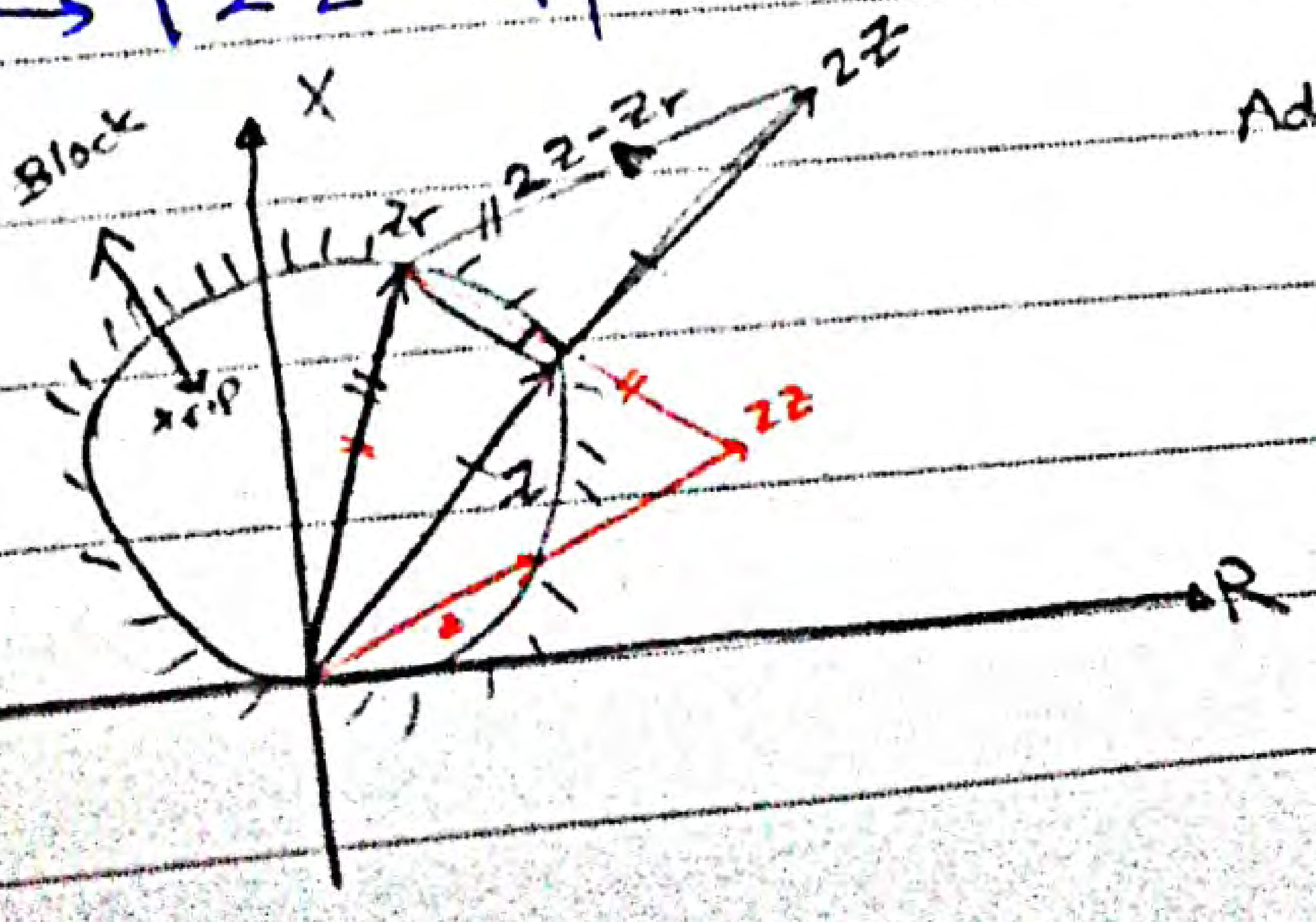
operating restraining

÷ I

$$|Z_r| \longrightarrow |2Z - Z_r|$$

Z- phone

Adv → directional



lec # 11

Monday

24/3/2014

Y-Plane:

$Y = G + jB$

$|I Z_r| \rightarrow |2V - I Z_r|$

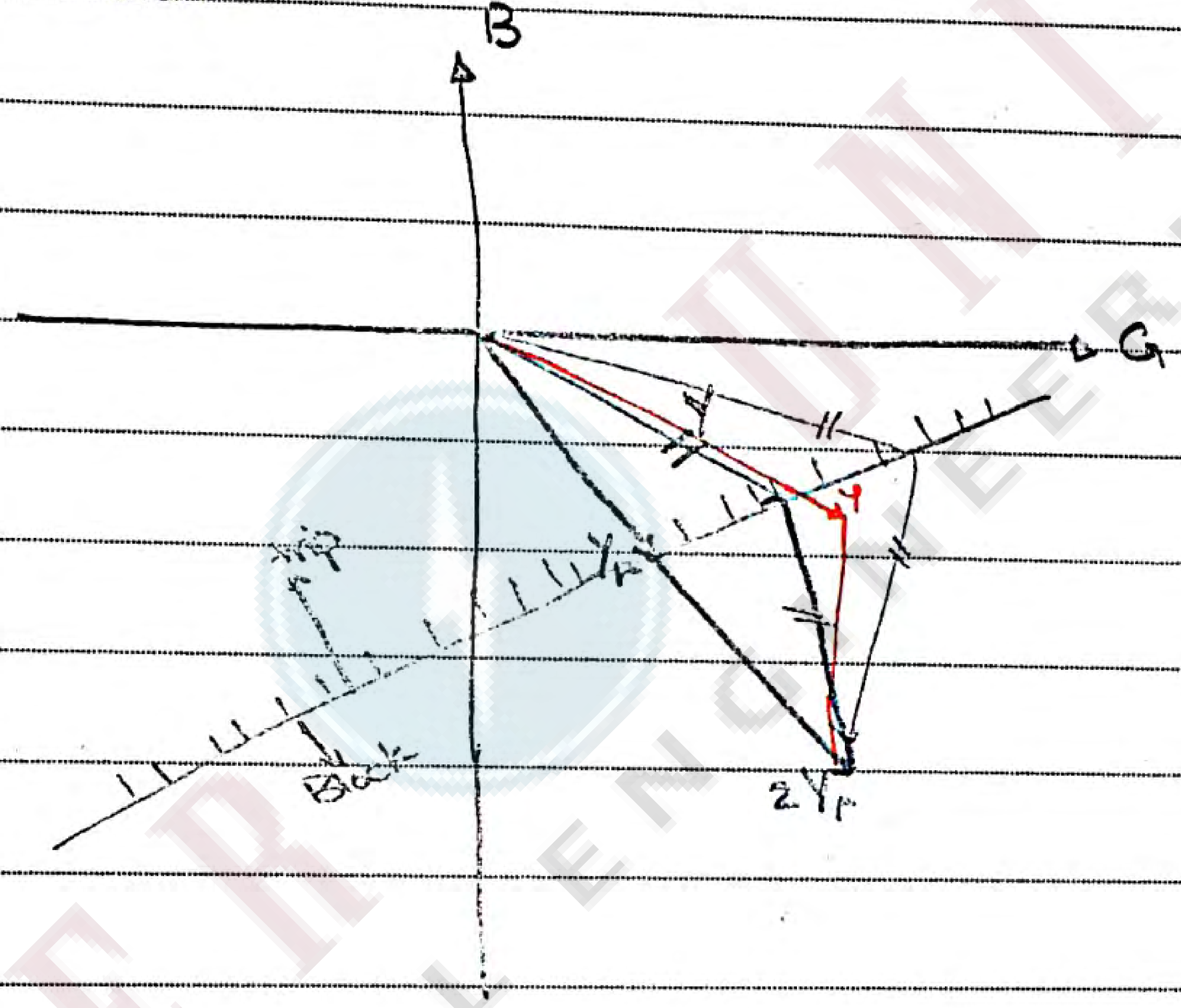
$\div Z_r$

$|Y V| \rightarrow |2 V Y_r - Y V|$

$\div V$

$|Y| \rightarrow |2 Y_r - Y|$

op. resh.

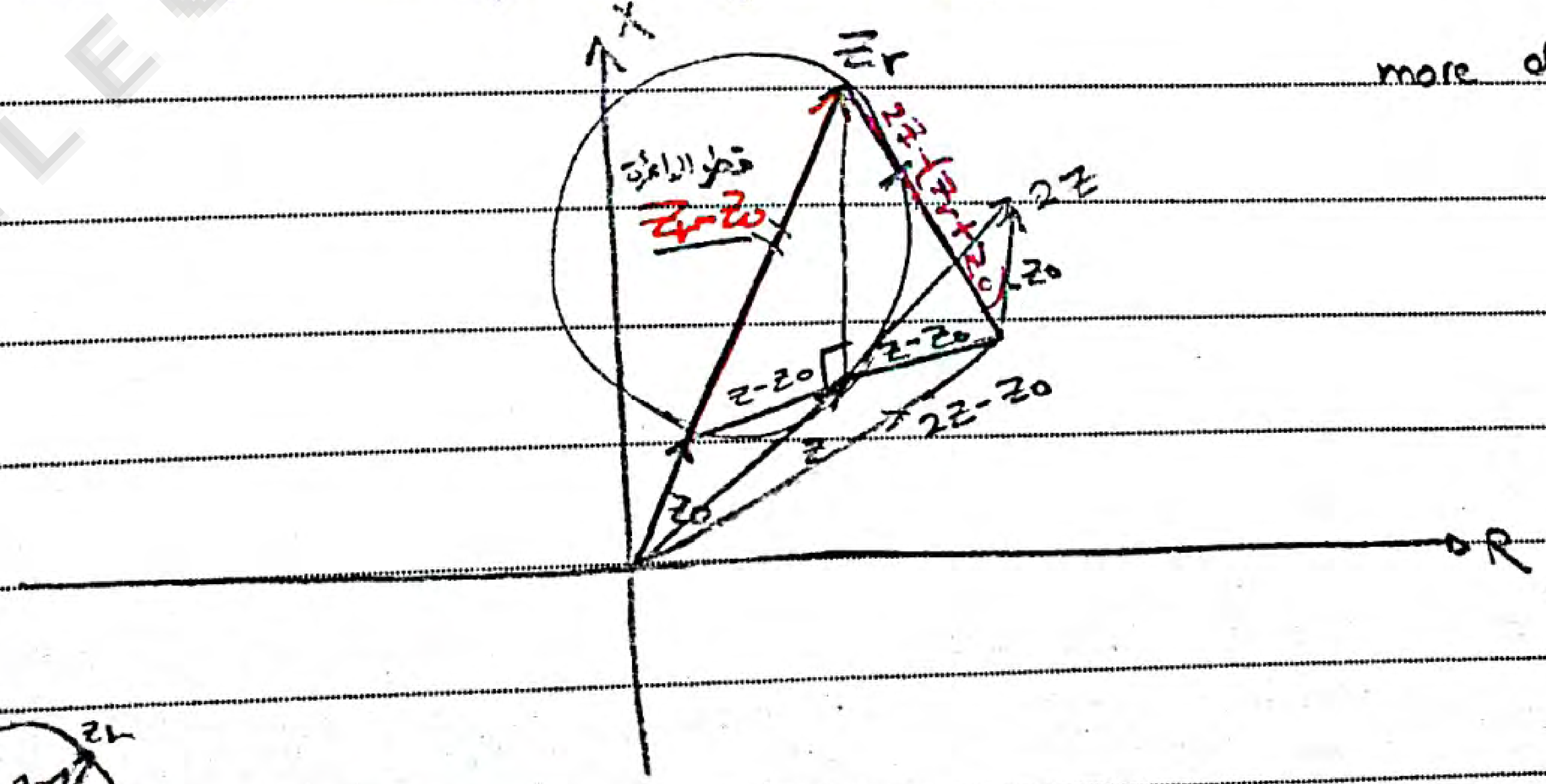


5- Off-set Mho Relay

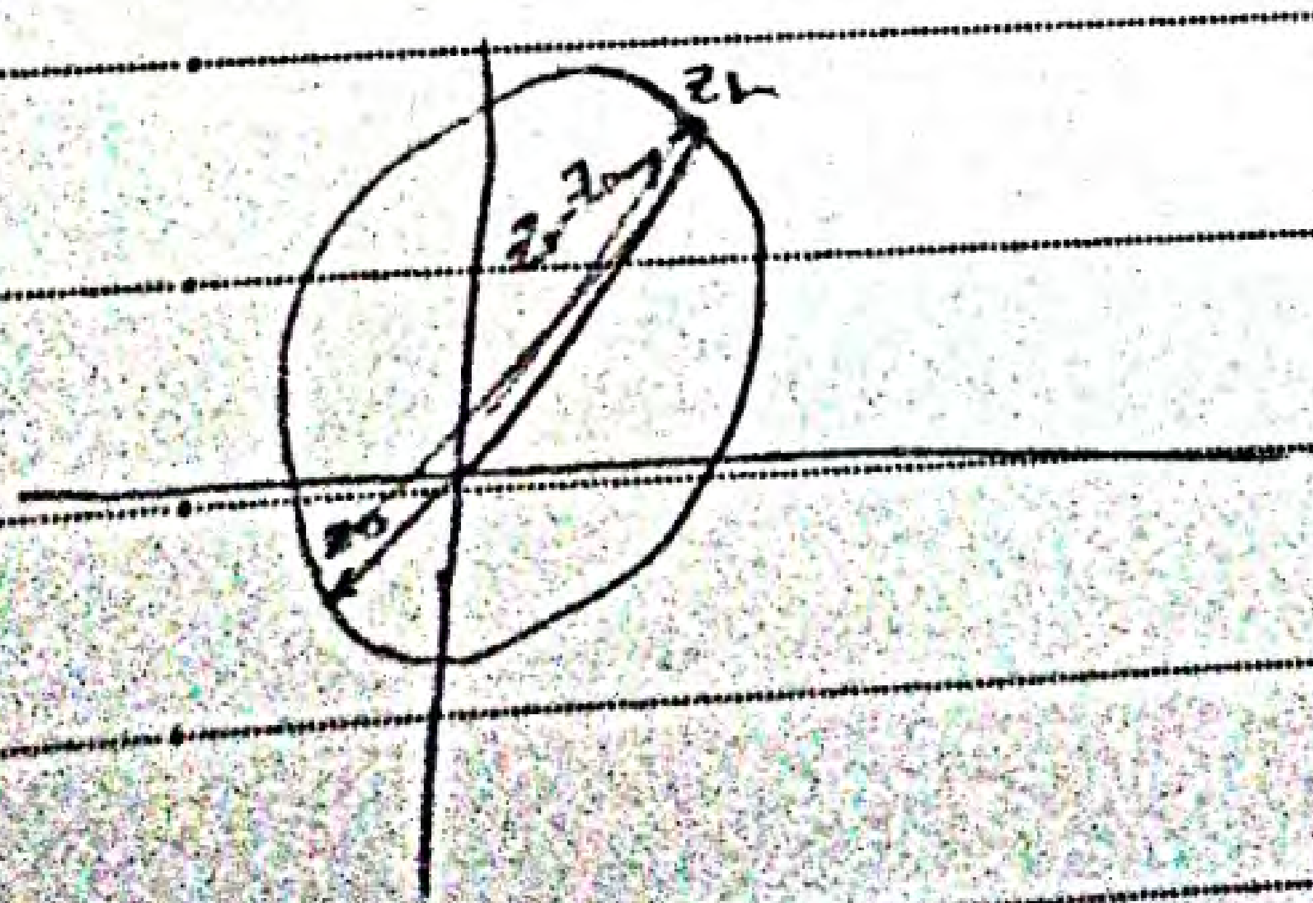
$|I(Z_r - Z_0)| \rightarrow |2V - I(Z_r + Z_0)|$

$\div I$

$|Z_r - Z_0| \longrightarrow |2Z - (Z_r + Z_0)|$



more directional



lec # 11

Monday

24/3/2014

Zone 1

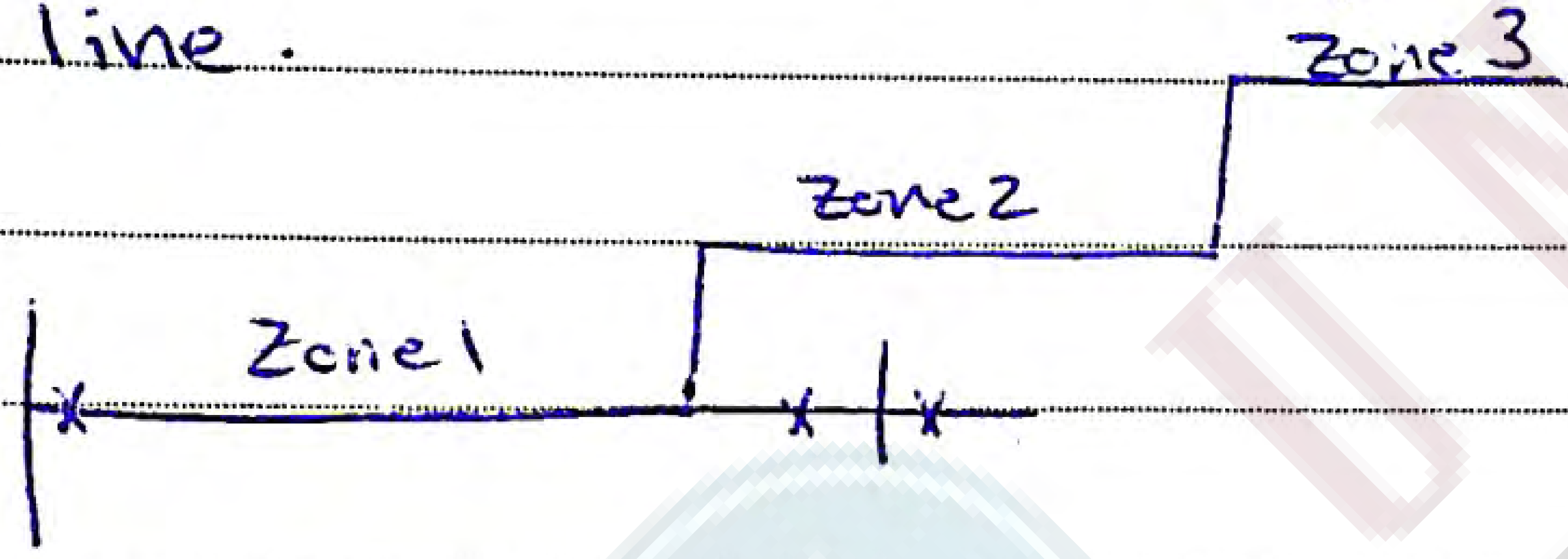
$Z_{r1}$ → Stage 1 extends to 80% of protected line

$Z_r$ → Zone 2

protected line +50% of the seconed shortest line

$Z_r$ → Zone 3

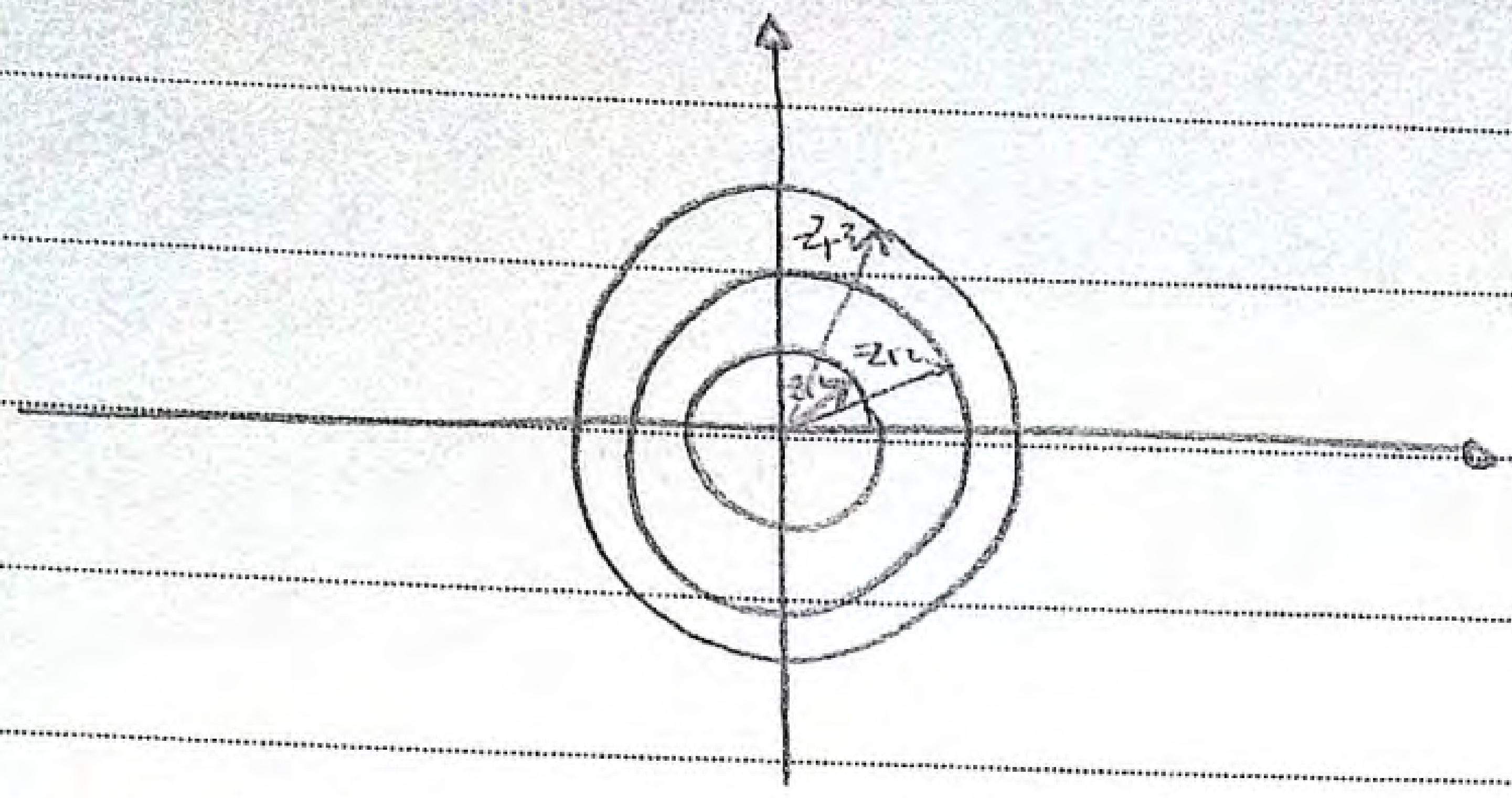
protected line + 2nd longest line + 25% of 3rd longest line.



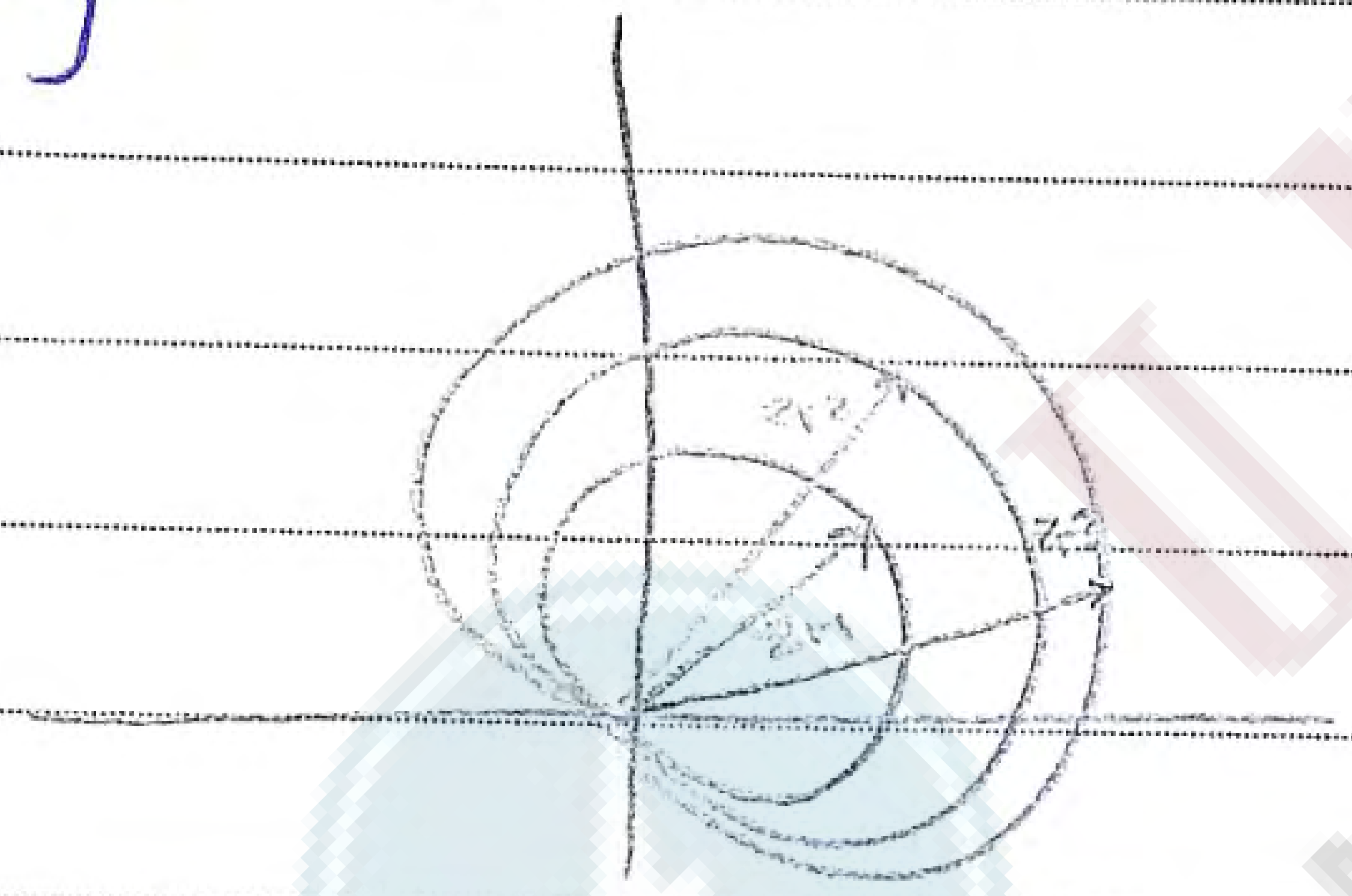
lec # 12

Wednesday
26/3/2014

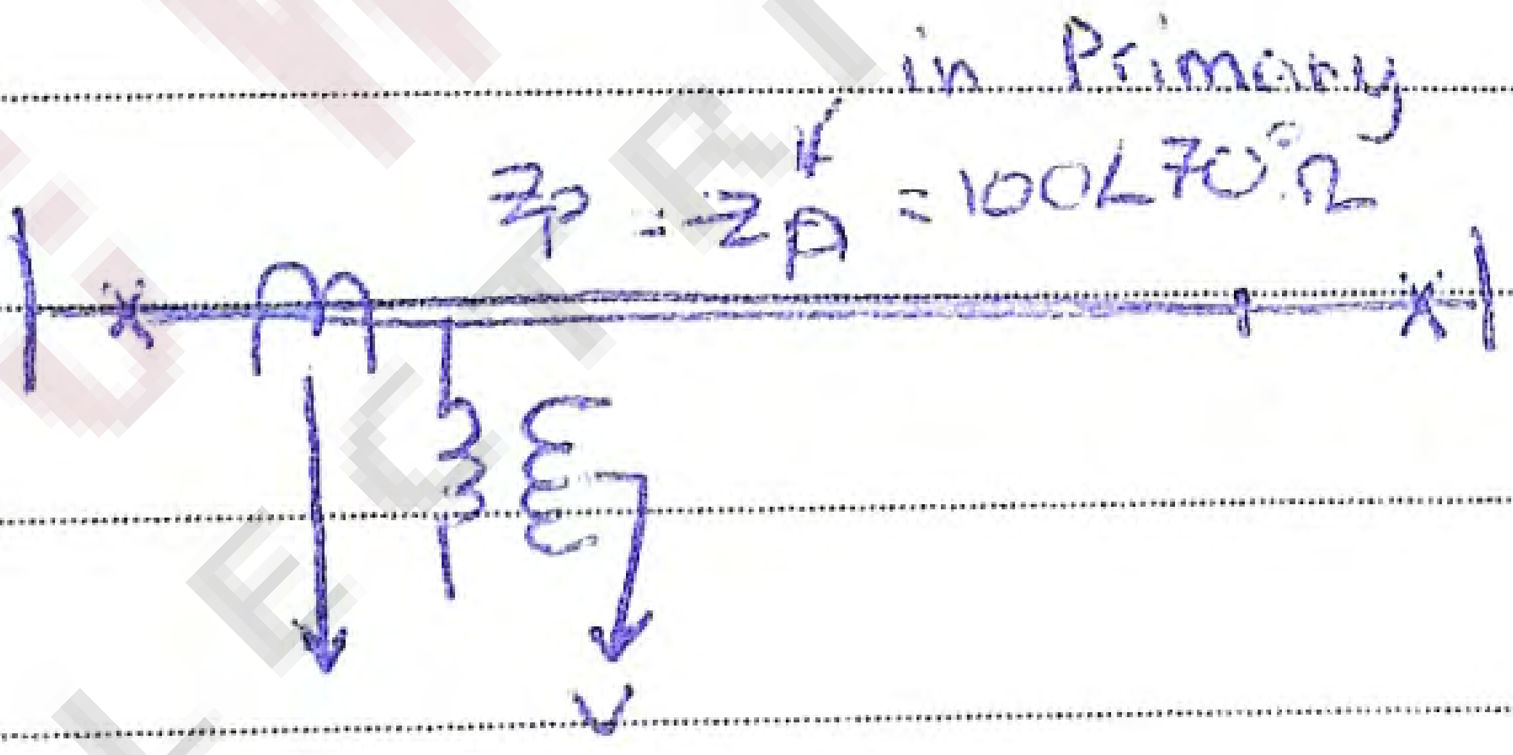
## Ohm relay

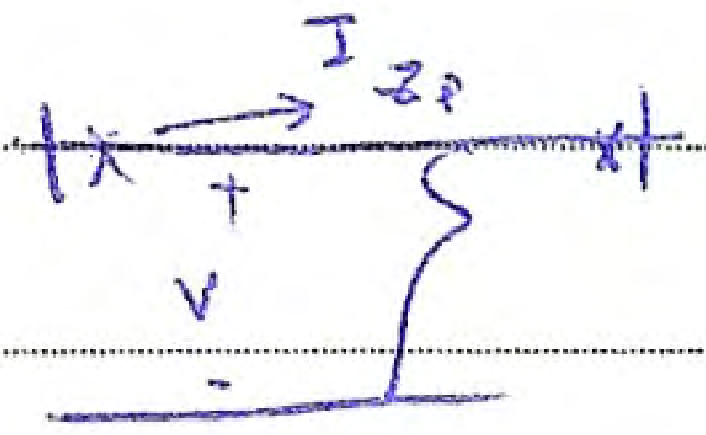


## Mho Relay



## Reachance Relay





in Secondary

$$\boxed{Z_s} = \frac{V_s}{I_s} = \frac{V_p / V.T\ ratio}{I_p / C.T\ ratio} = Z_p \frac{C.T\ ratio}{V.T\ ratio}$$

$Z_{r_1}$

$$= 100\angle 70 \frac{500/1}{(132K/\sqrt{3})/(110/\sqrt{3})}$$

lec # 12

Wednesday
26/3/2014

## Power System Stability:

is the ability of the synchronous generator in the power system to run in synchronism (at $W_{sm}$ (Single mechanical speed (it is constant))) Following a ~~[illegible]~~ disturbance.

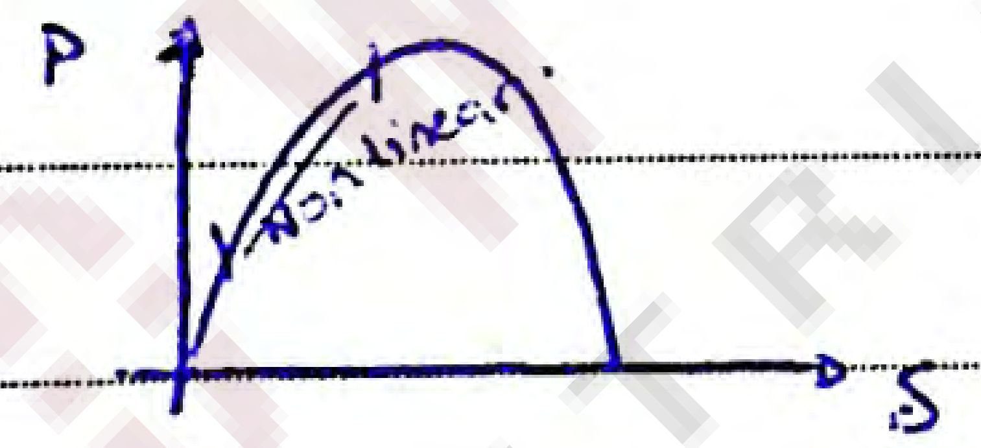
- Large Disturbance
  - fault 3-ph fault for 0.1 sec
  - generator out of service
  - Large change in load
- Small Disturbance
  - Small change in power
  - Small change in controller setting. power / voltage

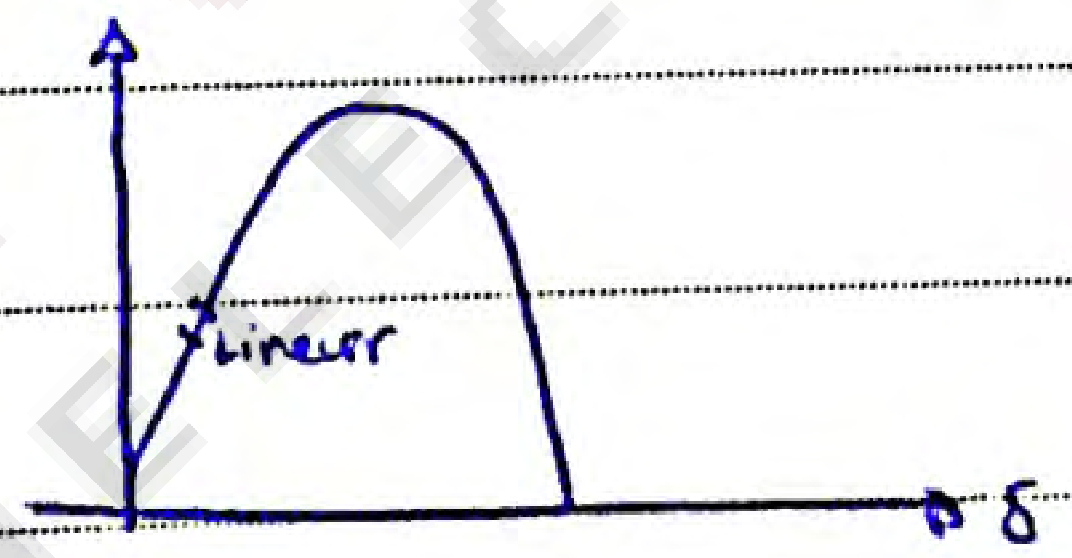
This Called Transient Stability

non-Linear differential equations (DE) + algebric equation (inital values). → in large Disturbance.

1 gen → infinite bus 10:04

26 D.E





This called Steady State stability

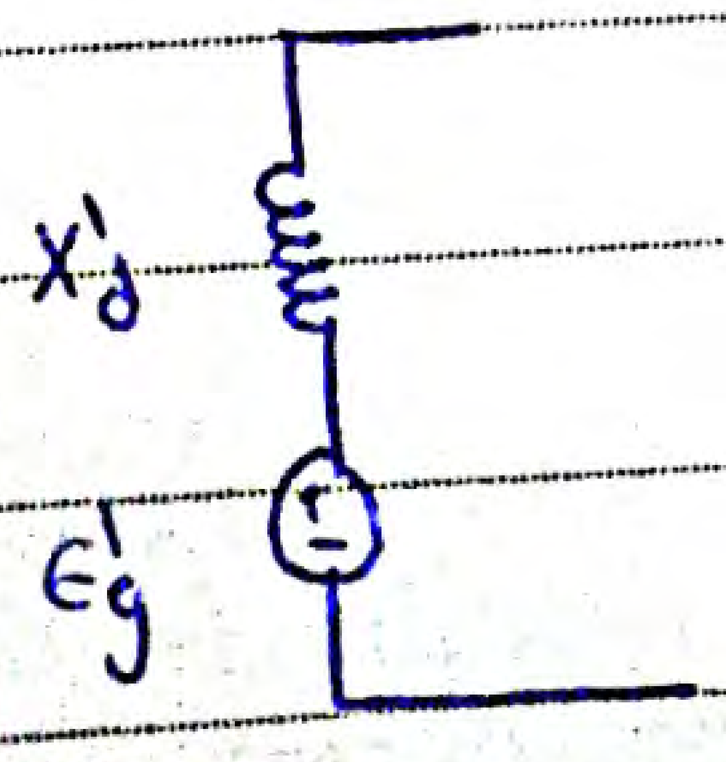
linearisation of equation

$x' = AX + BU$

$Y = CX + DU$

$[SI - A]$ → in Small Disturbance.

First swing → 1sec



→ controllers are not considered.

$E_g'$ = constant not affected by speed change

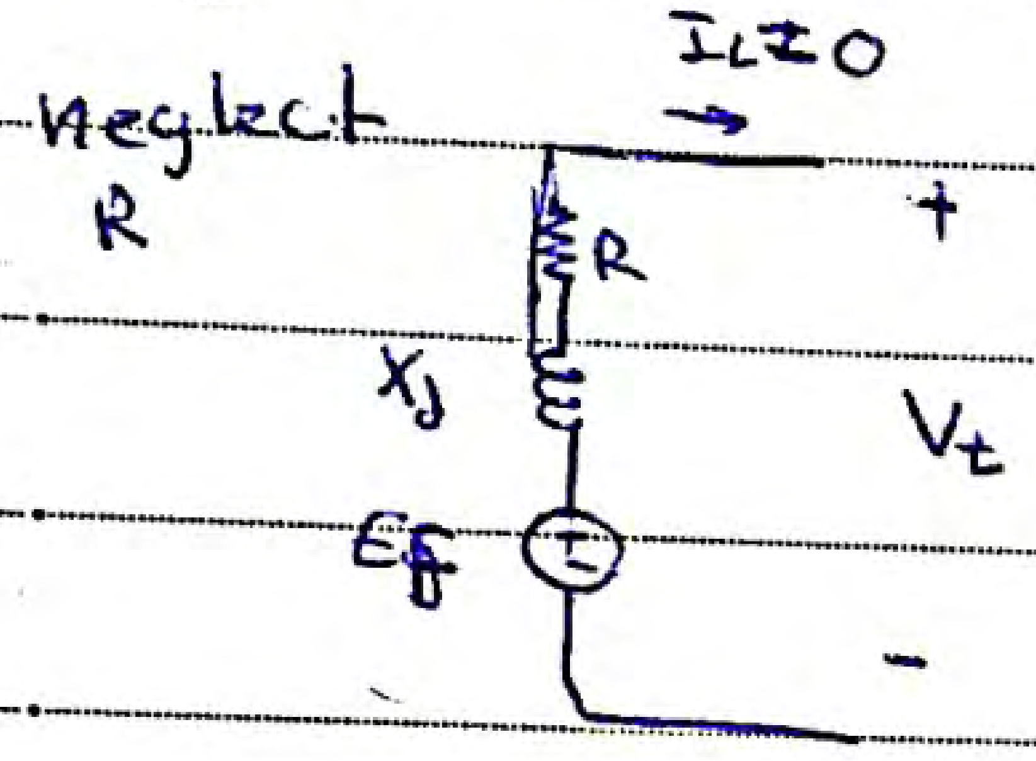
lec # 12

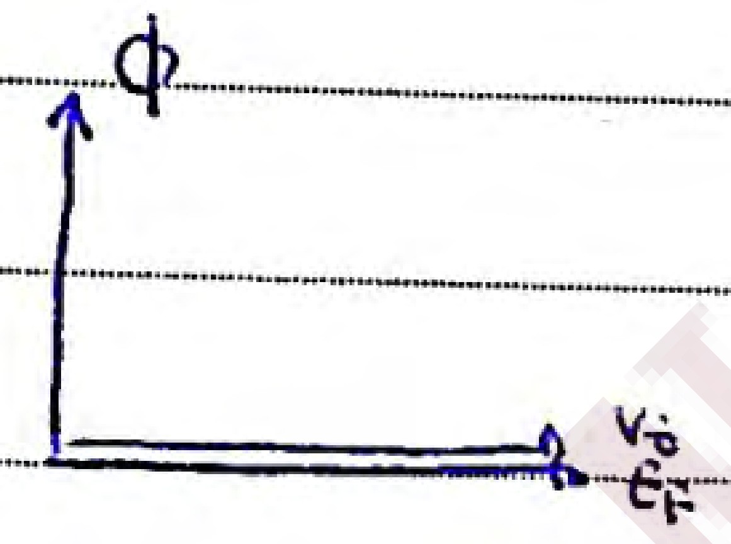
Wednesday
26/3/2014

- neglect D.C
- neglect harmonics
- 3$\phi$ fault →

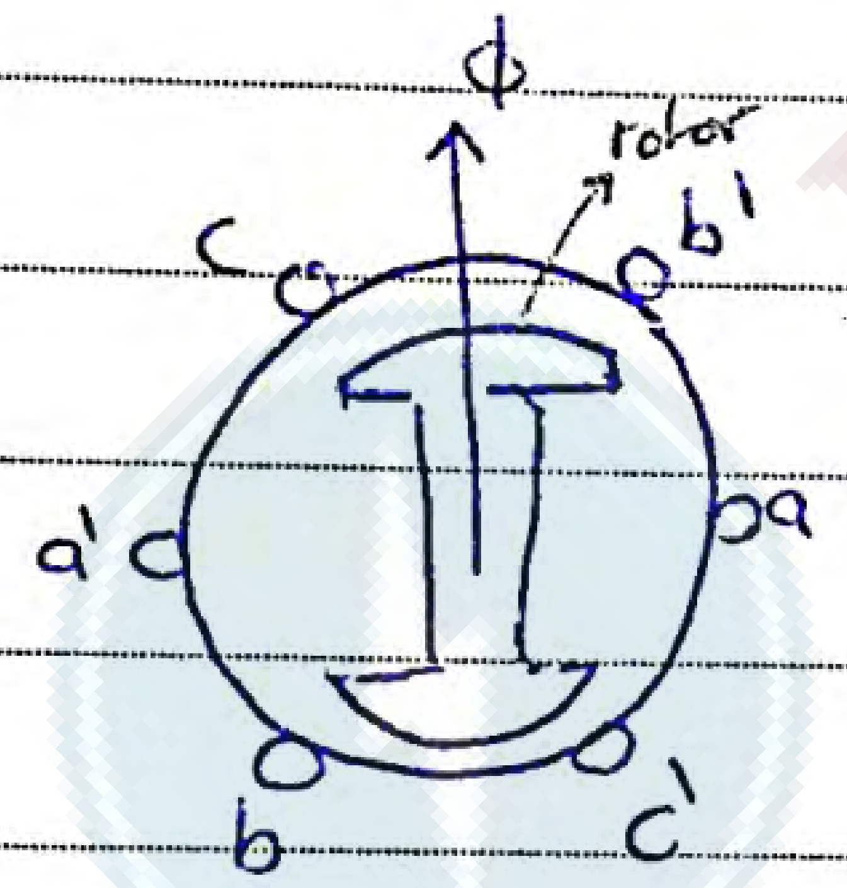
unbalanced : Symmetrical Component 10:21

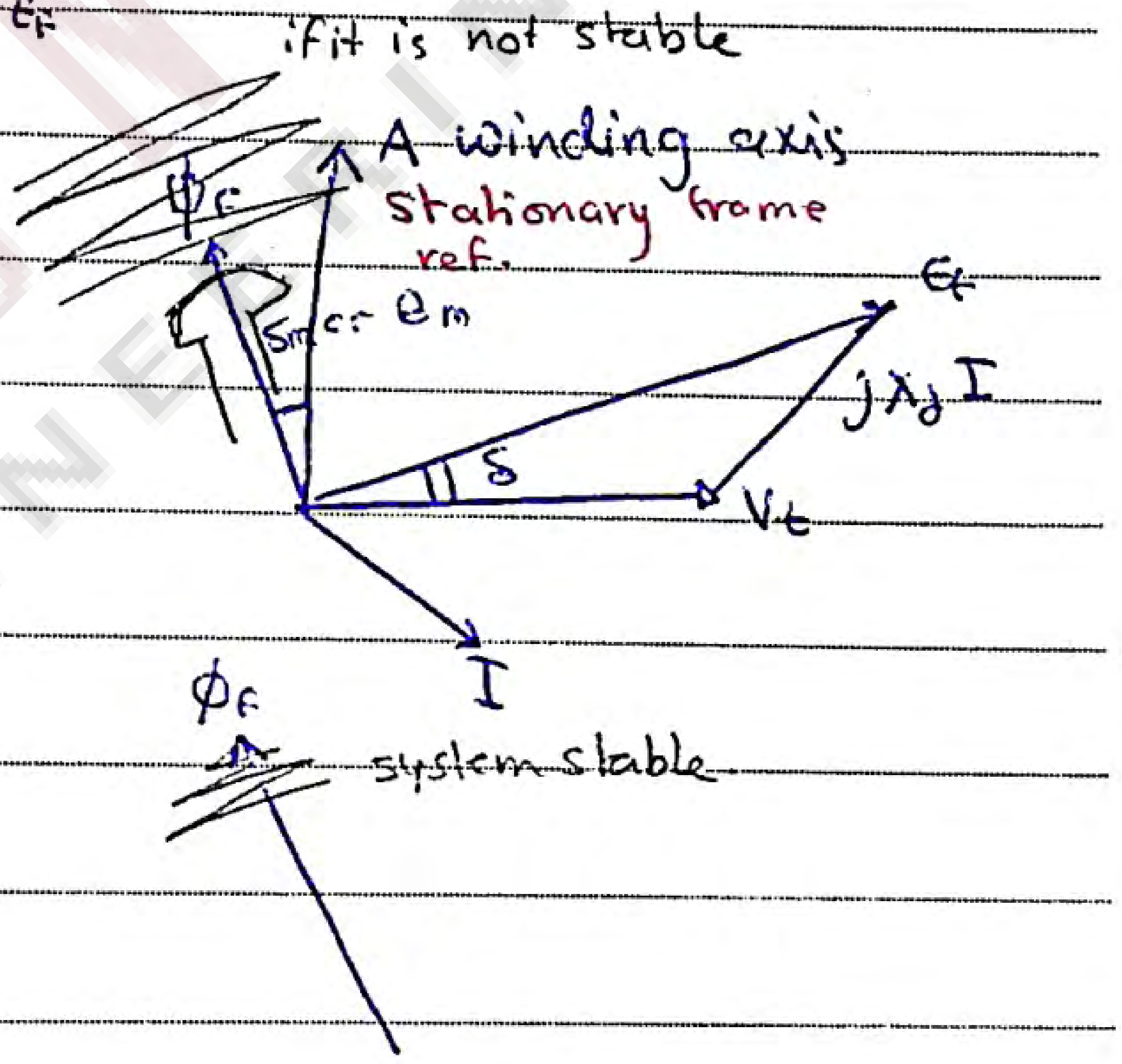
generator at Steady State:





$\phi_f \perp E_f$





Equation of motion:

$$J\frac{d^2\theta_m}{dt^2} = \underbrace{T_m}_{\text{constant}} - T_e = T_a$$ → this for generator

↳ moment of inertia $Kg.m^2$

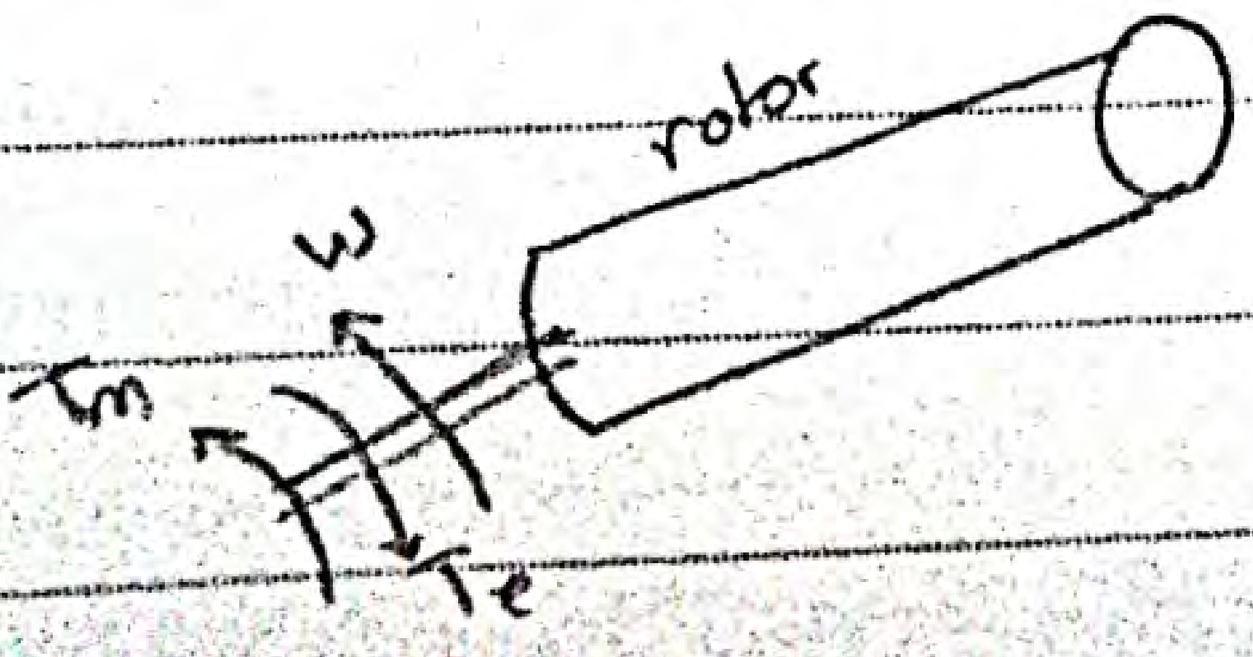
$\theta_m$ : angular displacement in mech. rad

$t$ : time sec

$T_m$ : net mechanical Torque (torque supplied by the prime-mover - F. & W. losses).

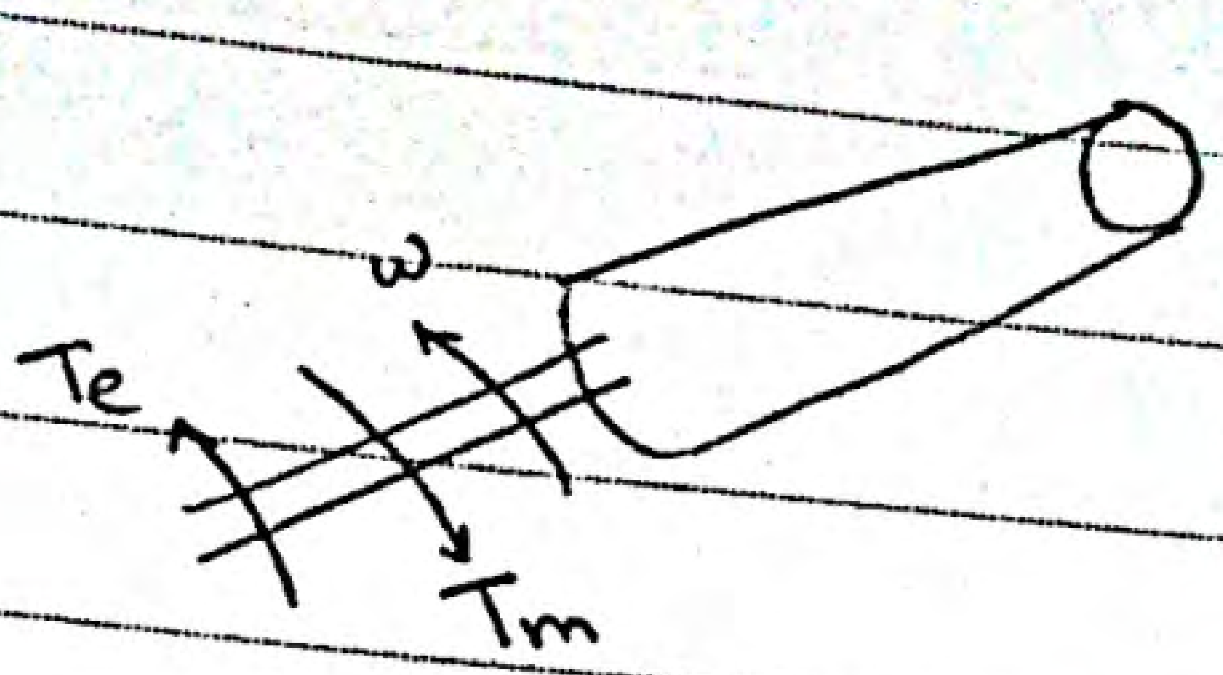
$T_e$: net air gap electrical torque.

generator:

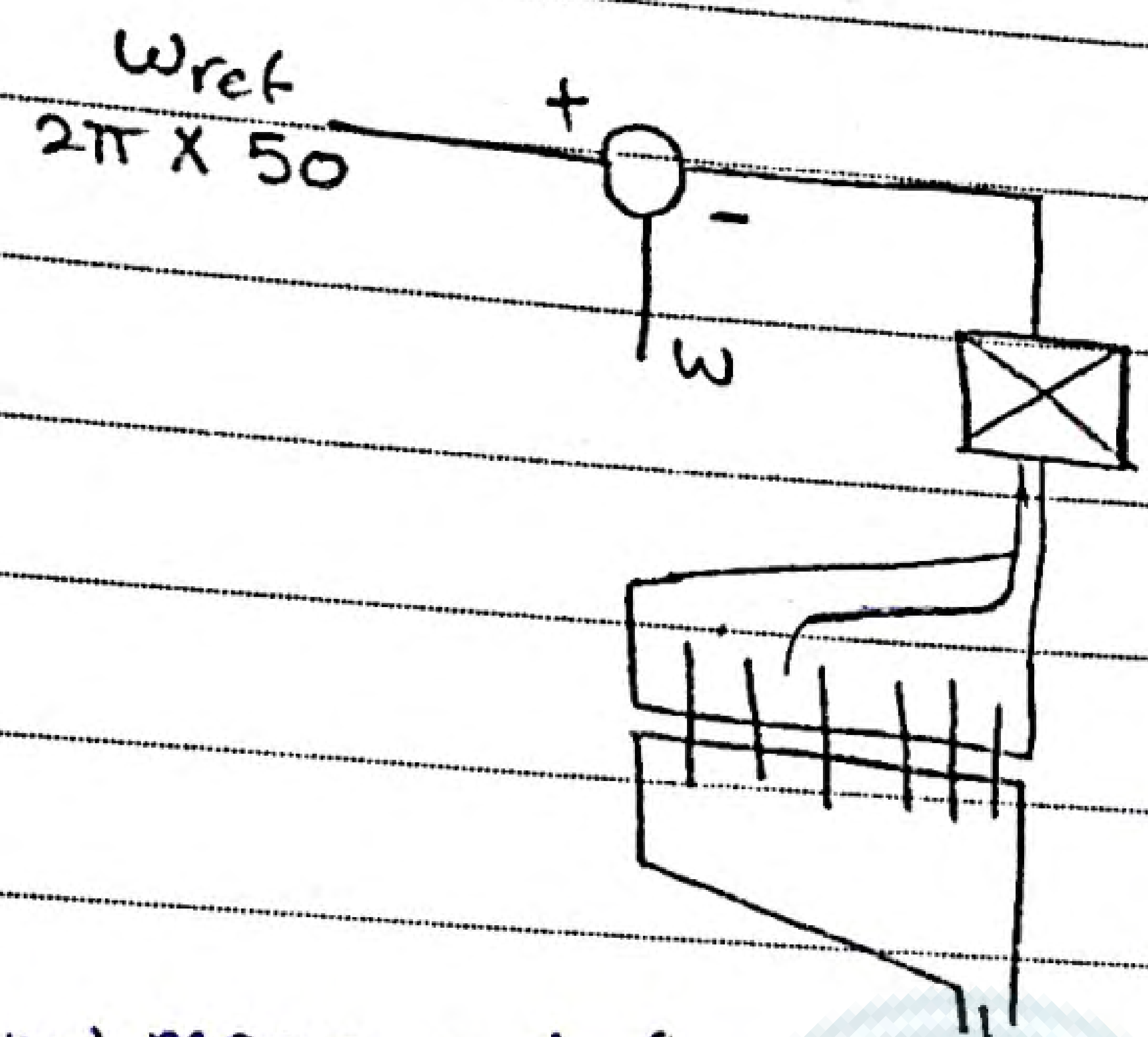


Wednesday
26/3/2014

motor:



$T_a = T_e - T_m$ in motor



$\theta_m$: measured from a stationary frame of refrence mech. rad

$\theta_m = \delta_m + \omega_{sm} t$

$\delta_m$: measured from a synchronously rotating frame of reference. mech. rad.

at $t = 0$, $\theta_m = \delta_m$

$$\frac{d\theta_m}{dt} = \frac{d\delta_m}{dt} + \omega_{sm}$$

→ $\omega_m$ mech. speed mech. rad/sec

$$\omega_m = \omega_{sm} + \frac{d\delta_m}{dt}$$ , $\omega_m \simeq \omega_{sm} \simeq$ constant

$$\frac{d^2\theta_m}{dt^2} = \frac{d\delta_m^2}{dt^2}$$

$$\omega_m\left(\frac{J d^2\delta_m}{dt^2} = T_m - T_e = T_a\right)$$

$$J\omega_m \frac{d^2\delta_m}{dt^2} = T_m\omega_m - T_e\omega_m$$

$$M\frac{d^2\delta_m}{dt^2} = P_m - P_e$$

$P_m$ : net mechanical power , $P_e$ : net air gap electrical Power

lec # 12

Wednesday
26/3/2014

M : inertia Constant

$P_m - P_e$ ( Joule / sec)

$\dfrac{d^2\delta_m}{dt^2}$ ( mech rad / $s^2$ )

$$M \left( \frac{\text{Joule}}{S} \times \frac{S^2}{\text{mech. rad}} \right)$$

$$\rightarrow \frac{\text{Joule } S}{\text{mech. rad}}$$

Monday
31/3/2014

lec # 13

constant → $M = J\omega_m$

$$\omega_m = \omega_{sm} + \frac{d\delta_m}{dt}$$

mechrad / sec.

$$M \frac{d^2\delta_m}{dt^2} = P_m - P_e \quad \text{Joule / Sec}$$

$$M \longrightarrow \frac{\text{Joule. Sec}}{\text{mech. rad}}$$

$$H \triangleq \frac{\text{K.E. stored in the rotor ( M Joule)}}{S_{machine} \ ( MVA )}$$

$$= \frac{\frac{1}{2} \overset{\overset{M}{\boxed{J \cdot \omega_{sm}}} \cdot \omega_{sm}}{J\omega_{sm}}}{S_{machine}} \quad ( \text{sec})$$

$$H = \frac{M\omega_{sm}}{2 S_{machine}}$$

$$M = \frac{2H S_{machine}}{\omega_{sm}}$$

$$\frac{2H \cancel{S_{machine}}}{\omega_{sm}} \frac{d^2\delta_m}{dt^2} = \frac{P_m - P_e}{S_{machine}} = P_m - P_e \text{ in P.U.}$$

lec # 13

Monday
31/3/2014

$$\frac{2H}{\omega_{sm}} \frac{d^2 \delta_m}{dt^2} = P_m - P_e$$

$\delta_m$ mech. rad

$\omega_{sm}$ mech.rad/sec

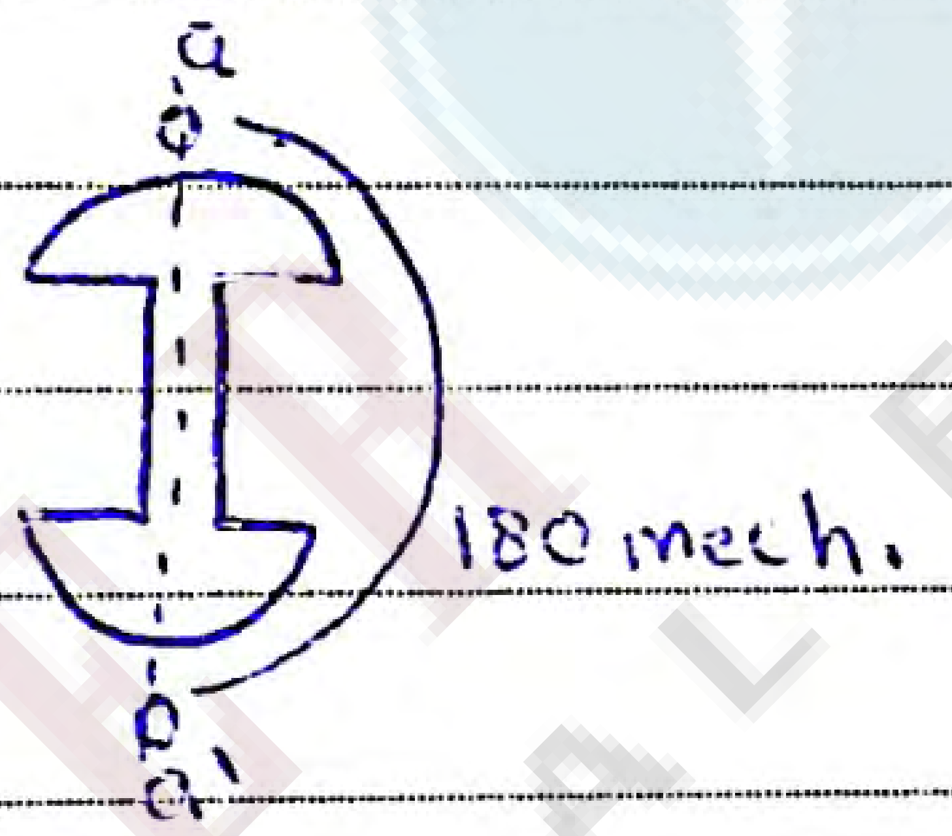
$\delta_e = P . \delta_m$

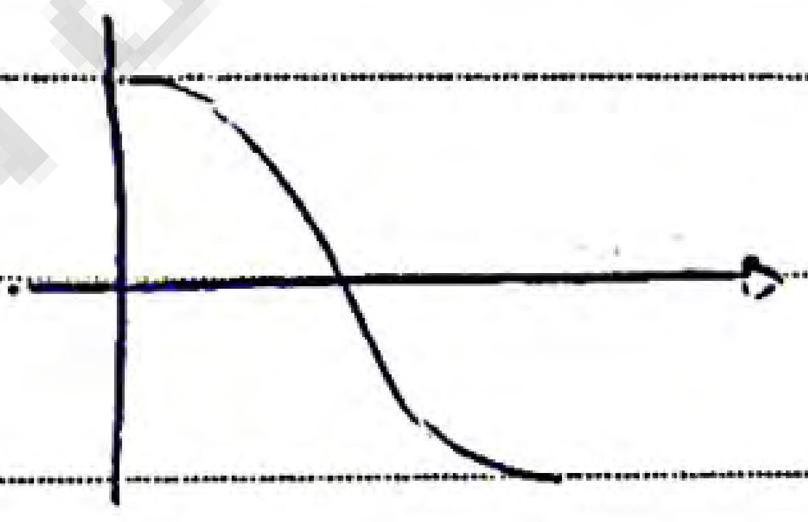
$\omega_{se} = P . \omega_{sm}$

$f = P \frac{n}{60}$ P : Pairs of Poles

$\omega_{sm} = 2\pi . \frac{n}{60}$

$\omega_{se} = 2\pi f = 2\pi \frac{Pn}{60}$





$$\frac{2H}{\omega_s} \frac{d^2 \delta}{dt^2} = P_m - P_e$$

$$\frac{2H}{2\pi f} \frac{d^2 \delta}{dt^2} = P_m - P_e$$

$$\frac{H}{\pi f} \frac{d^2 \delta}{dt^2} = P_m - P_e \quad \delta \text{ in rad}$$

$$\frac{H}{180 f} \frac{d^2 \delta}{dt^2} = P_m - P_e \quad \delta \text{ in degree}$$

$$\omega = \omega_s + \frac{d\delta}{dt} \quad ①$$

$$\frac{d\omega}{dt} = \frac{d^2 \delta}{dt^2}$$

lec # 13

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$$\frac{2H}{\omega_s}\frac{d\omega}{dt} = P_m - P_e \quad ②$$

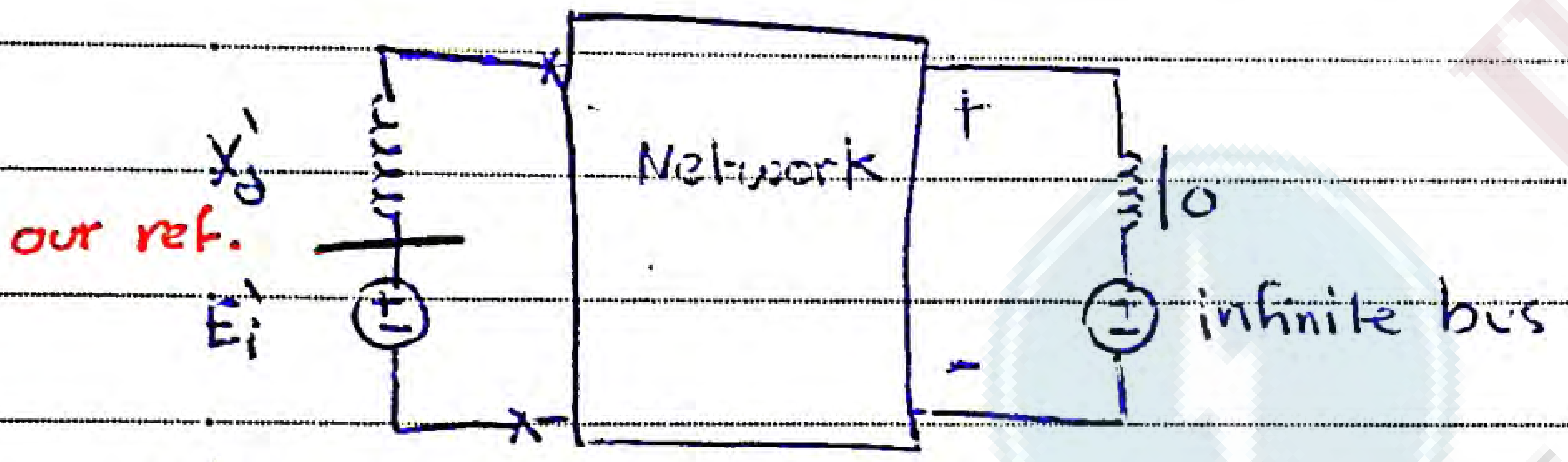
$$\boxed{\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} = P_m - P_e}$$

if $P_m = P_e$ we are in Steady state

$P_m > P_e$ " " " accelarate mode

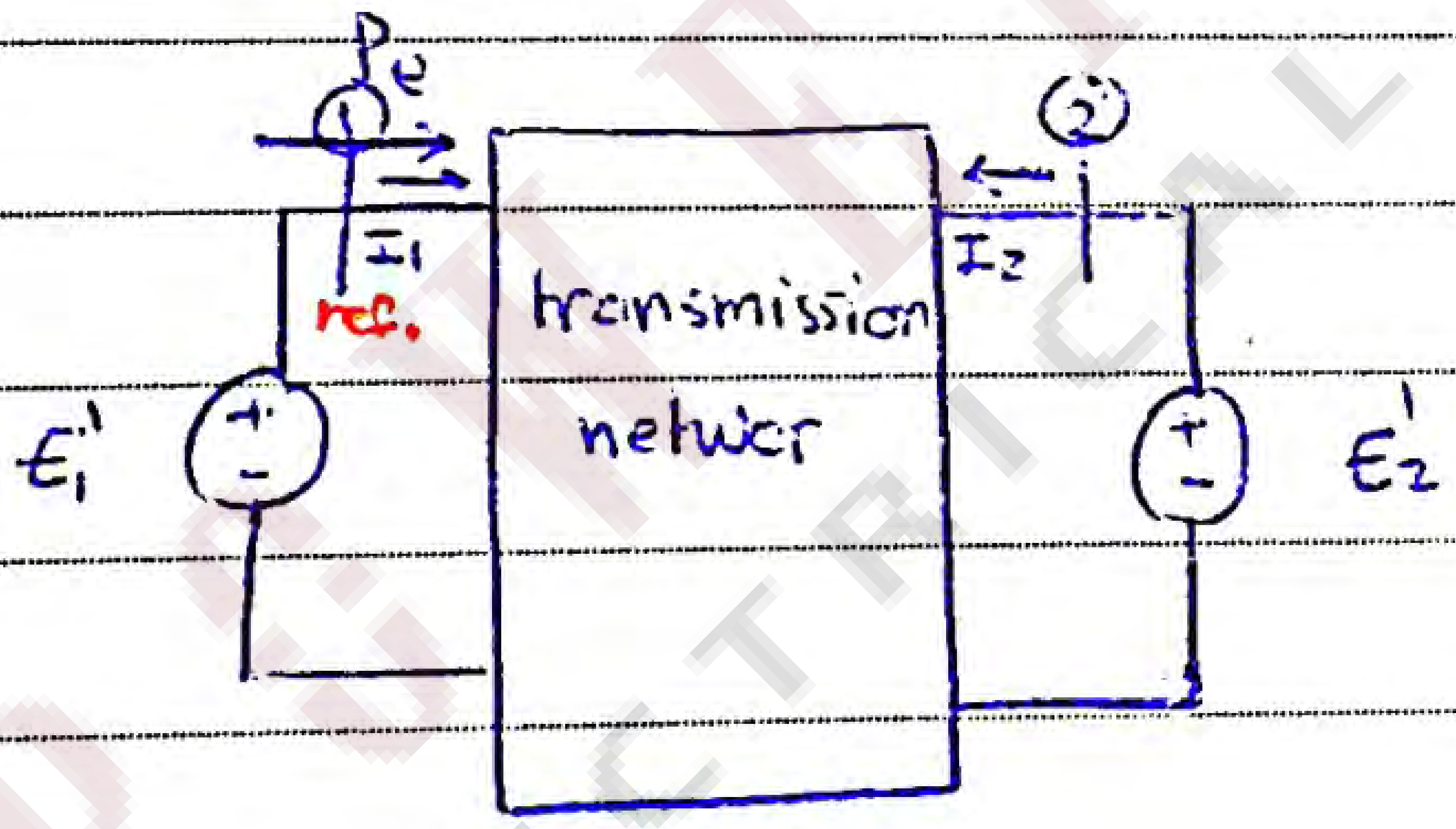
$P_m < P_e$ deaccelarate mode

$P_m$ constant



$E_i'$ → constant ∝ w

↳ change By field But we assume $E_i'$ constant.



$$S_1 = V_1 \sum_{k=1}^{n} Y_{1k}^* V_k^*$$

$$= E_1' \sum_{k=1}^{n} Y_{1k}^* E_k'^*$$

$$S_1 = E_1' \cdot Y_{11}^* E_1'^* + E_1' Y_{12}^* E_2'^*$$

$Y_{11} = G_{11} + j B_{11}$

$E_1' = |E_1'| \angle \delta_1$

$E_2' = |E_2'| \angle \delta_2$

$Y_{12} = |Y_{12}| \angle \theta_{12}$

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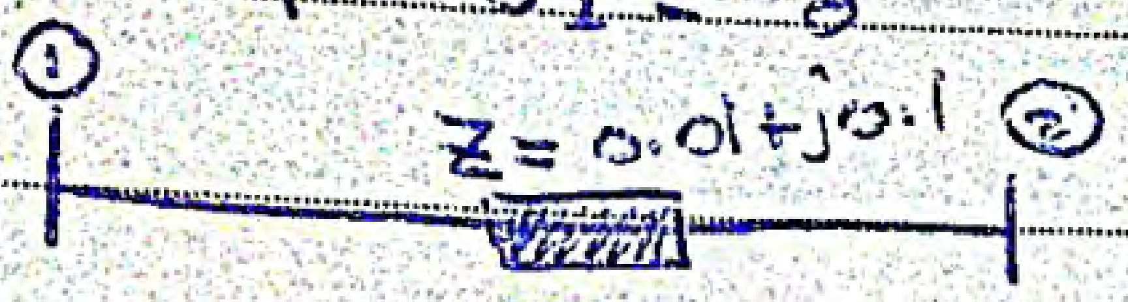
$$S_1 = |E_1'|^2 (G_{11} - jB_{11}) + |E_1'||E_2'||Y_{12}| \angle \delta_1 - \delta_2 - \theta_{12}$$

$$P_1 = |E_1'|^2 G_{11} + |E_1'||E_2'||Y_{12}| \cos(\underbrace{\delta_1 - \delta_2}_{\delta} - \underbrace{\theta_{12}}_{-\frac{\pi}{2} - \gamma})$$

$$\delta_1 - \delta_2 = \delta$$



$$Y = \frac{1}{Z} = \frac{1\,(0.01 - j0.1)}{\underbrace{(0.01 + j0.1)(0.01 + -j0.1)}_{0.0001 + 0.01}} \cong 1 - j10$$

$$Y_{12} = -Y = -1 + j10$$

$$\sqrt{101}\,\underline{|95°}$$

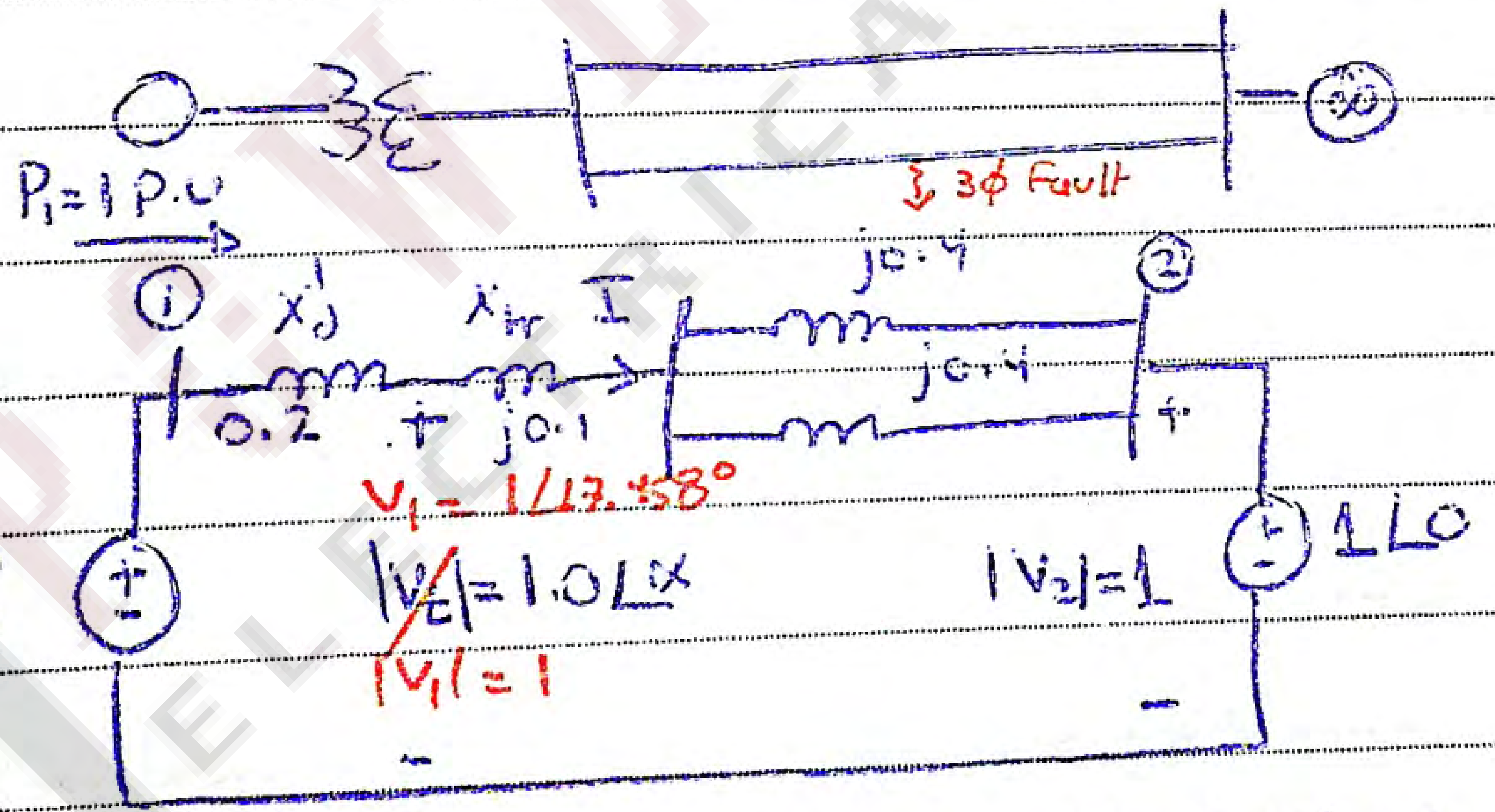
$$\theta_{12} = \frac{\pi}{2} + \gamma$$

$$P_1 \underset{2}{=} |E_1'| G_{11} + |E_1'||E_2'||Y_{12}| \sin(\delta - \gamma)$$

For lossless system

$$P_1 = |E_1'||E_2'||Y_{12}| \sin\delta \qquad P = \frac{|V_1||V_2|}{|B|} \sin\delta$$

Example :



Power angle equation ? $P = \frac{|V_1||V_2|}{|X_{12}|} \sin \overset{\alpha}{\cancel{\delta}}$

$$1 = \frac{1 * 1}{0.3} \sin\alpha$$

$$\alpha = \sin^{-1}(0.3) = 17.458°$$

$$I = \frac{1\angle 17.458 - 1\angle 0}{j0.3} = 1.012 \angle 8.729°$$

$$E_1' = 1\angle 17.458 + j0.2 * 1.012 \angle 8.729° = 1.05 \angle \underbrace{28.44°}_{\delta}$$

lec # 13

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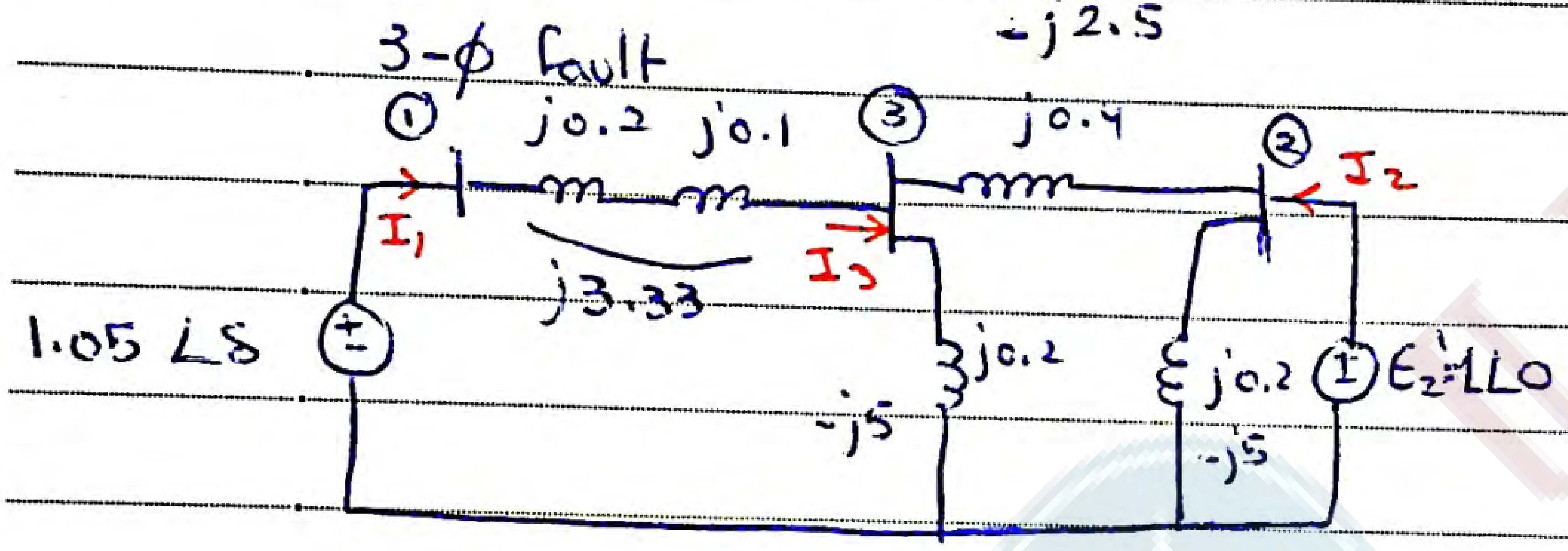
$E_2' = 1\angle 0$

## Prefault Condition :

$P_1 = |E_1'||E_2'| \, |Y_{12}| \sin\delta$

$= \frac{1.05 \times 1}{0.5} \sin\delta = 2.1 \sin\delta$

$\delta_0$ at steady state $= 28.44°$



$$\begin{array}{cc} & K \qquad\qquad L \\ Y = & \left[\begin{array}{cc|c} -j3.33 & 0 & j3.33 \\ 0 & -j7.5 & j2.5 \\ \hline j3.33 & j2.5 & -j10.833 \end{array}\right] \\ & \qquad L^T \qquad M \end{array}$$

eliminate bus 3

$Y = K - L M^{-1} L^T$

$$= \begin{bmatrix} -j3.33 & 0 \\ 0 & -j7.5 \end{bmatrix} - \begin{bmatrix} j3.33 \\ j2.5 \end{bmatrix} \begin{bmatrix} -j10.833 \end{bmatrix}^{-1} \begin{bmatrix} j3.33 & j2.5 \end{bmatrix}$$

$$= \begin{bmatrix} -j2.308 & j0.769 \\ j0.769 & -j6.923 \end{bmatrix}$$

## during Fault :

$P_1 = 1.05 * 1 * 0.769 * \sin\delta$

$= 0.808 \sin\delta$

$Y_{12} = \left.\frac{I_1}{V_2}\right|_{V_1 = 0}$ from Network $I_1 = Y_{11}V_1 + Y_{12}V_2$

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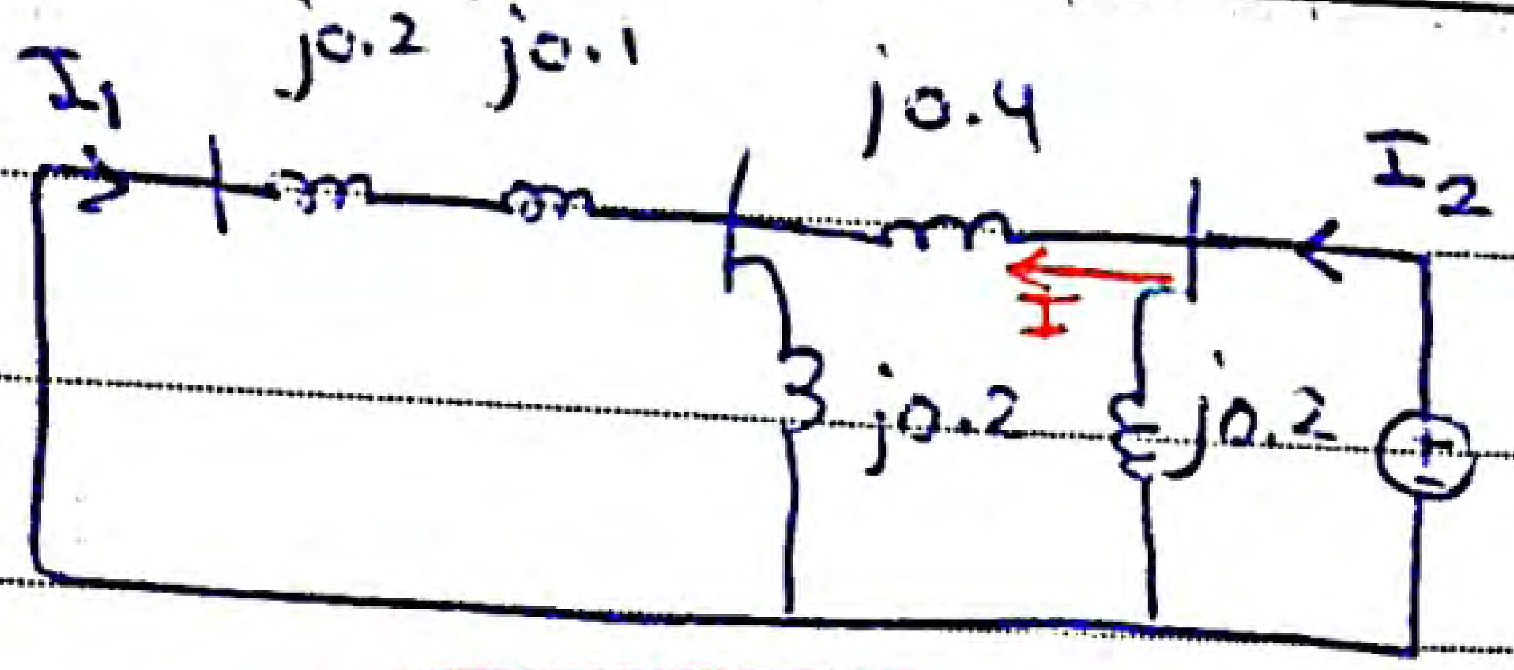
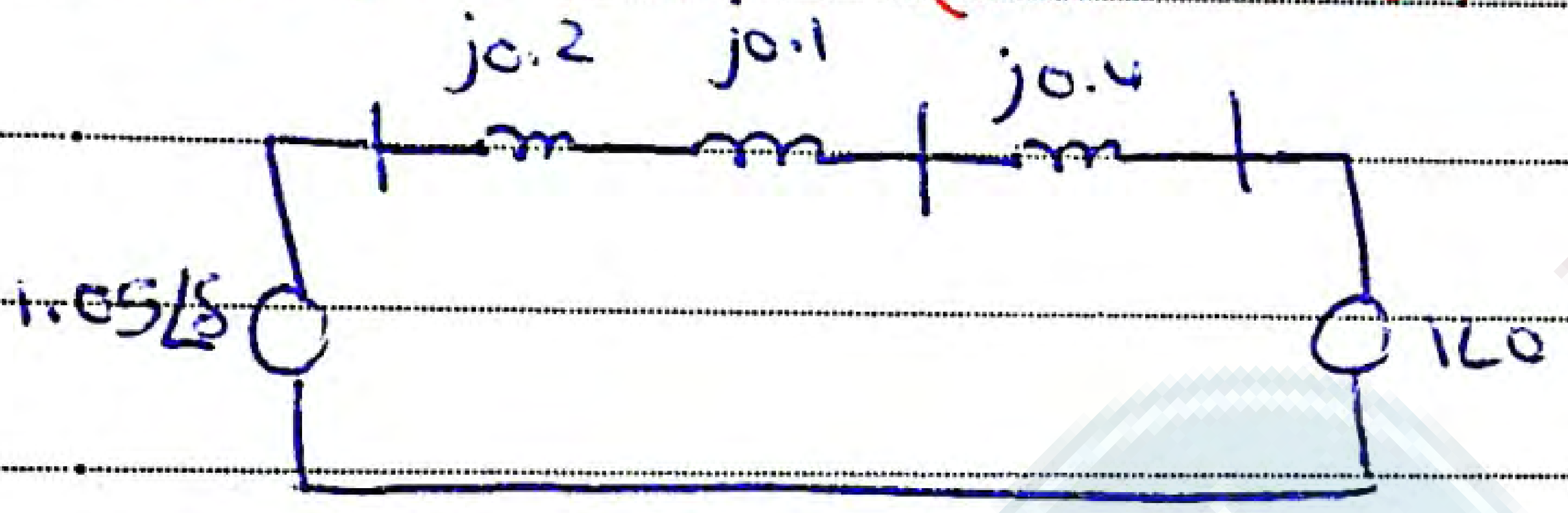


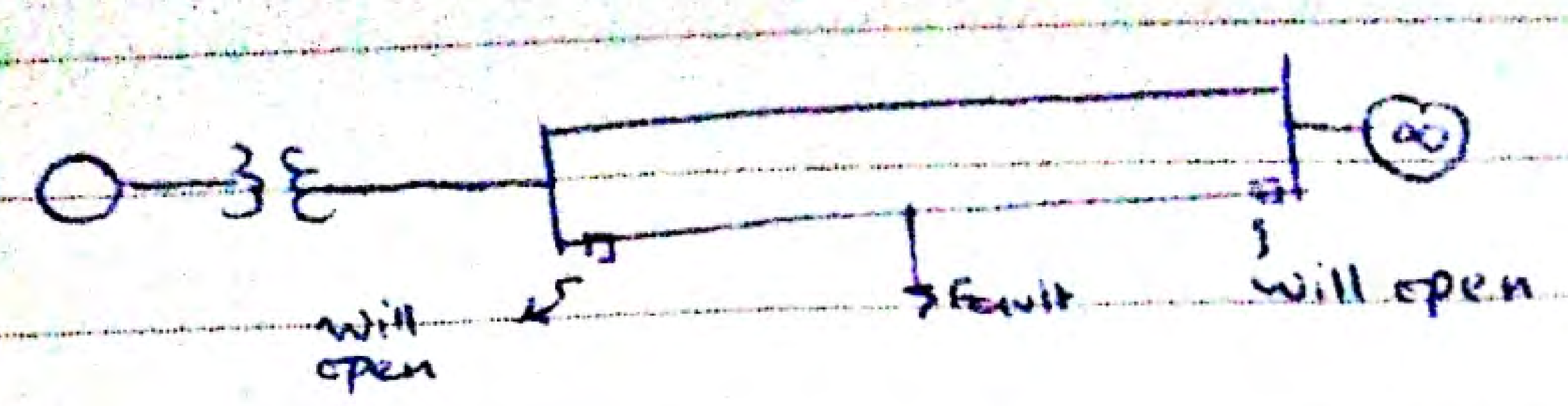
$$I_1 = \underbrace{\frac{-1\angle 0}{j0.4 + j0.2 // j0.3}}_{I} \times \frac{0.2}{0.5} = j0.769$$

After fault (Post fault):



$$P_1 = \frac{1.05*1}{0.7} \sin\delta = 1.5 \sin\delta$$

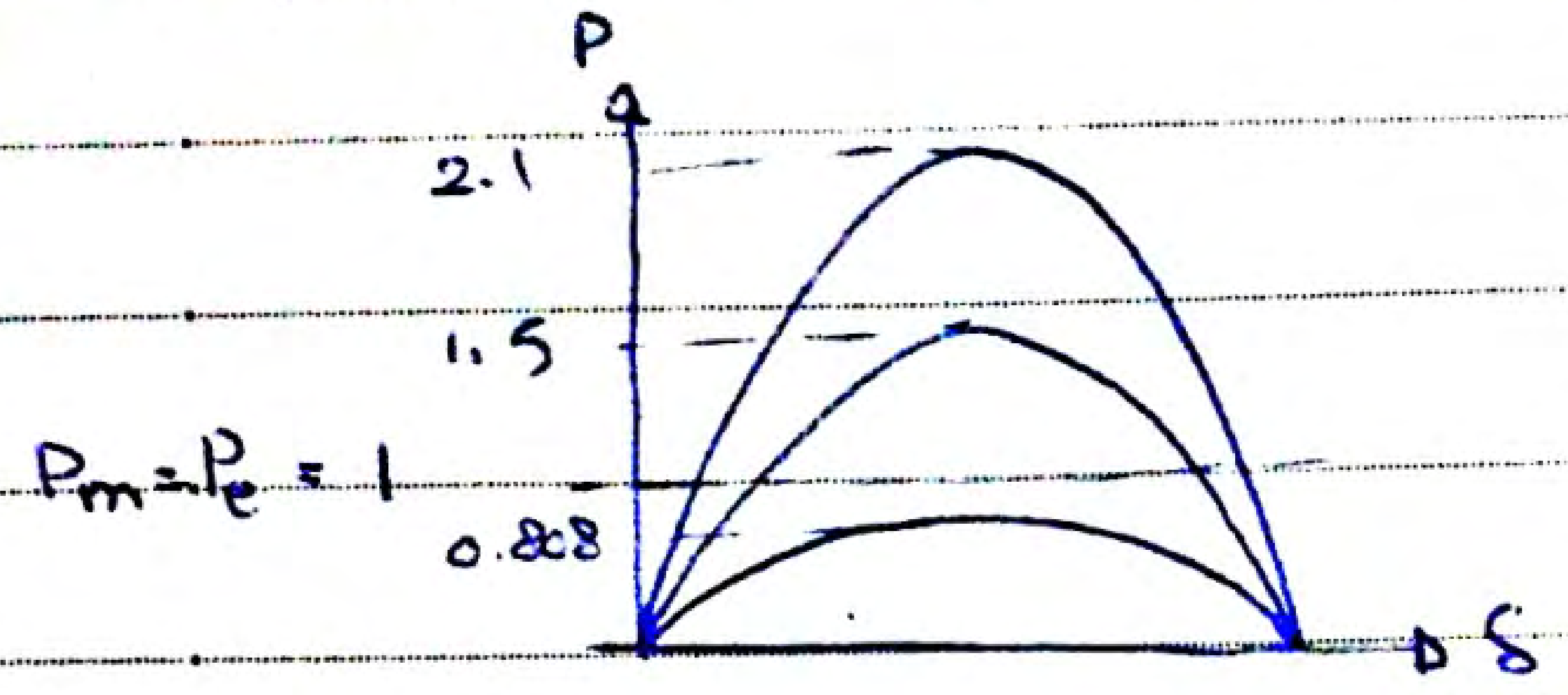
lec # 14 2/4/2014

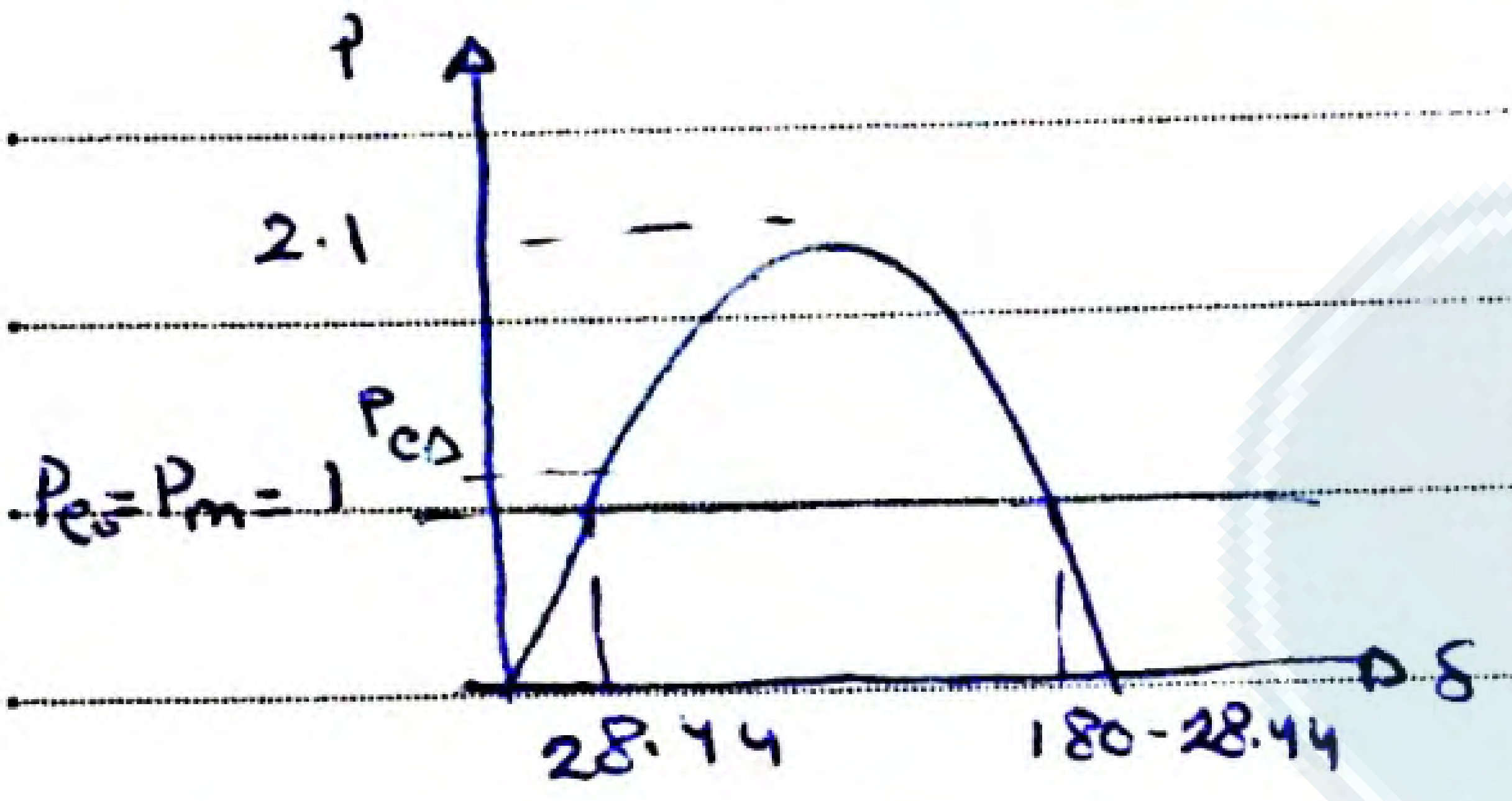


Pre fault : $P_e = 2.1 \sin\delta$

during fault : $P_e = 0.808 \sin\delta$

post Fault : $P_e = 1.5 \sin\delta$





$$\frac{2H}{\omega_s}\frac{d^2\delta}{dt} = P_m - P_e$$

$$\delta = \delta_0 + \delta_\Delta$$

$$P_e = P_{e0} + P_{e\Delta}$$

$$P_e = P_{max}\sin(\delta_0+\delta_\Delta) = P_{max}\sin\delta_0\cos\delta_\Delta + P_{max}\cos\delta_0\sin\delta_\Delta$$

$$\sin\delta_\Delta \approx \delta_\Delta$$

$$\cos\delta_\Delta \simeq 1$$

$$P_e = \underbrace{P_{max}\sin\delta_0}_{= P_{e0} = P_m} + P_{max}(\cos\delta_0)\delta_\Delta$$

$$\frac{2H}{\omega_s}\frac{d^2(\delta_0+\delta_\Delta)}{dt^2} = \cancel{P_m} - \cancel{P_{max}\sin\delta_0} - P_{max}(\cos\delta_0)\delta_\Delta$$

$$\frac{2H}{\omega_s}\frac{d^2\delta_\Delta}{dt^2} + \overset{S_p}{\cancel{P_{max}(\cos\delta_0)}}\delta_\Delta = 0$$

$P_{max}\cos\delta_0 = S_p$ (Synchronizing power coefficient)

$$\frac{d^2\delta_\Delta}{dt^2} + \frac{\omega_s S_p}{2H}\delta_\Delta = 0$$

lec # 14

Wednesday

2/4/2014

$(S^2 + \omega_n^2)\, \delta_0(S) = 0$

$S^2 + 2\alpha S + \omega_n^2$

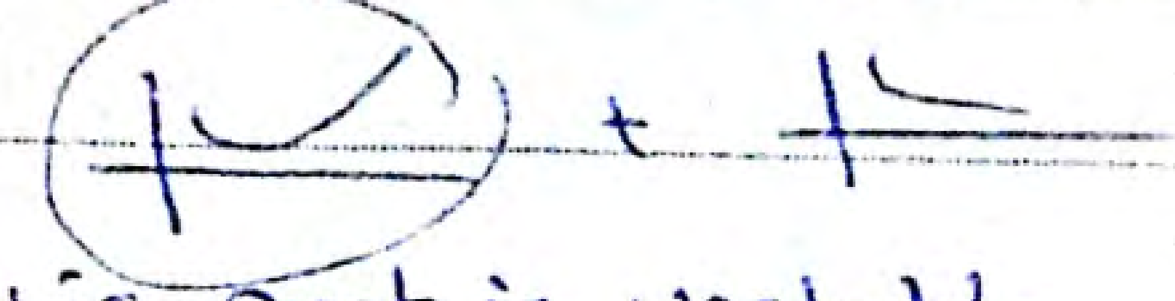
Damping الـ عند

Solution: $S^2 = -\omega_n^2$ , if $\omega_n^2 \to +ve$ , $S_{1,2} = \mp j\omega_n$

$\omega_n^2 \to -ve$ , $S_{1,2} = \mp \omega_n$

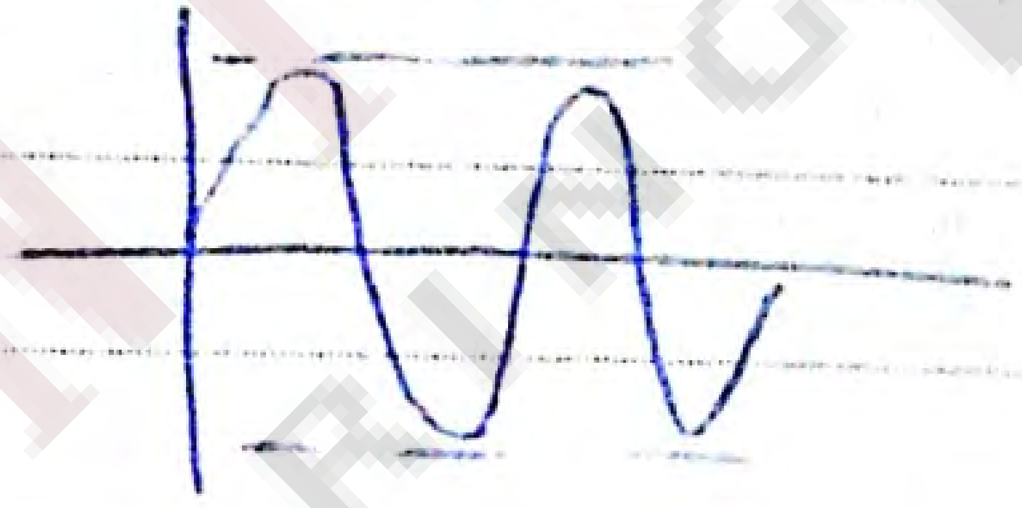
$\omega_n^2$ +ve $= A_1 e^{j\omega_n t} + A_2 e^{-j\omega_n t}$

-ve $= A_1 e^{\omega_n t} + A_2 e^{-\omega_n t}$ → unstable

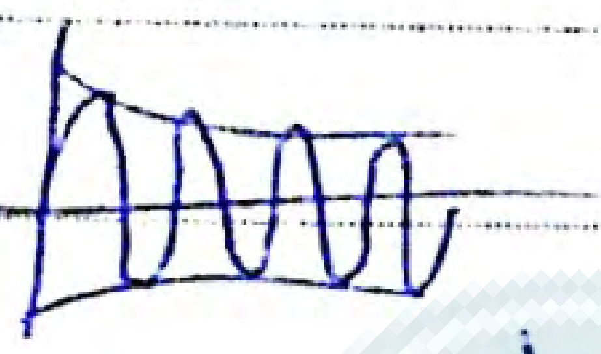


this part is unstable.

$\omega_n$ +ve → $e^{-\alpha t}(A \cos \omega_d t + B \sin \omega_d t)$



with R

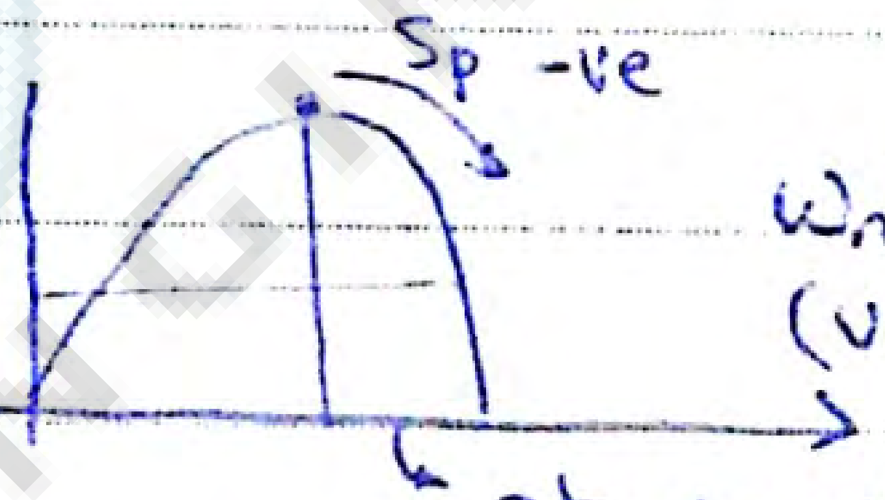


our equation does not have damping → damped sinusoidal

- Friction + Winding

$\omega_n^2 = \frac{\omega_s \boxed{S_p}}{2H}$ بتغير

+ve → $\omega_s$ ; $2H$ → +ve



$\omega_n^2 = -ve$ (unstable)

at steady state can't work here.

$2\pi f_n \sim \omega_n = \sqrt{\frac{\omega_s S_p}{2H}}$

oscillation frequency

1 ~ 3 HZ

$\omega_s + \omega_n$ → when in same direction

$\omega_s - \omega_n$ → when in opposite direction

Same Example:

$S_p = P_{max} \cos \delta_0$

$= 2.1 * \cos(28.44) = 1.8466$

$\omega_n = \sqrt{\frac{\omega_s S_p}{2H}} = \sqrt{\frac{377 \times 18466}{2 \times 5}} = 8.343$ rad/s $= 1.33$ HZ

oscillation freq.

good → 1~3 HZ

$\omega_s = 314$ , $f = 50$ HZ

$\omega_s$ 377 , $F = 60$ HZ

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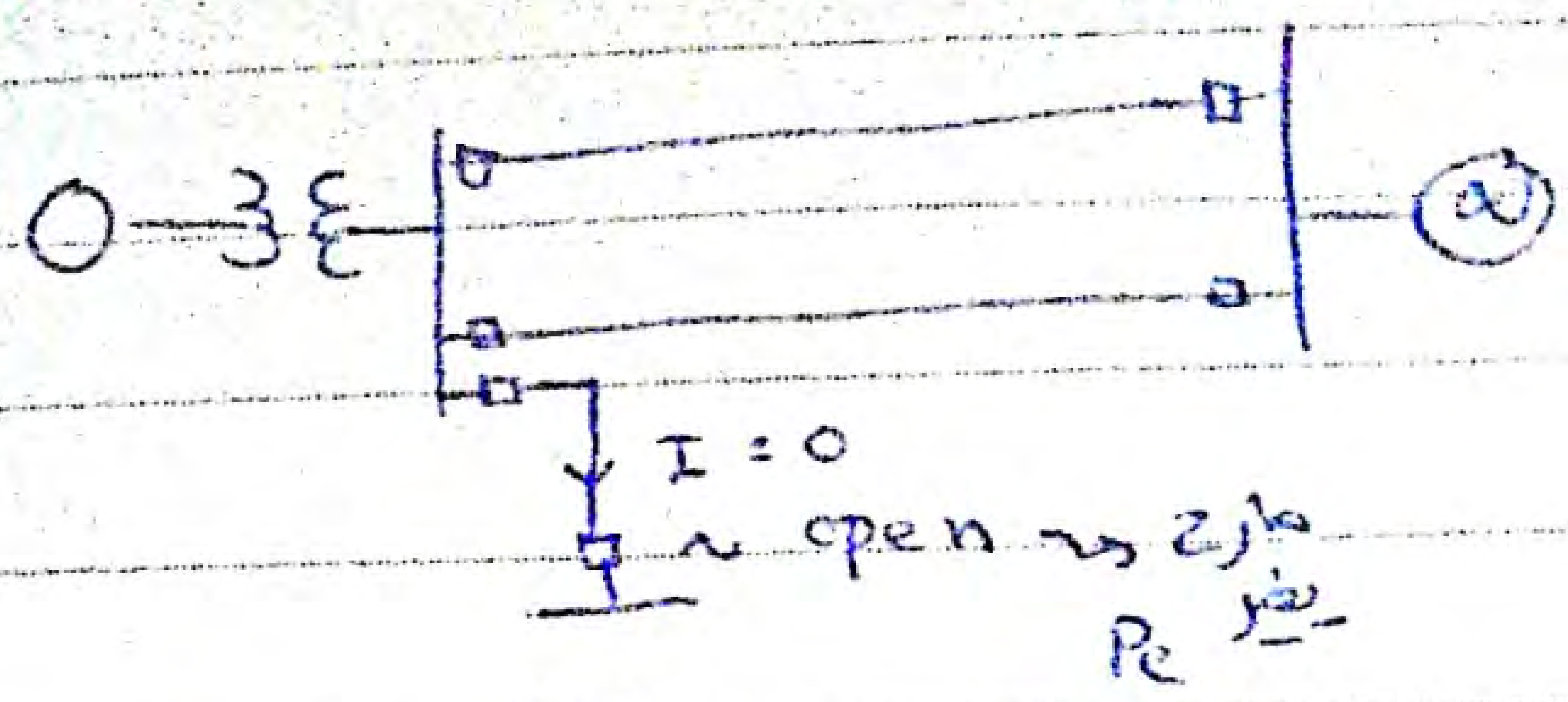
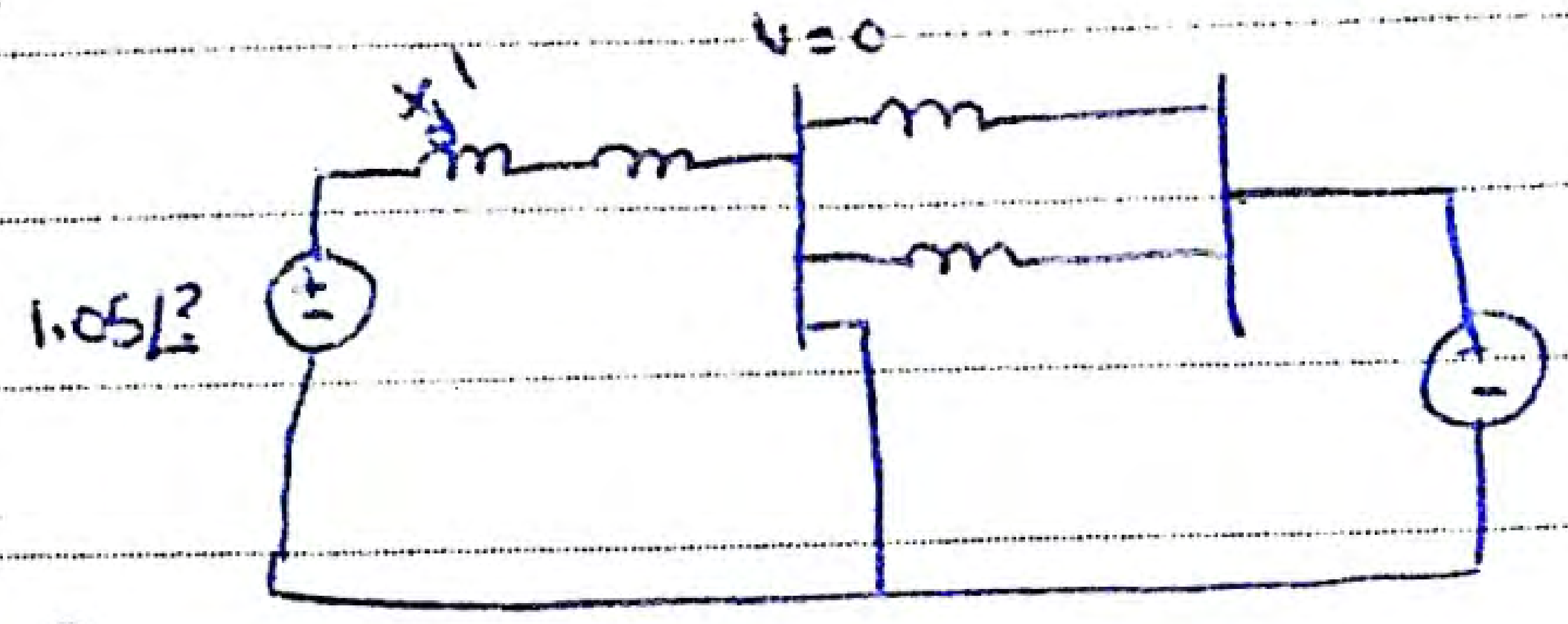
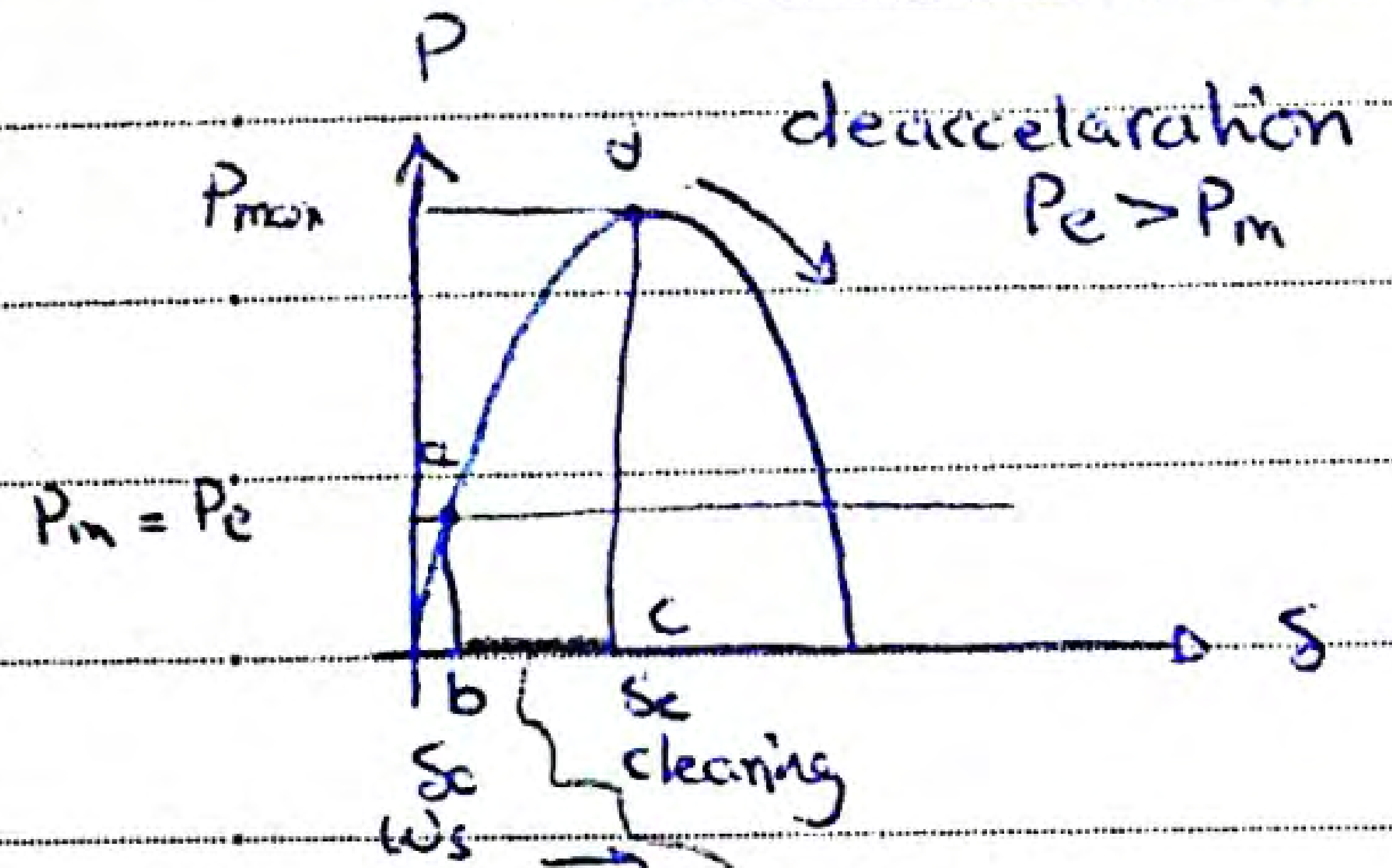
lec # 14

# Equal Area Criterion of Stability







بتسارع → $\frac{d\delta}{dt} = +ve$

$\frac{d^2\delta}{dt} = +ve$

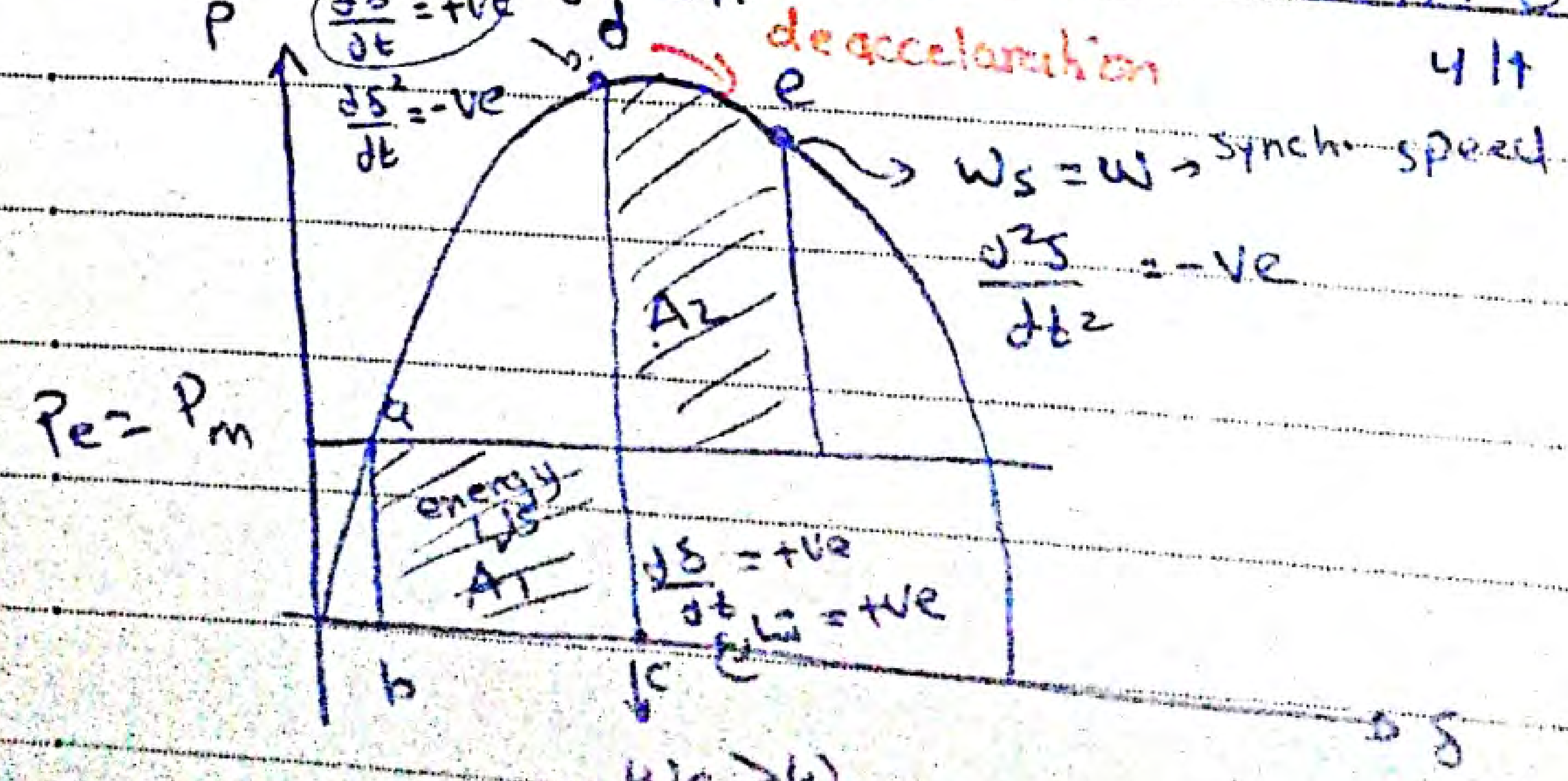
during fault: $\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} = P_m - \cancel{P_e}^{0}$

$$\frac{d^2\delta}{dt} = \frac{\omega_s}{2H} P_m$$

$\omega - \omega_s = \frac{d\delta}{dt} \rightarrow$ change in speed $= \int_0^0 \frac{\omega_s}{2H} P_m dt$

$$= \frac{\omega_s}{2H} t P_m + 0$$

يعني δ بتزيد $\delta = \int_0^t \frac{\omega_s}{2H} P_m t \cdot dt = \frac{\omega_s P_m t^2}{4H} + \delta_0$



$\omega_c > \omega_b$

$\omega_c = \omega_d$ → مابتغير
instantaneous

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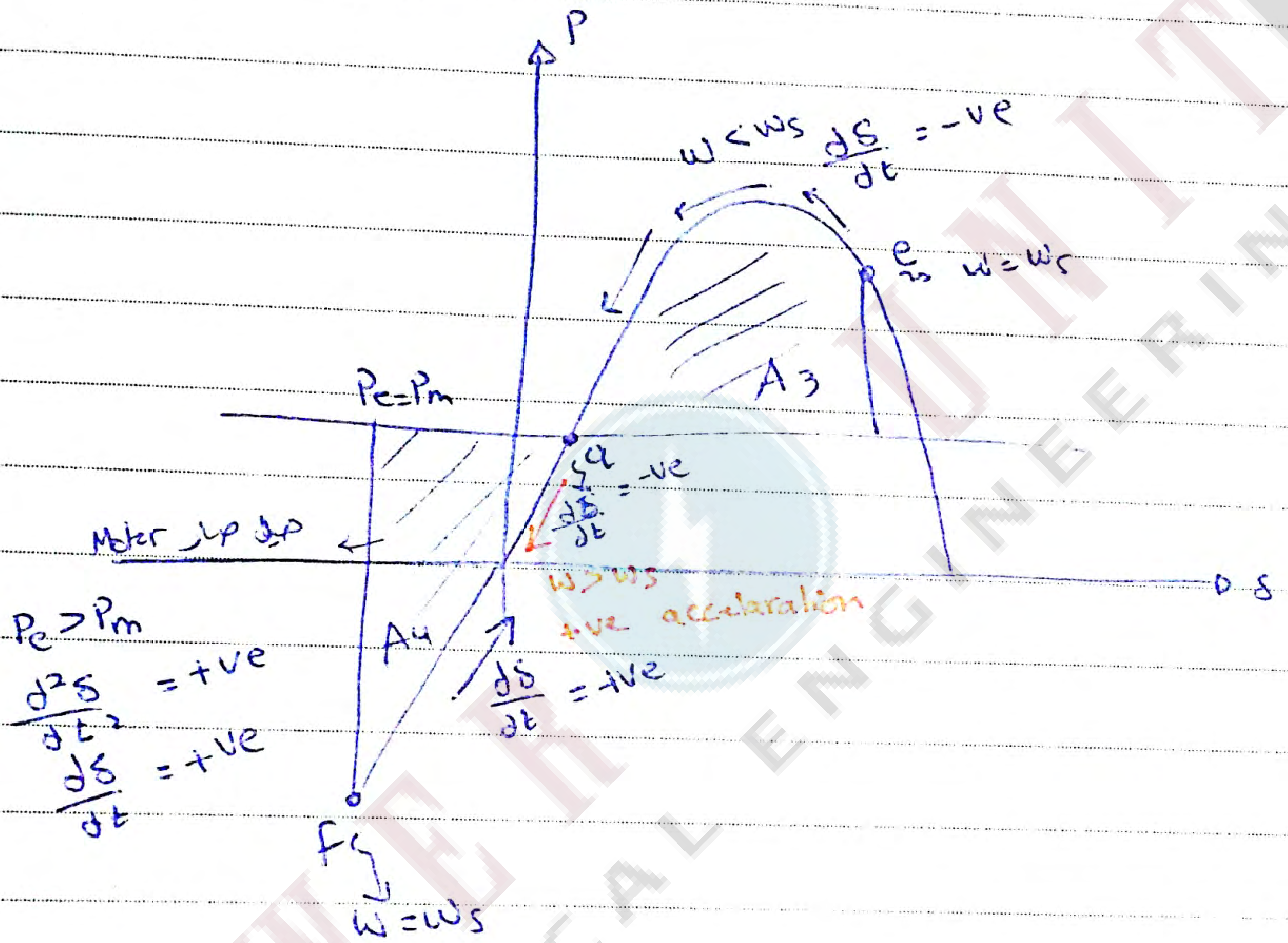
at d → $\omega > \omega_s$   $\frac{d\delta}{dt} = \omega - \omega_s$

at c → $\frac{d\delta}{dt} = \frac{\omega_s}{2H} P_m t_c$

$$\delta = \frac{\omega_s P_m t_c^2}{4H} + \delta_0$$



lec # 15

Monday
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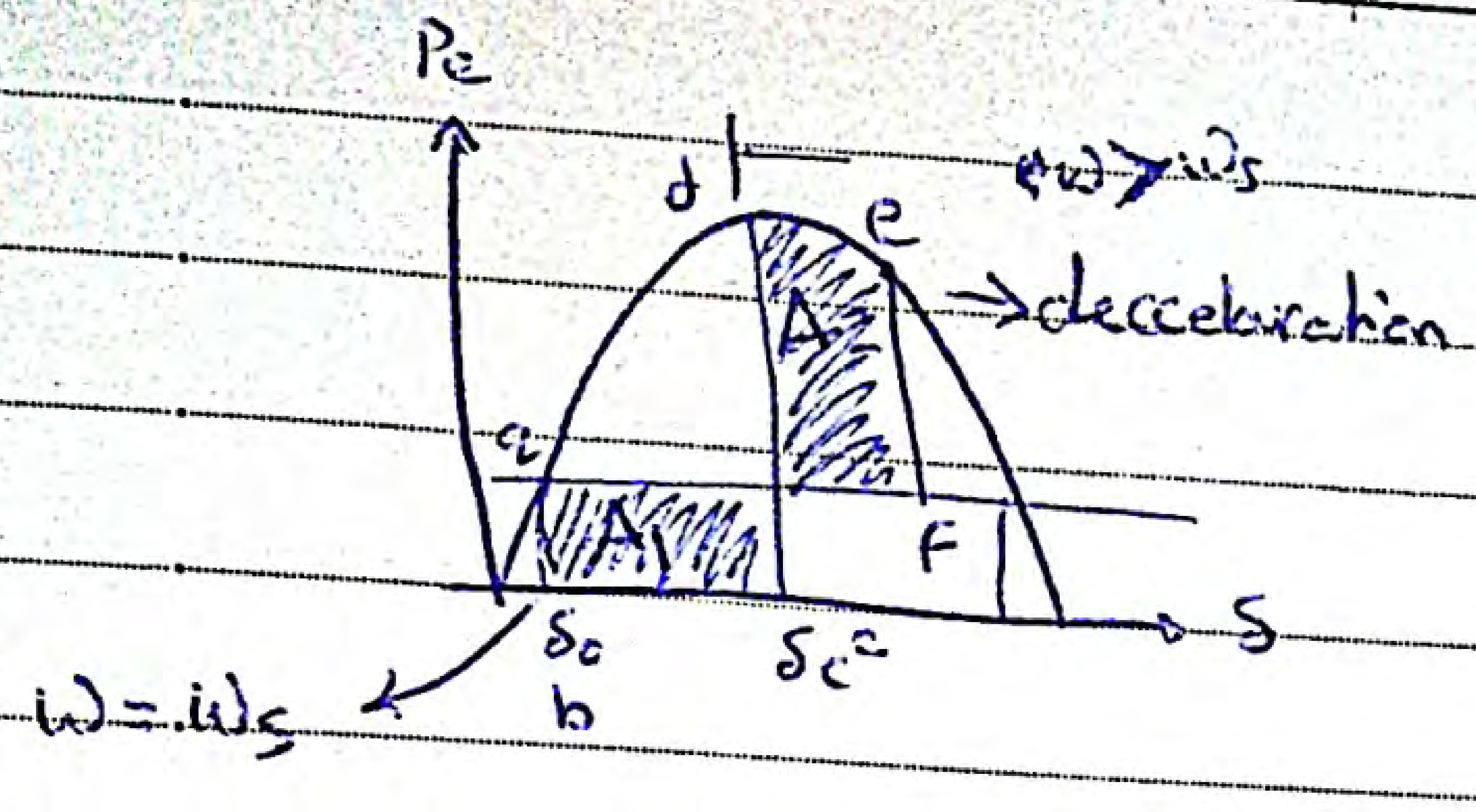
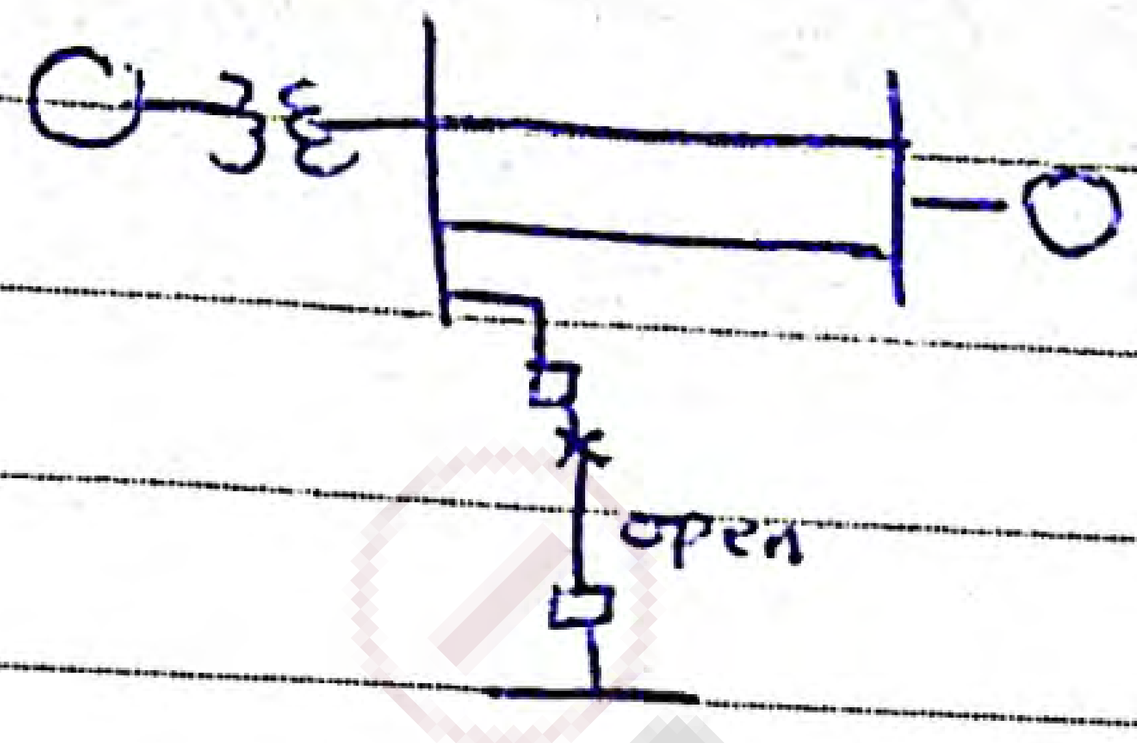
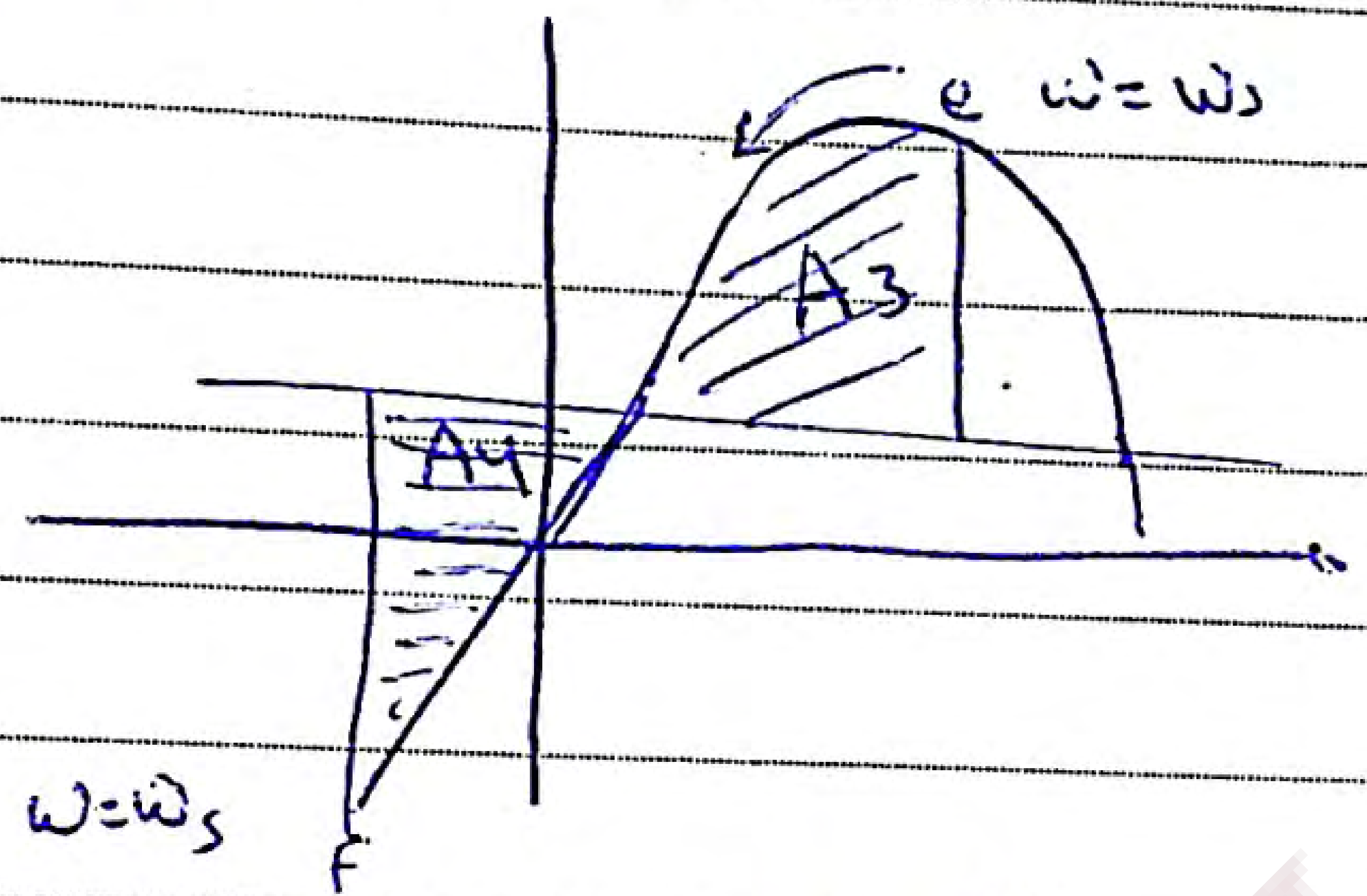
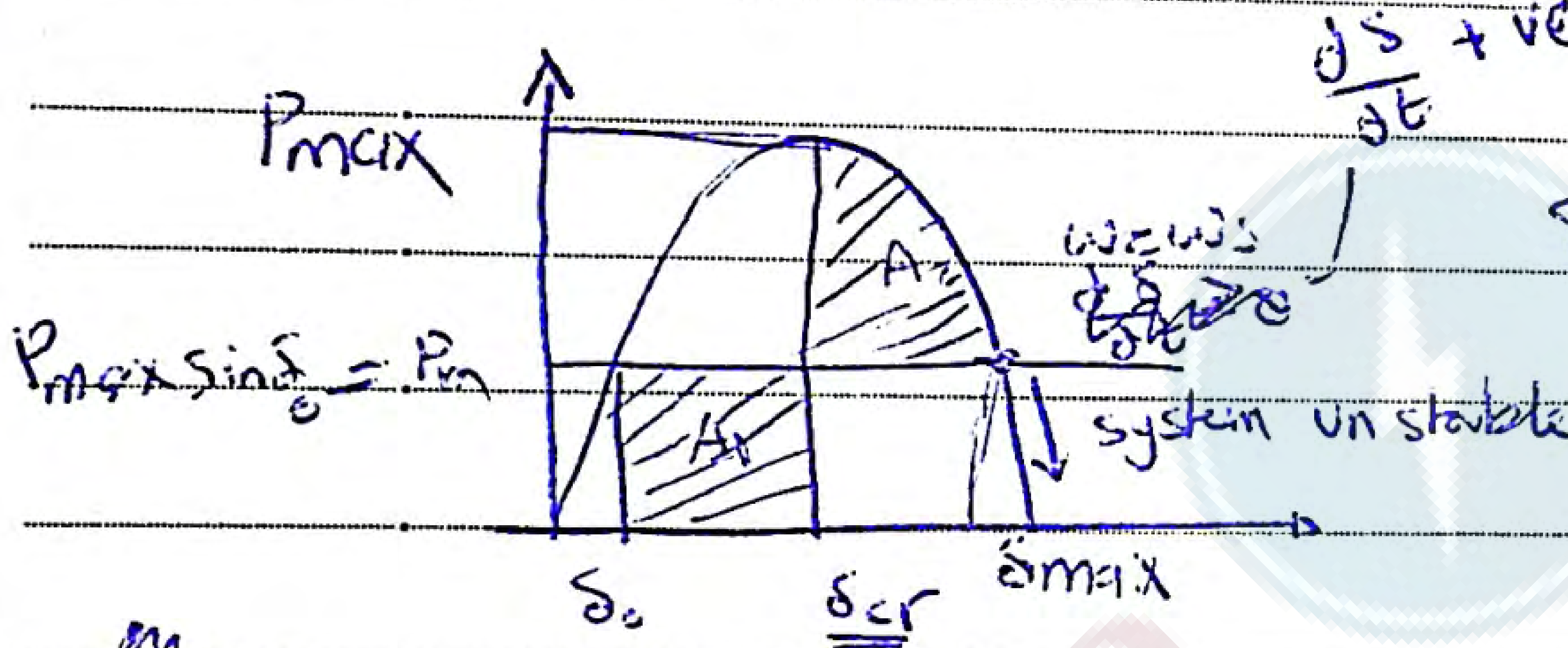








$t_c$

$$\delta_c = \frac{\omega_s}{4H} P_m t_c^2 + \delta_0$$

$$A_1 = A_2$$

$$A_1 = \int_{\delta_0}^{\delta_{cr}} (P_m - 0)\, d\delta$$

$$A_2 = \int_{\delta_{cr}}^{\delta_{max}} P_{max}\sin\delta - P_m \, d\delta$$

$$A_1 = P_m(\delta_{cr} - \delta_0) = A_2 = P_{max}(-\cos\delta)\Big|_{\delta_{cr}}^{\delta_{max}} - P_m(\delta_{max} - \delta_{cr})$$

$$\frac{\cancel{P_m\delta_{cr}} - P_m\delta_0}{P_{max}} = \frac{P_{max}\cos\delta_{cr}}{P_{max}} - \frac{P_{max}\cos\delta_{max}}{P_{max}} - \frac{P_m\delta_{max} + \cancel{P_m\delta_{cr}}}{P_{max}}$$

$$\cos\delta_{cr} = \frac{P_m}{P_{max}}(\delta_{max} - \delta_0) + \cos(\delta_{max})$$

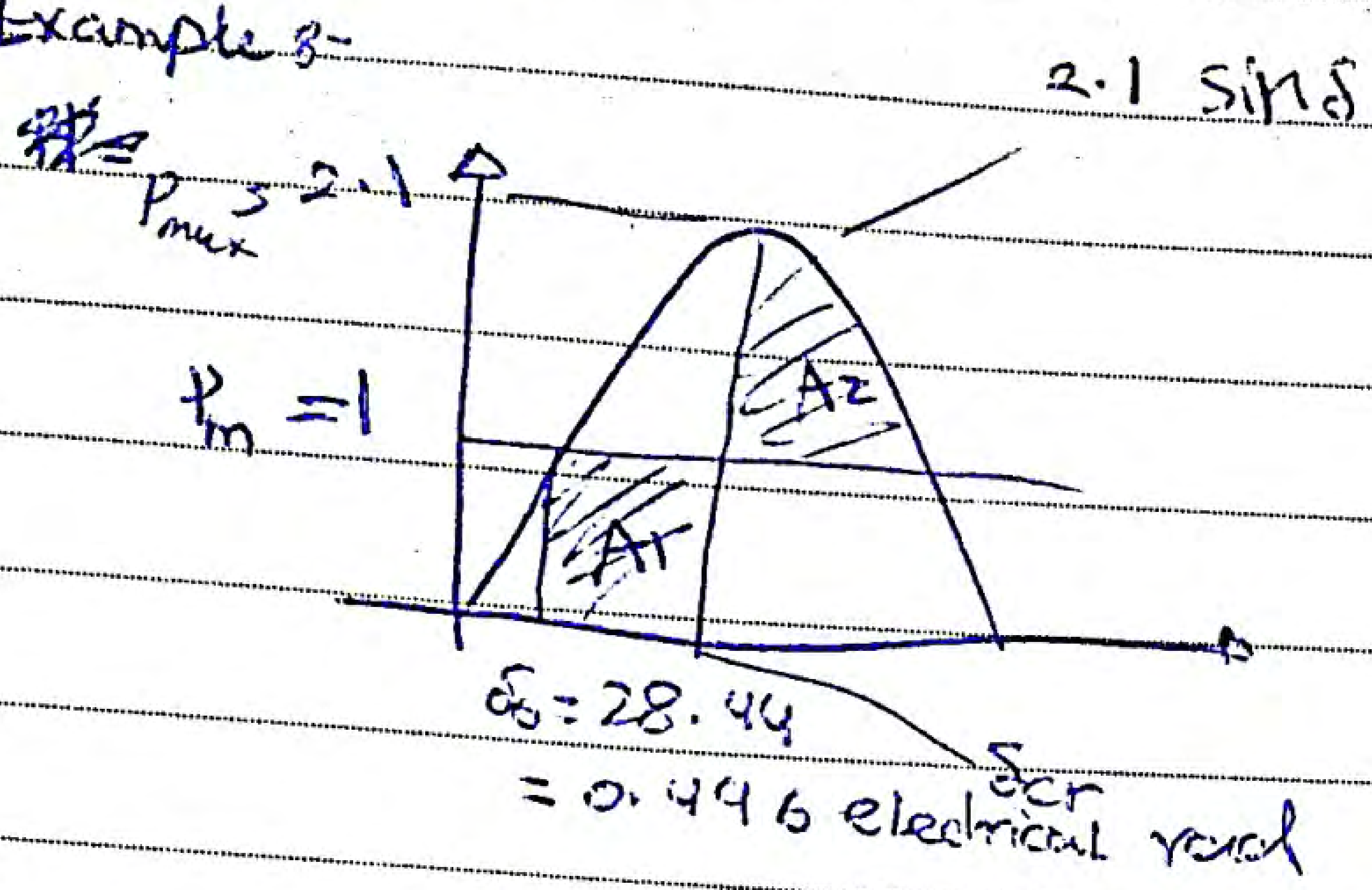
$$\cos\delta_{cr} = \sin\delta_0(\pi - 2\delta_0) - \cos\delta_0$$

$$\delta_{cr} = \cos^{-1}(\sin\delta_0(\pi - 2\delta_0) - \cos\delta_0)$$

الزاوية اللي بفصل عندها [illegible]
بيضل ال system ← stable

$H = 5$ sec

Example 8:-



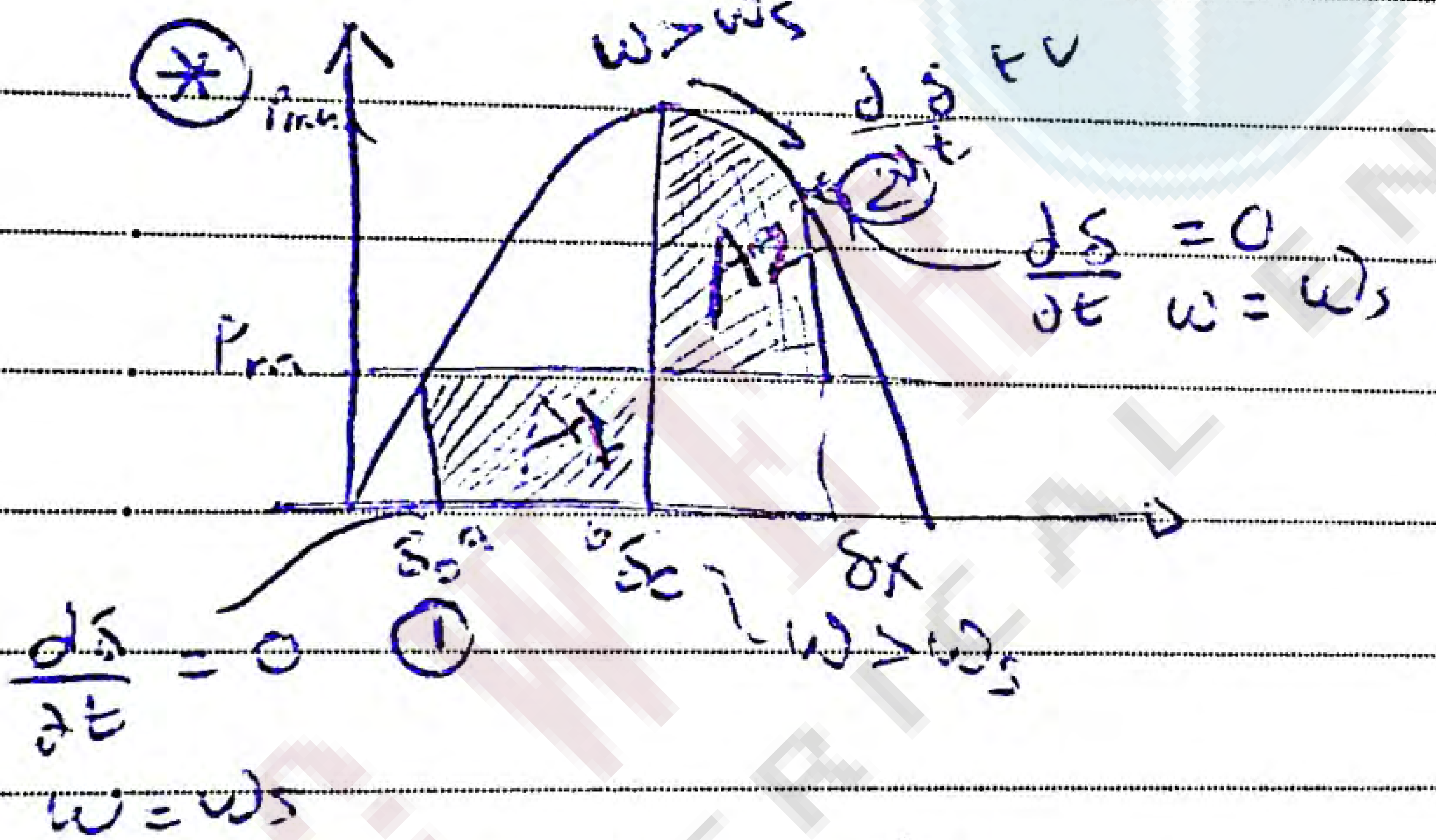
$$\delta_{cr} = \cos^{-1}\left(\sin(28.44)(\pi - 2 * 0.496) - \cos 28.44\right)$$

$$= 1.426 \text{ elec rad}$$

only when $r = 0$

$$t_c = \sqrt{\frac{(\delta_c - \delta_0)\, 4H}{\omega_s P_m}} = \sqrt{\frac{(1.426 - 0.496) \times 4 \times 5}{377 \times 1}}$$

$$= 0.222 \text{ s}$$



a-b → ω increasing

$$\frac{2H}{\omega_s} \frac{d^2\delta}{dt} = P_m - P_e$$

$$\frac{d^2\delta}{dt^2} = \frac{\omega_s}{2H}(P_m - P_e)$$

$$\frac{d\delta}{dt} = \omega - \omega_s = \omega_r$$ deviation on speed

$$\frac{d^2\delta}{dt^2} = \frac{d\omega_r}{dt}$$

lect#15

Monday

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$$\omega_r \times \frac{2H}{\omega_s}\frac{d\omega_r}{dt} = (P_m - P_e)\frac{d\delta}{dt}$$

$$\frac{H}{\omega_s} 2\omega_r \frac{d\omega_r}{dt} = (P_m - P_e)\frac{d\delta}{dt}$$

$$\frac{H}{\omega_s}\frac{d\omega_r^2}{dt} = (P_m - P_e)\frac{d\delta}{dt}$$

$$\frac{H}{\omega_s}\int_{\omega_{r1}}^{\omega_{r2}} d\omega_r^2 = \int_{\delta_1}^{\delta_2}(P_m - P_e)\,d\delta$$

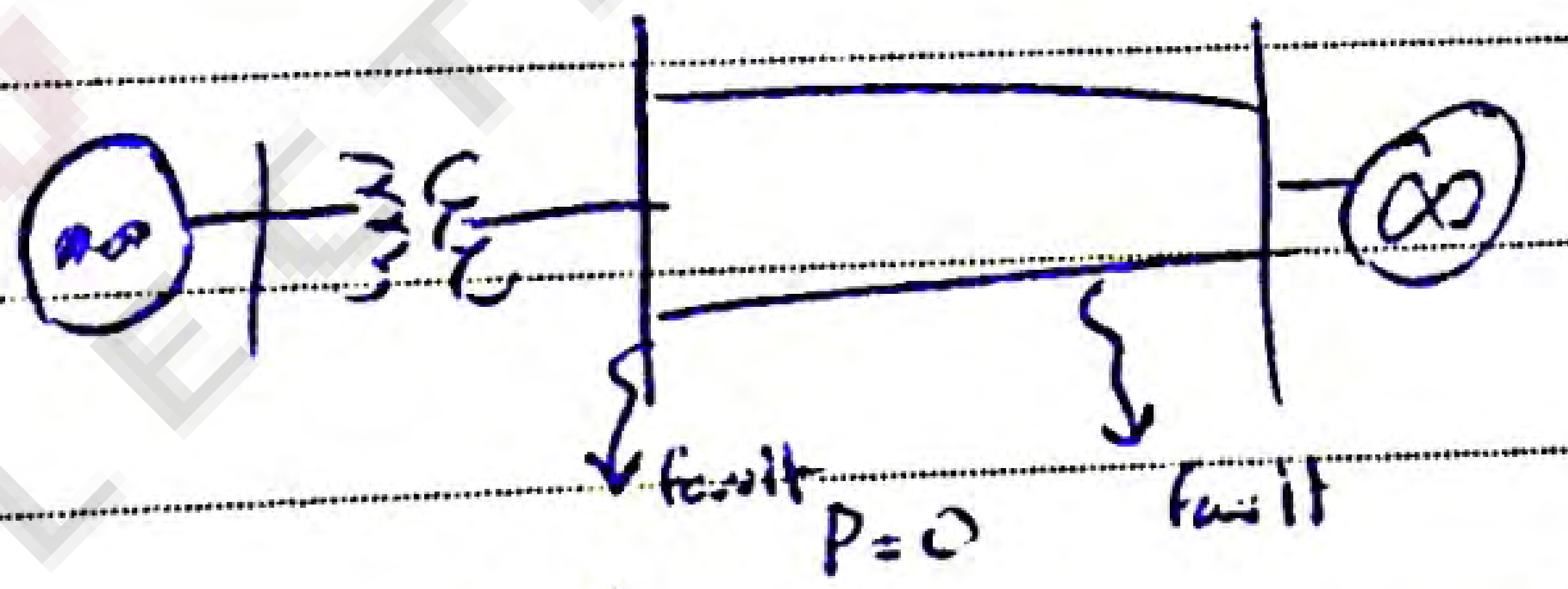
$$0 = \frac{H}{\omega_s}\left(\overset{0}{\cancel{\omega_{r2}}} - \overset{0}{\cancel{\omega_{r1}}}\right) = \int_{\overset{\cancel{\delta_1}}{\delta_o}}^{\overset{\delta_x}{\cancel{\delta_2}}}(P_m - P_e)\,d\delta$$

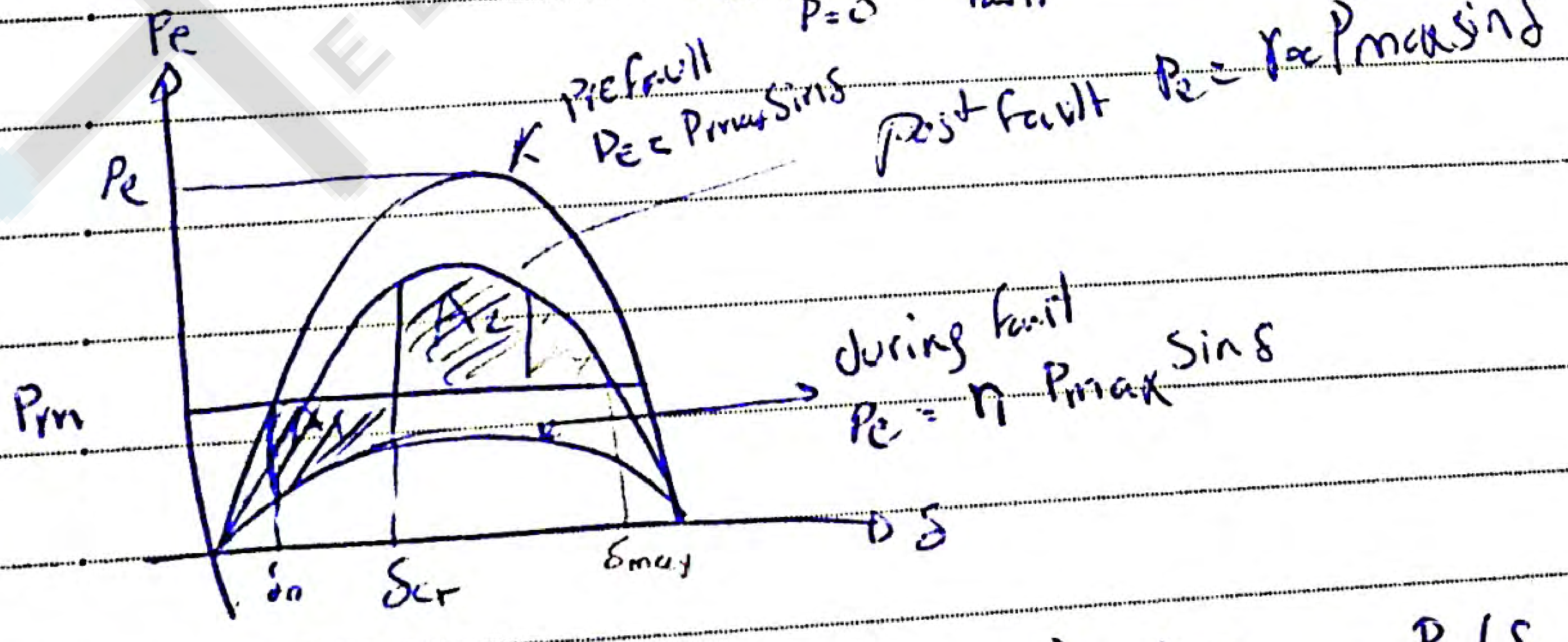
10:05

$$0 = \int_{\delta_o}^{\delta_c}(P_m - P_e)\,d\delta + \int_{\delta_c}^{\delta_x}(P_m - P_e)\,d\delta$$

$$\underbrace{\int_{\delta_c}^{\delta_x}(P_e - P_m)\,d\delta}_{A_2} = \underbrace{\int_{\delta_o}^{\delta_c}(P_m - P_e)\,d\delta}_{A_1}$$

$$A_2 = A_1$$





$$A_1 = \int_{\delta_o}^{\delta_{cr}}(P_m - r_1 P_{max}\sin\delta)\,d\delta = P_m(\delta_{cr} - \delta_o) + r_1 P_{max}(\cos\delta_{cr} - \cos\delta_o)$$

lec# 15

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$$A_2 = \int_{\delta_{cr}}^{\delta_{max}} (r_2 P_{max} \sin\delta - P_m)\, d\delta$$

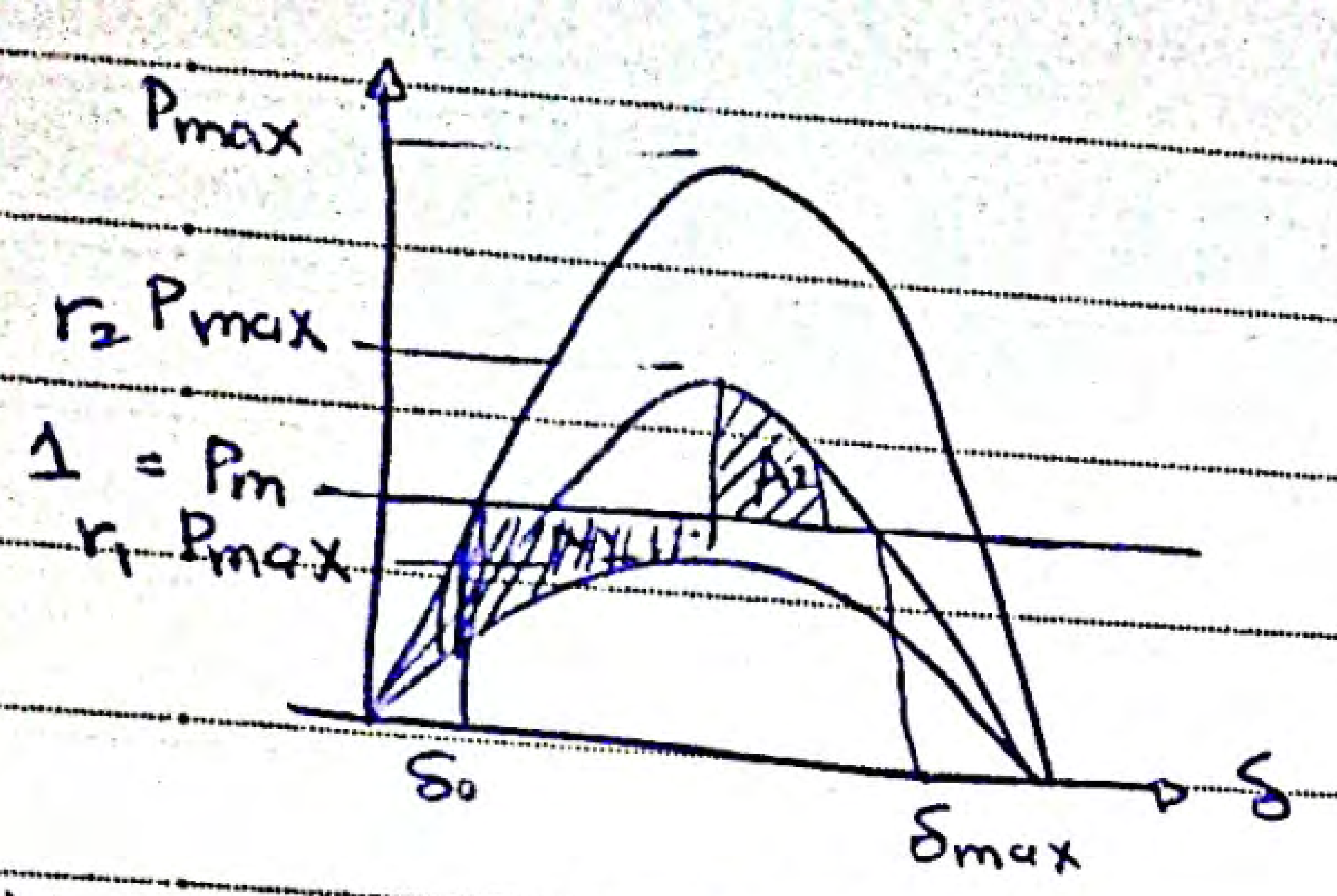
$$= r_2 P_{max}\left[\cos\delta_{cr} - \cos\delta_{max}\right] - P_m(\delta_{max} - \delta_{cr})$$

$$\cos(\delta_{cr}) = \frac{\underset{\sin\delta_0}{\cancel{\frac{P_m}{P_{max}}}}(\delta_{max} - \delta_0) + r_2\cos\delta_{max} - r_1\cos\delta_0}{r_2 - r_1}$$

→ general case.

Lec # 16

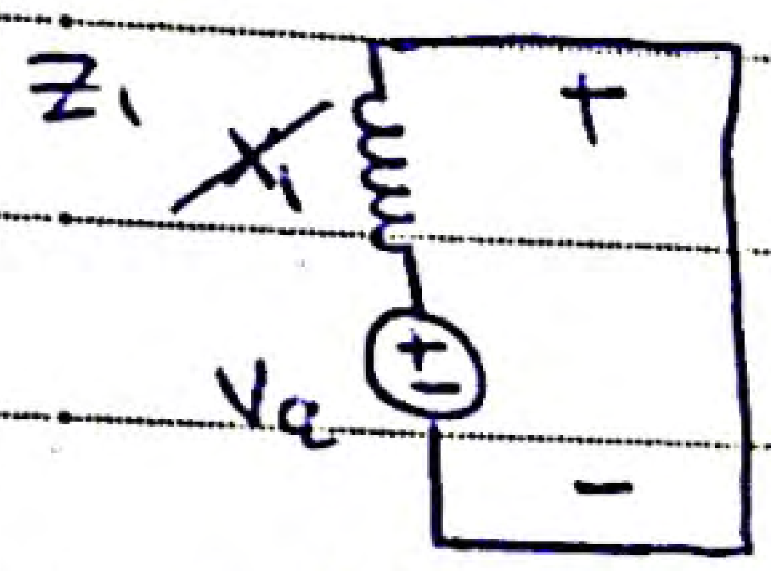
Wednesday
9/4/2014



①

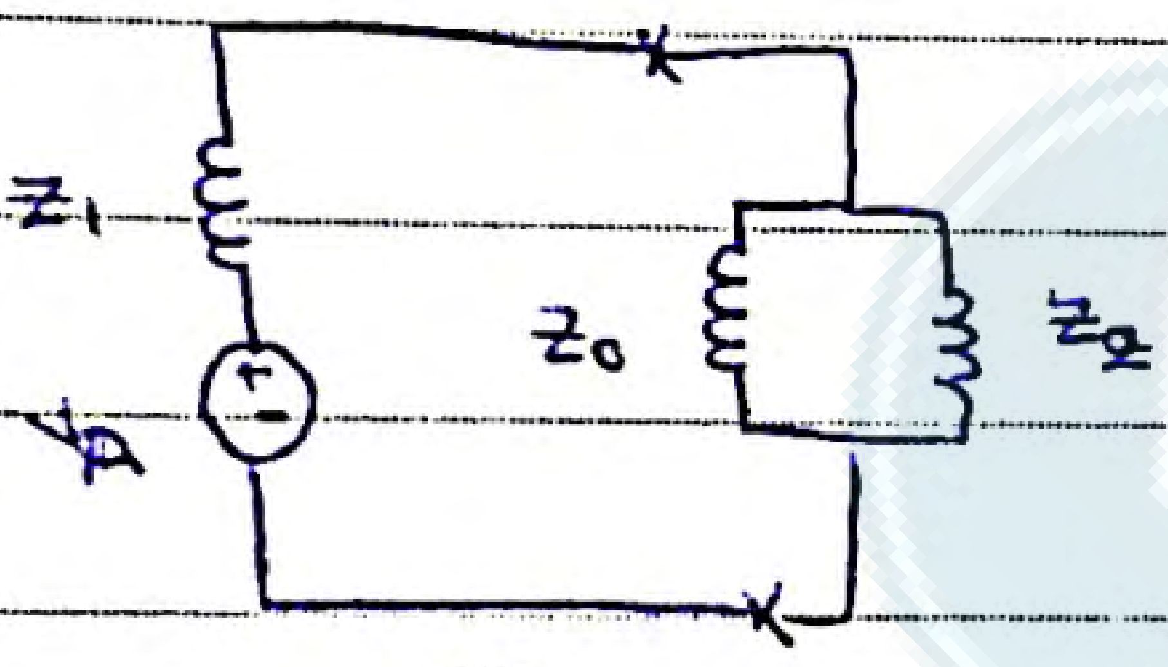
0.1 sec 3-phase fault
0.2 sec if system slow

Fault قبل



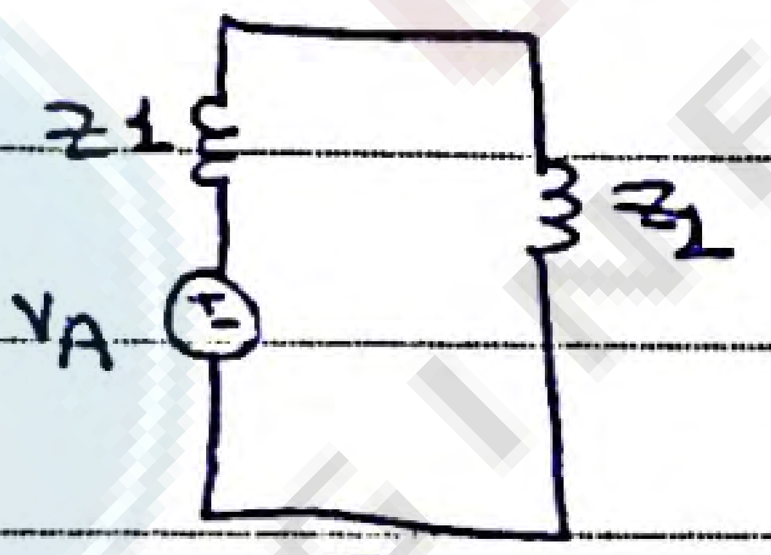
$I_a = \frac{V_a}{jX_{Z_1}}$ @ 3-phase fault

+ve sequence circuit.
L-L-N



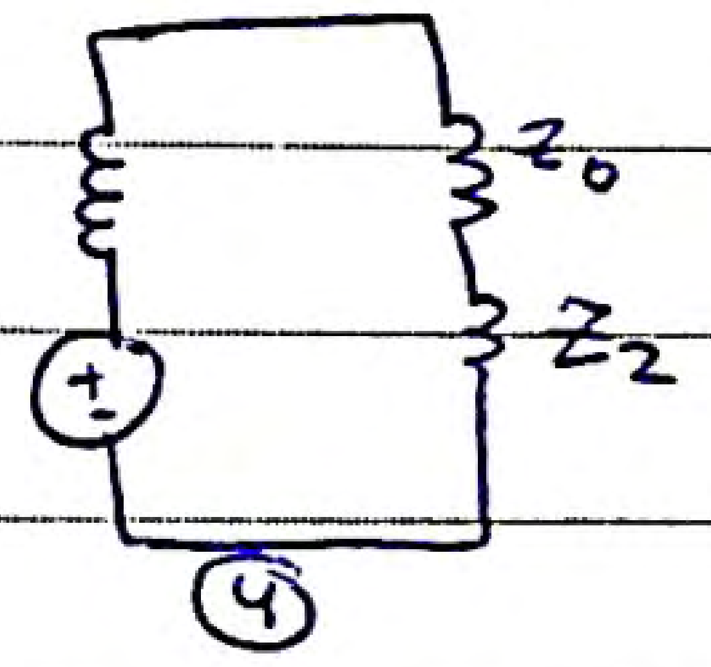
②

L-L



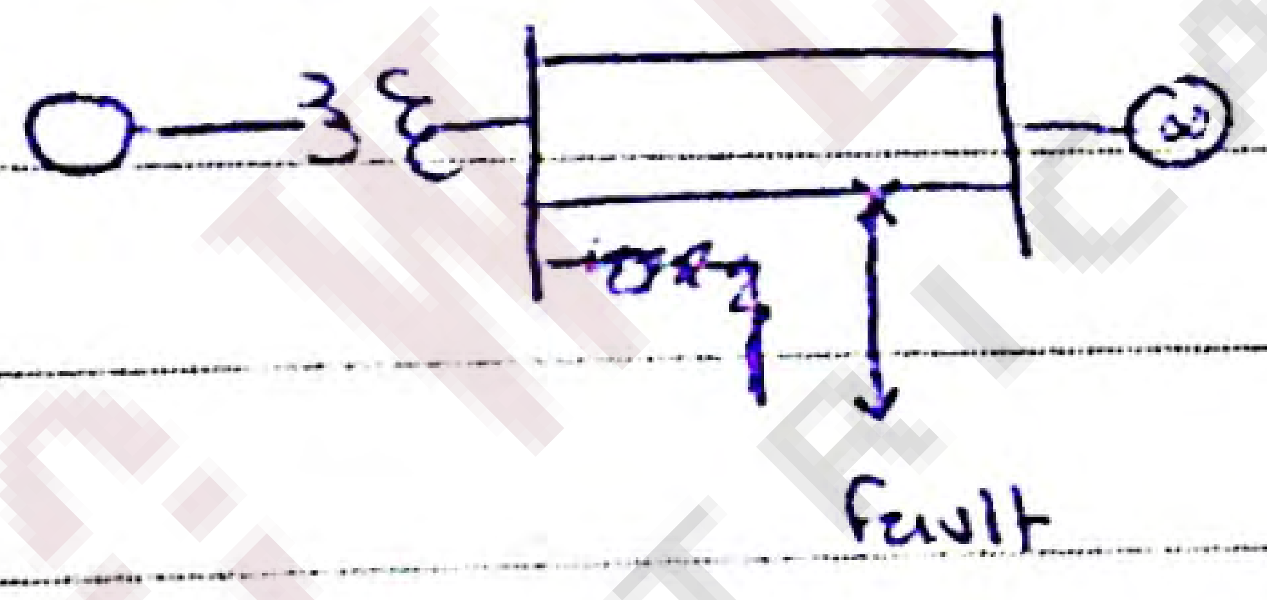
③

L-E



④

Example:



Pre fault : $P_e = 2.1 \sin\delta$

during fault : $P_e = 0.808 \sin\delta$

Post fault : $P_e = 1.5 \sin\delta$

$\delta_o = 28.44° = 0.496$ rad , find $\delta_{cr}$?

$r_1 = \frac{0.808}{2.1} = 0.385$ , $r_2 = \frac{1.5}{2.1} = 0.714$

$\delta_o = 28.44°$

$\delta_{max} = \pi - \sin^{-1}\frac{1}{1.5} = ~~41.8~~\ 138.19° = 2.412$ rad

$$\cos\delta_{cr} = \frac{\frac{1}{2.1}(2.412 - .496) + 0.714\cos(138.19) - 0.385\cos 28.44}{0.714 - 0.385}$$

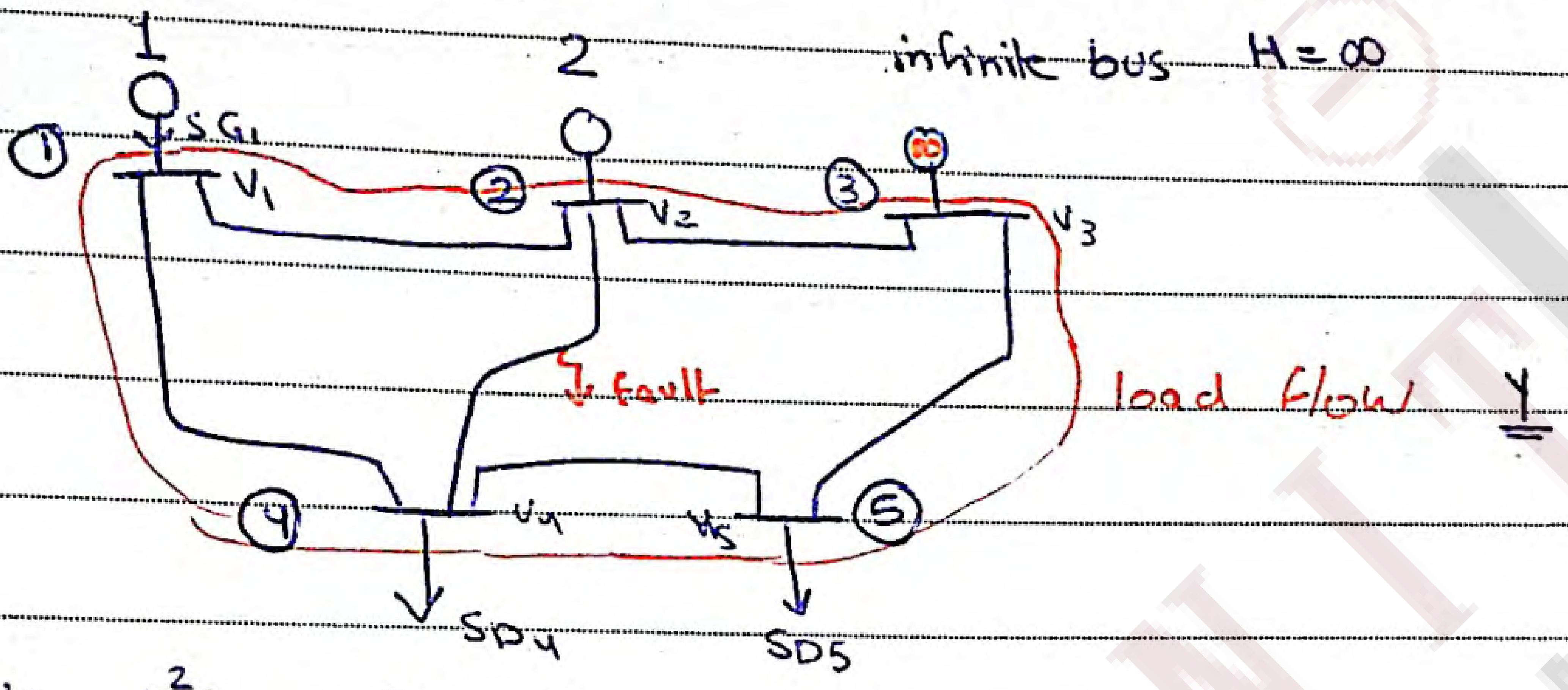
$= 82.726°$

lec # 15

Wednesday

9/4/2014

## Classical Stability Study:
(multi-machine study):



$S_i = V_i \sum Y_{ik}^* V_k^*$

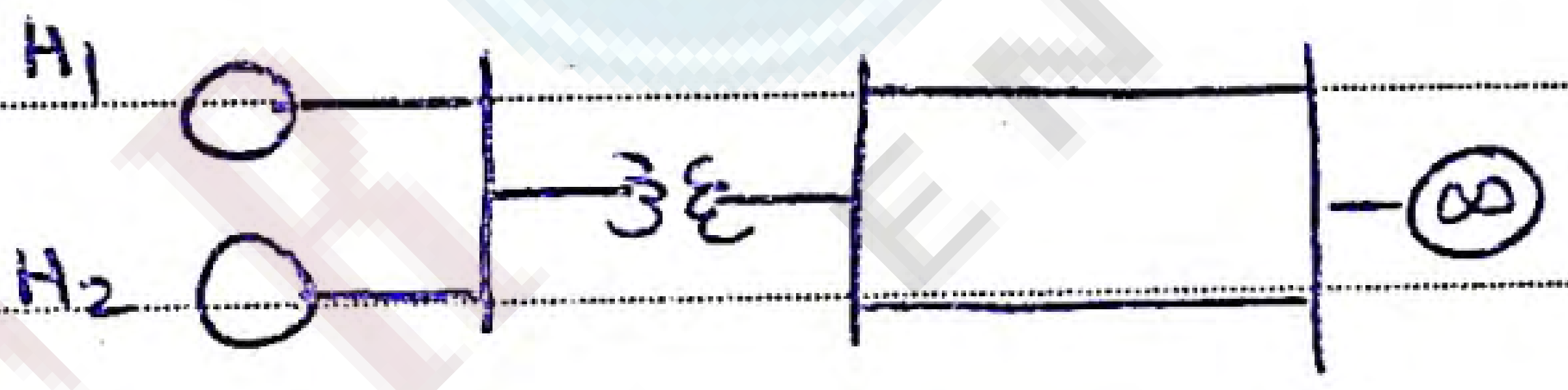
$$\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} = P_m - P_e$$

$$\frac{d^2\delta}{dt^2} = \frac{\omega_s}{2H}(P_m - P_e)$$

@ infinite bus $H = \infty$ then $\frac{d^2\delta}{dt^2} = 0$

ما بهتز

* * * *



$$\frac{2H_1}{\omega_s}\frac{d^2\delta_1}{dt^2} = P_{m_1} - P_{e_1}$$

$$\frac{2H_2}{\omega_s}\frac{d^2\delta_2}{dt^2} = P_{m_2} - P_{e_2}$$

$$\frac{d^2\delta_1}{dt^2} = \frac{d^2\delta_2}{dt^2} = \frac{d^2\delta}{dt^2}$$

$$\frac{2(H_1 + H_2)}{\omega_s}\frac{d^2\delta}{dt^2} = (P_{m_1} + P_{m_2}) - (P_{e_1} + P_{e_2})$$

this machine called Coherent machines

equivelant $H = H_1 + H_2$

* * * *

lec # 15

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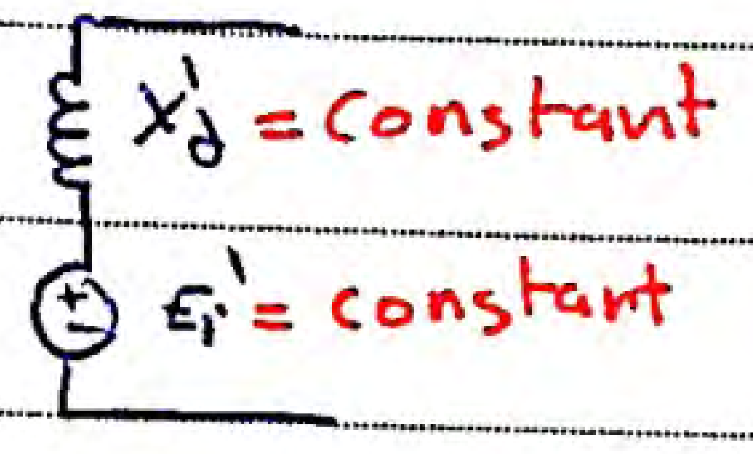
1. $P_m$ For all machines is constant

2. damping is neglected $(\underset{\downarrow \frac{d^2\delta}{dt^2}}{s^2} + 2\alpha \underset{\downarrow \frac{d\delta}{dt}}{s} + \omega_n^2)\,\delta_\Delta(s)$

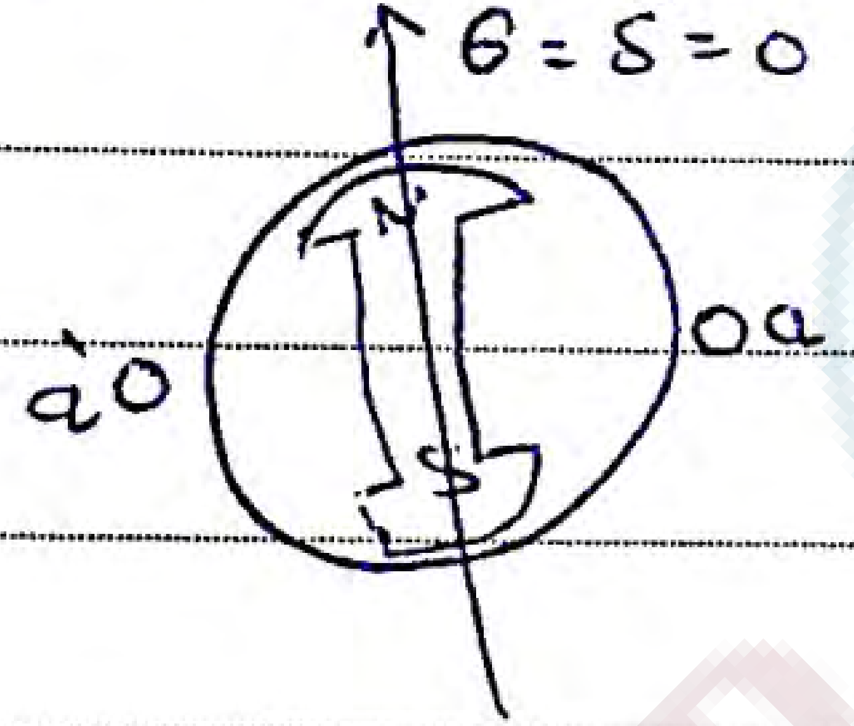
3.



$x'_d$ function in $\omega \rightarrow \omega$ constant then $X'_d$ constant

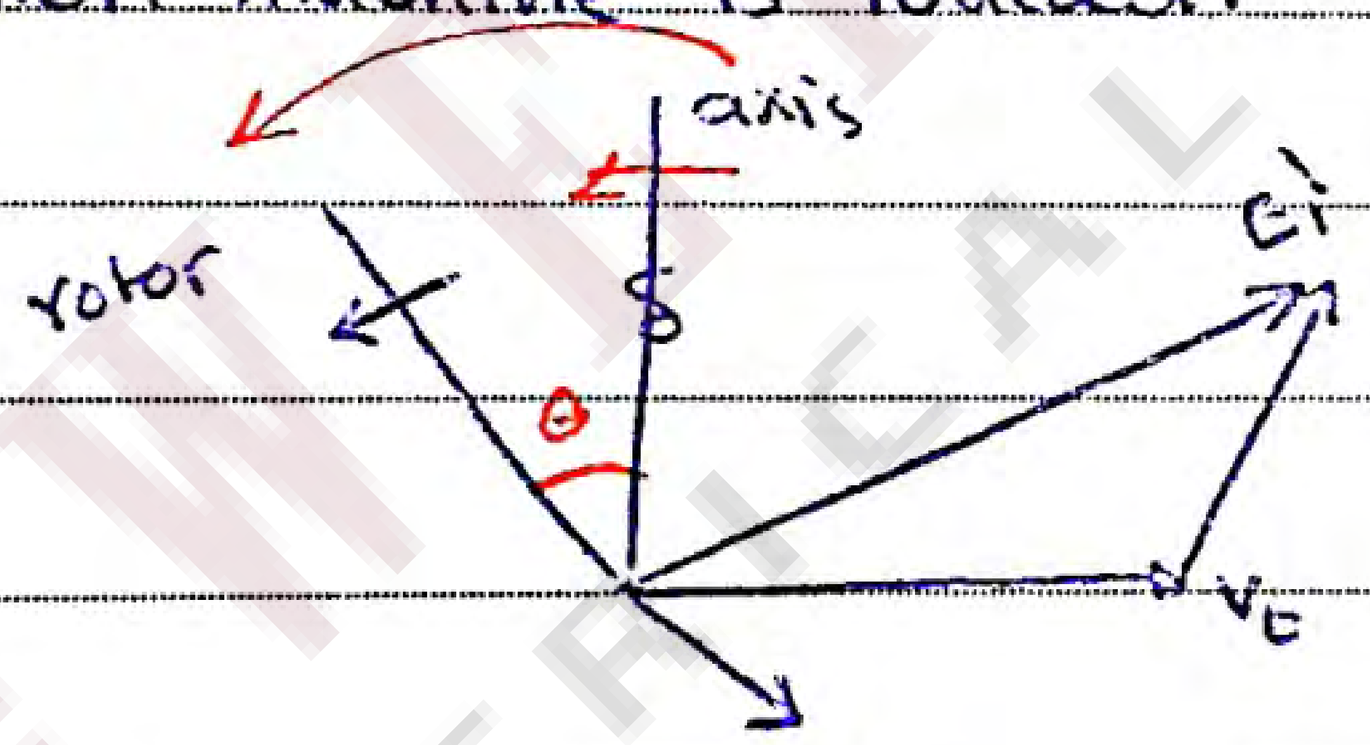
4. $\theta_m = \delta_m + \omega_{sm} t$

$\theta = \delta + \omega_s t$ → electrical



in this case the machine is unloaded.

when machine is loaded:

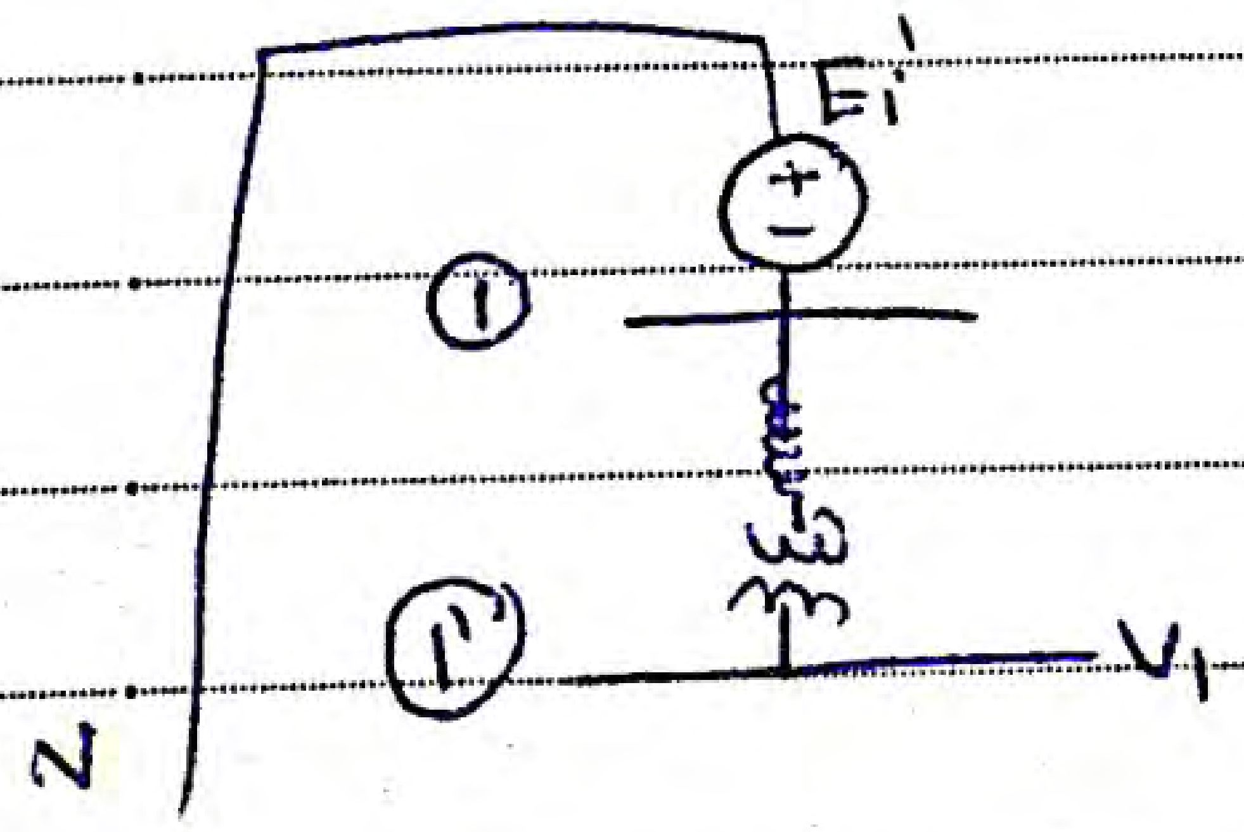


$\delta$ → measured at rotated axis

$\theta$ → measured at stationary axis

5. loads are represented by its admittance.

1. load Flow Study:



$S_{G1}$, $V_1$

$S = V I^*$

$$E'_i = V_1 + I\,(j x'_d + j\, x_{tran})$$

lec # 16

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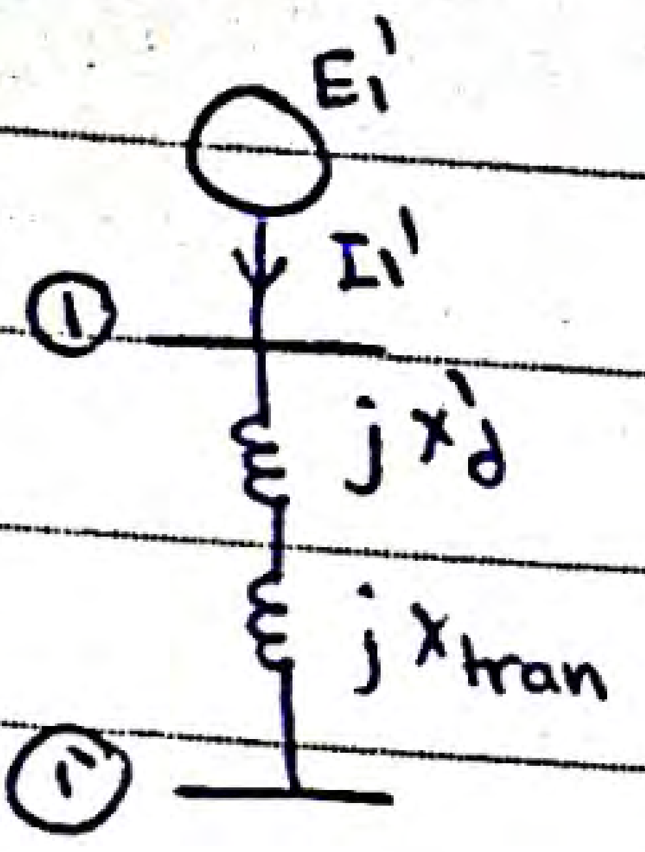
9/4/2014



we will make 3 Y matrix ?

1) augmented $\overset{\text{prefault}}{(}$ Y matrix : load Flow + general transforme reactor + gen. trans. react.

$$5\times5 \xrightarrow{\text{By cron}} 3\times3$$

$$\begin{bmatrix} K & L \\ L^T & M \end{bmatrix}_{5\times5}$$

3X3

2. Y matrix during fault.

3. Y-matrix post fault.

$P_{e1} = |E_1'|^2 G_{11} + |E_1'||E_2'||Y_{12}|\sin(\delta_1-\delta_2-\theta_{12}) + |E_1'||E_3'||Y_{13}|\sin(\delta_1-\delta_3-\theta_{13})$

to find Y for $S_{D4}$ :

$S = VI^*$

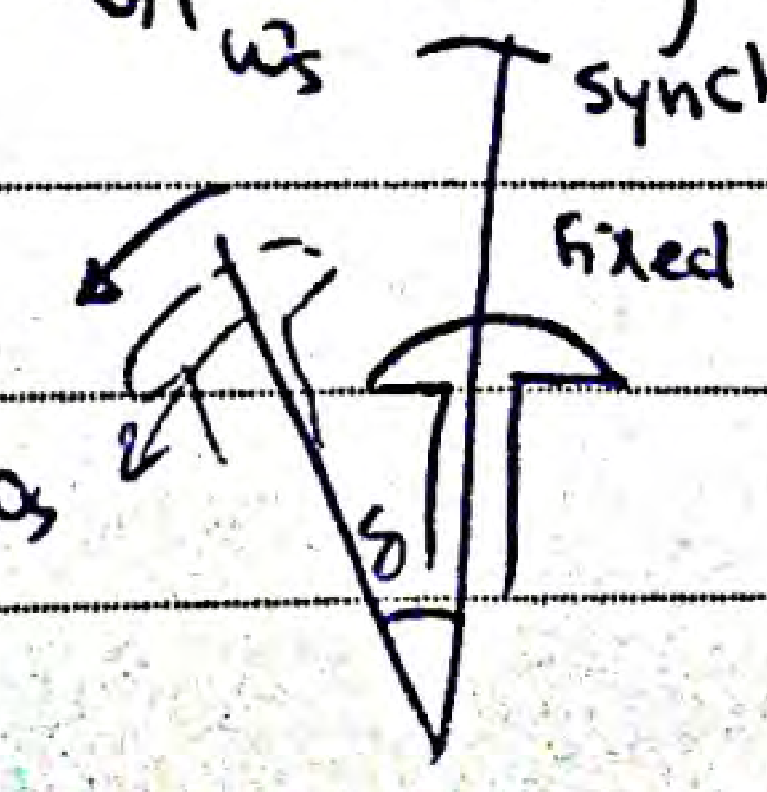
$I = \dfrac{S^*}{V^*}$ , $I = YV$

$$Y = \frac{I}{V} = \frac{S^*}{V \times V^*} = \frac{S^*}{|V|^2}$$

if $S_{G1} = 1.8 + j0.9$ then $P_m = 1.8$ ~~..~~ p.u.

$\omega_s$ synchronously rotating frame of refrence.

fixed



δ

بتتغير مع ال fault

lec # 16

wednesday
9/4/2014

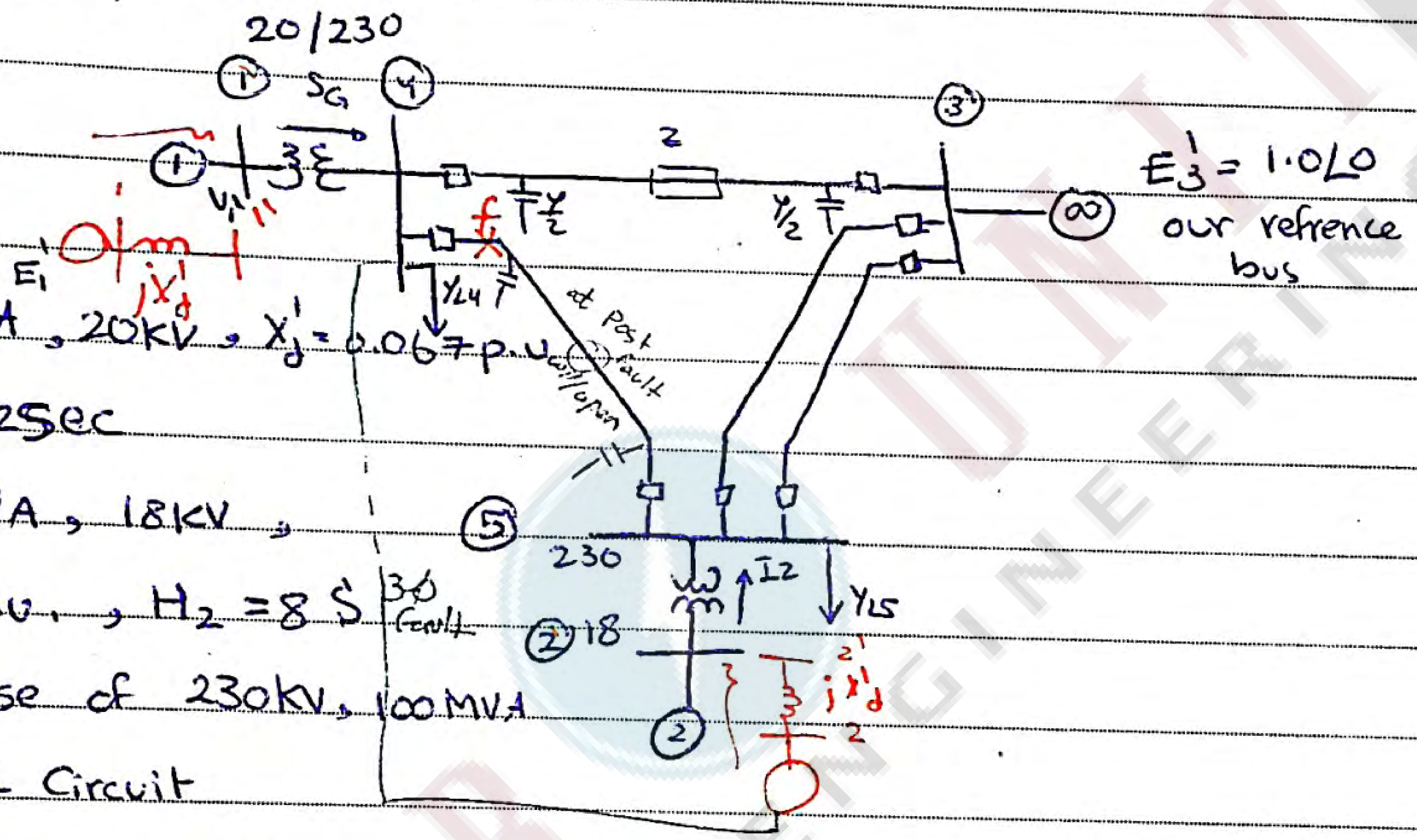
Example:

in next lecture.

lec #17

Monday
14/4/2014

Example:



$G_1$ : 400 MVA , 20kV , $X_d' = 0.067$ p.u

$H_1 = 11.25$sec

$G_2$: 250 MVA , 18kV ,

$X_d' = 0.1$ p.u. , $H_2 = 8$ S

given on base of 230kV, 100 MVA

TL Circuit

From load flow study:

| bus | Voltage | P, Q gen. | | P, Q load | |
|---|---|---|---|---|---|
| 1' | $1.03\angle 8.88°$ | 3.5 | 0.71 | — | — |
| 2' | $1.02\angle 6.38°$ | 1.85 | 0.98 | — | — |
| 3 | $1.0\angle 0$ | — | — | — | — |
| 4 | $1.018\angle 4.68°$ | — | — | 1.0 | 0.44 |
| 5 | $1.011\angle 2.27°$ | — | — | 0.5 | 0.1 |

Trans 1' : 4 x = 0.022 p.u

Trans 2' : 5 x = 0.04 p.u

Line 3-4 : Z = 0.007 + j0.04 , Y = 0.082

X Line 3-5 : Z = 0.008 + j0.047 , Y = 0.098

Line 4-5 : Z = 0.018 + j0.11 , Y = 0.226

on base 230 kV , 100 MVA

lec # 17

Monday 10:09

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$$I_1 = \frac{S_1^*}{V_1^*} = \frac{3.5 - j0.71}{1.03 \angle -8.88^\circ} = 3.486 \angle -2.619 \text{ p.u.}$$

$$E_1' = 1.03 \angle 8.88 + j0.067 I_1$$

$$= 1.1 \angle 20.82$$

$$I_2 = \frac{S_2^*}{V_2^*} = \frac{1.85 - j0.298}{1.02 \angle -6.38^\circ} = 1.837 \angle -2.771^\circ$$

$$E_2' = 1.02 \angle 6.38 + j0.1 I_2 = 1.065 \angle 16.19^\circ$$

$P_{m1} = P_{E1}$ Before the fault.

$P_{m1} = 3.5$ p.u. $= P_{e10}$

$P_{m2} = 1.85$ p.u. $= P_{e20}$

$$Y_{L4} = \frac{S_4^*}{|V_4|^2} = \frac{1.0 - j0.44}{(1.018)^2} = 0.9649 - j0.4246$$

$$Y_{L5} = \frac{S_5^*}{|V_5|^2} = \frac{0.5 - j0.16}{(1.011)^2} = 0.4892 - j0.1565$$

row1

$$Y_{11} = \frac{1}{j0.067 + j0.22}$$

$Y_{12} = 0$

$Y_{13} = 0$

$$Y_{14} = \frac{-1}{j0.067 + j0.22}$$

$Y_{15} = 0$

row4

$Y_{41} = Y_{14}$

$Y_{42} = 0$

$$Y_{43} = \frac{-1}{0.007 + j0.4}$$

$$Y_{44} = \frac{1}{j0.067 + j0.22} + j0.041 + \frac{1}{0.007 + j0.4} + \frac{1}{0.018 + j0.11} + j0.113$$

$$+ 0.9649 - j0.4246$$

augmented Y-matrix

→ get matrix 5x5

$$Y_{45} = \frac{-1}{0.618 + j0.11}$$

lec # 17

Monday
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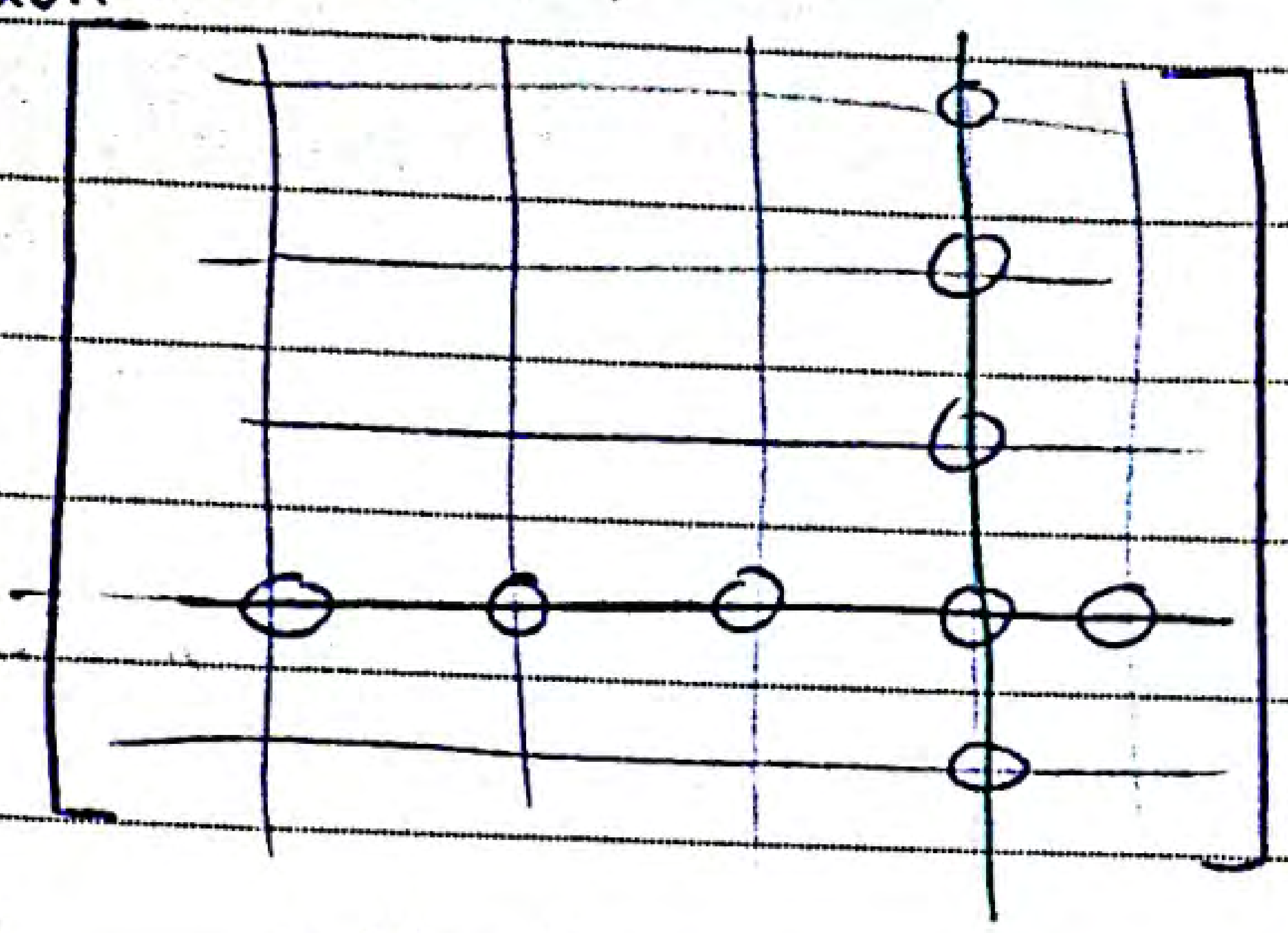
during fault:



eliminate row 4 & Column 4
and we will get 4x4 matrix

$P_{e1} = 0$ , $V_4 = 0$

$Y_{23} = 5.1665 \angle 90.7752^\circ$

$$\begin{bmatrix} 0-j11.236 & 0 & 0 \\ 0 & \overset{6.2752\angle -88.756}{0.1362-j6.2737} & Y_{23} \\ 0 & & \end{bmatrix}_{3\times3}$$

eliminated bus matrix during fault.

$$P_{e1} = |E_1'|^2 \underset{0}{\underline{\underline{G_{11}}}} + |E_1'||E_2'|\underset{0}{\cancel{Y_{12}}}\sin(\quad) + |E_1'||E_2'|\underset{0}{\cancel{Y_{23}}}\sin(\quad)$$

$1.065^2 \times 0.1362$ $\quad 1.065 * 1 * 5.165$ $\cos(\delta_2 - \delta_3 - 90.755$

$$P_{e2} = |E_1'||E_2'|\overset{0}{\cancel{Y_{21}}}\ \cos + |E_2'|^2 G_{22} + |E_2'||E_3'||Y_{23}|\sin(\delta_2 - \delta_3 - .755)$$

$$P_{e2} = 0.1545 + 5.5023\sin(\delta_2 - 0.755)$$

swing equation.

$$P_{e1} \rightarrow \frac{H_1}{180f}\frac{d^2\delta_1}{dt^2} = 3.5 - 0$$

$$P_{e2} \longrightarrow \frac{H_2}{180f}\frac{d^2\delta_2}{dt^2} = 1.85 - P_{e2}$$

during Post fault :
augmented prefault matrix

$$\begin{bmatrix} & & \\ & & \\ & & \end{bmatrix}_{5\times5}$$

$Y_{45} = 0$

$Y_{54} = 0$

$Y_{44} = Y_{44old} - \frac{1}{Z_{45}} - j0.113$

$Y_{55} = Y_{55old} - \frac{1}{Z_{54}} - j0.113$

and it will be 3x3

lec # 18

Wednesday

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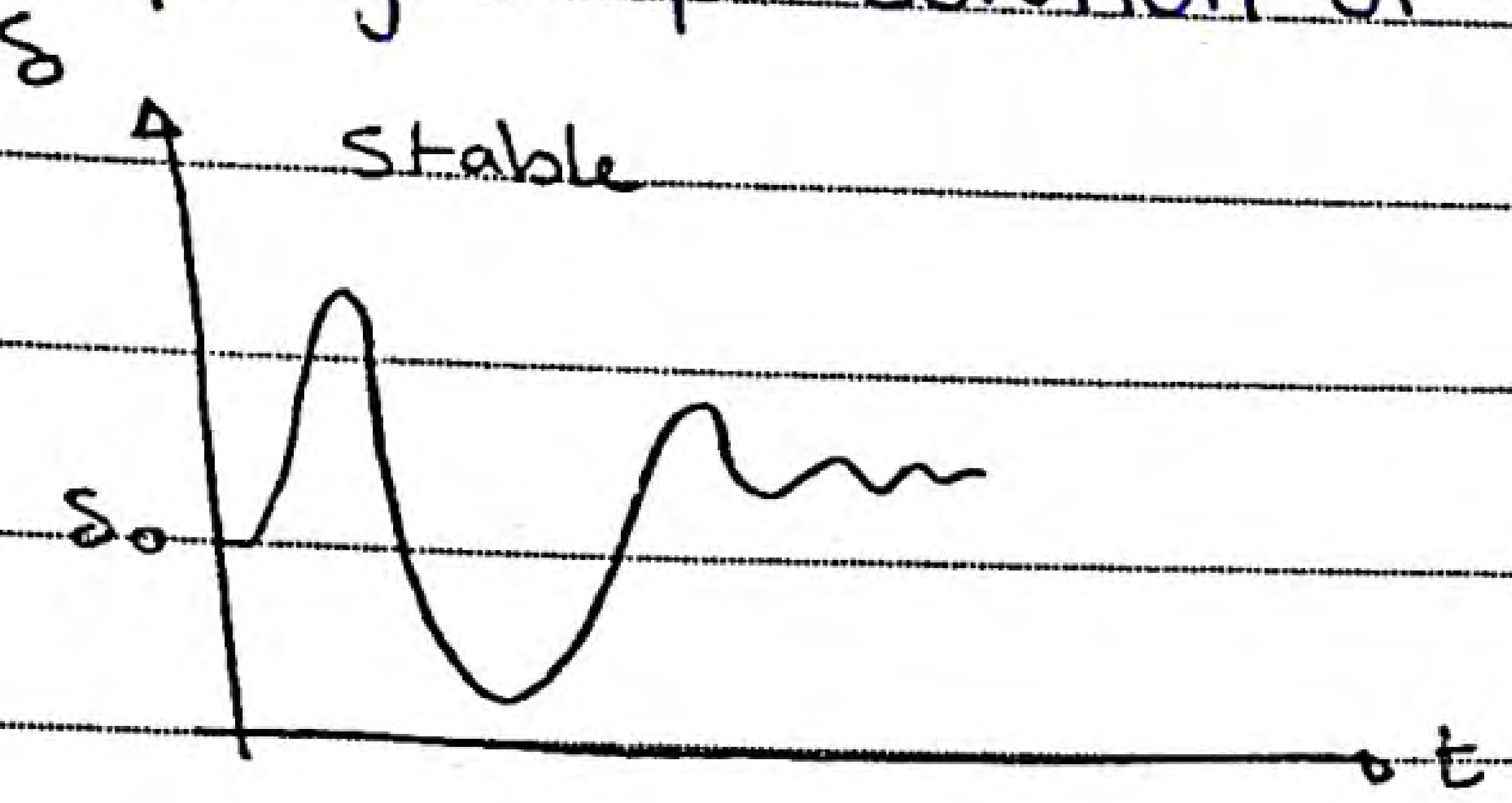
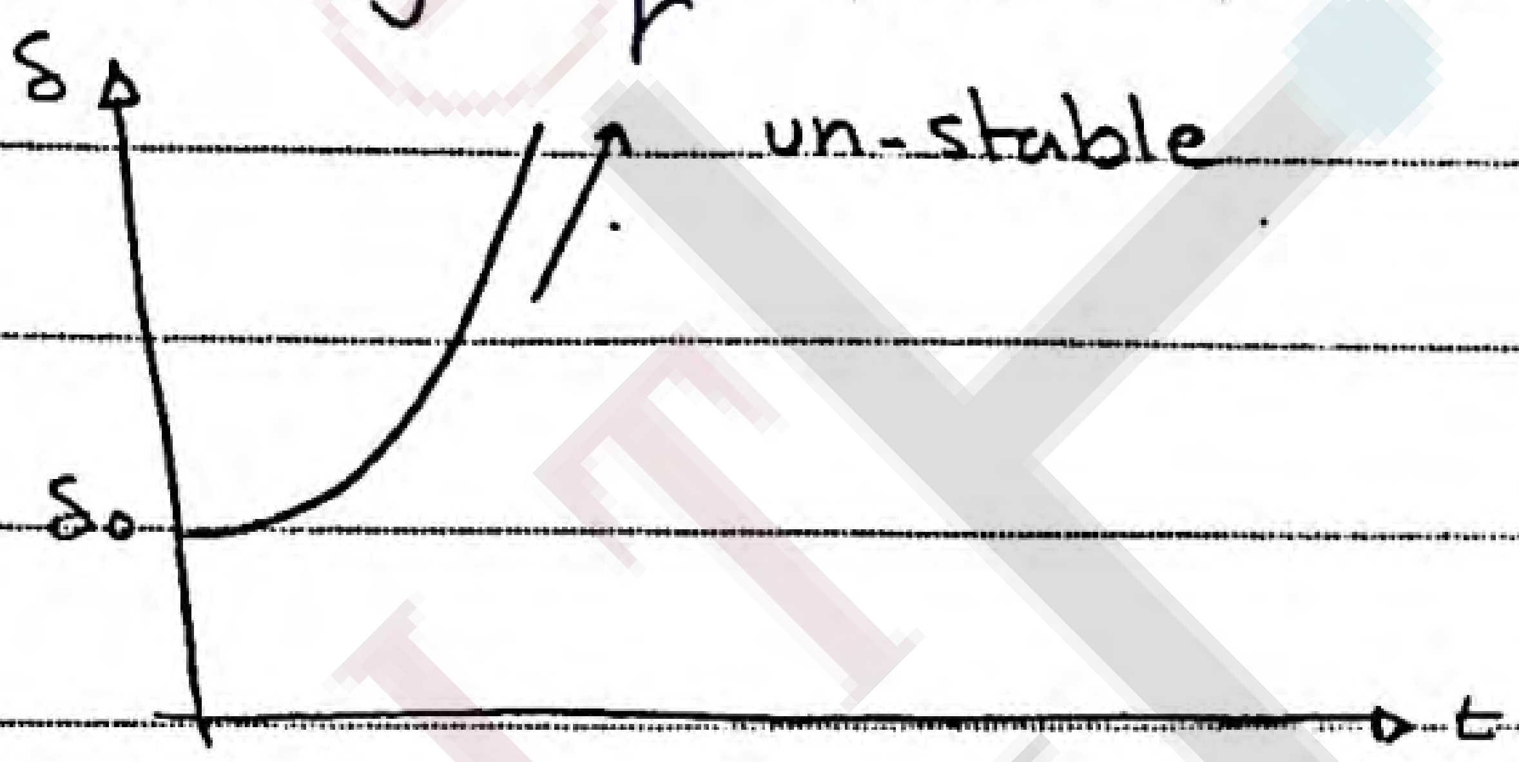
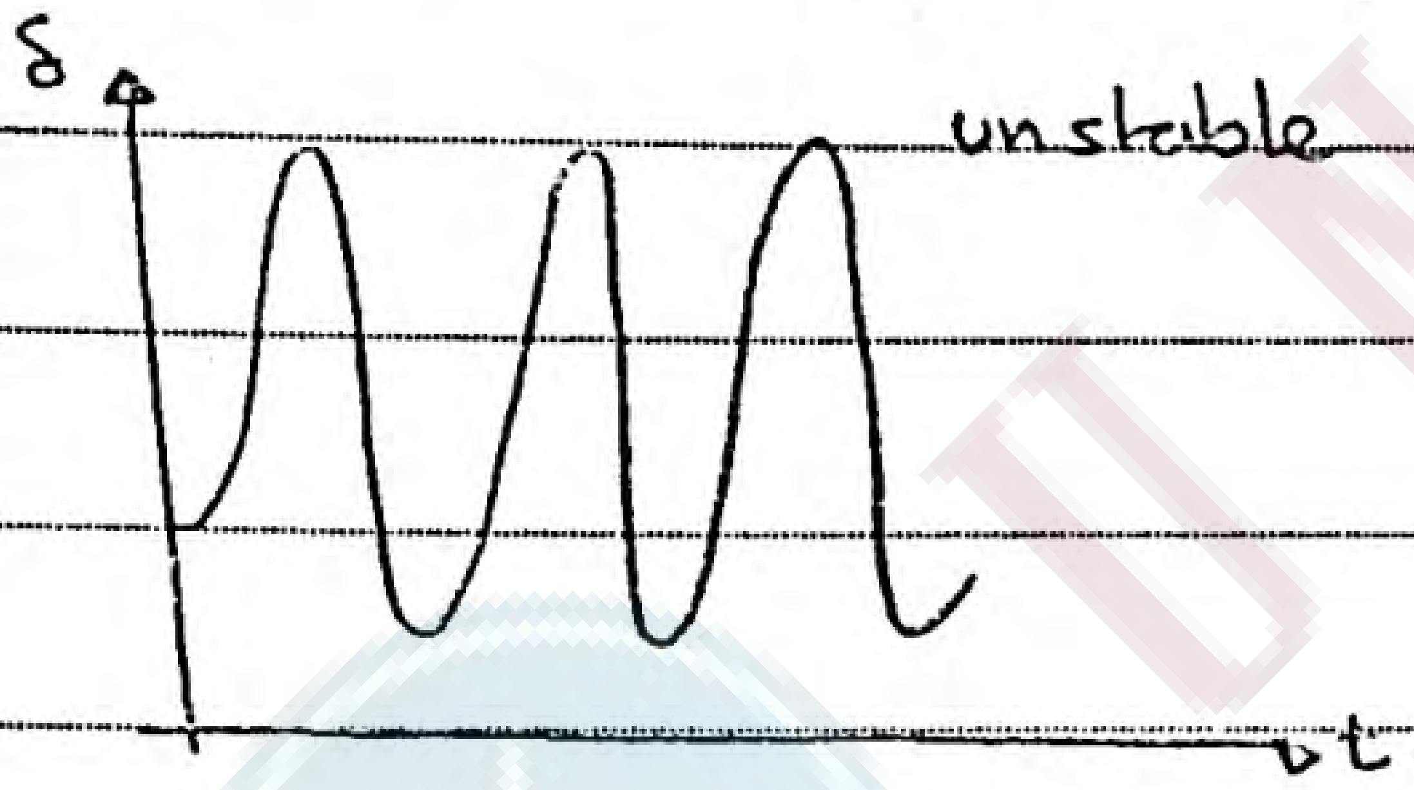
$$\frac{H}{180f}\frac{d^2\delta}{dt^2} = P_m - P_e = P_a$$

## Step by step solution of the swing equation :

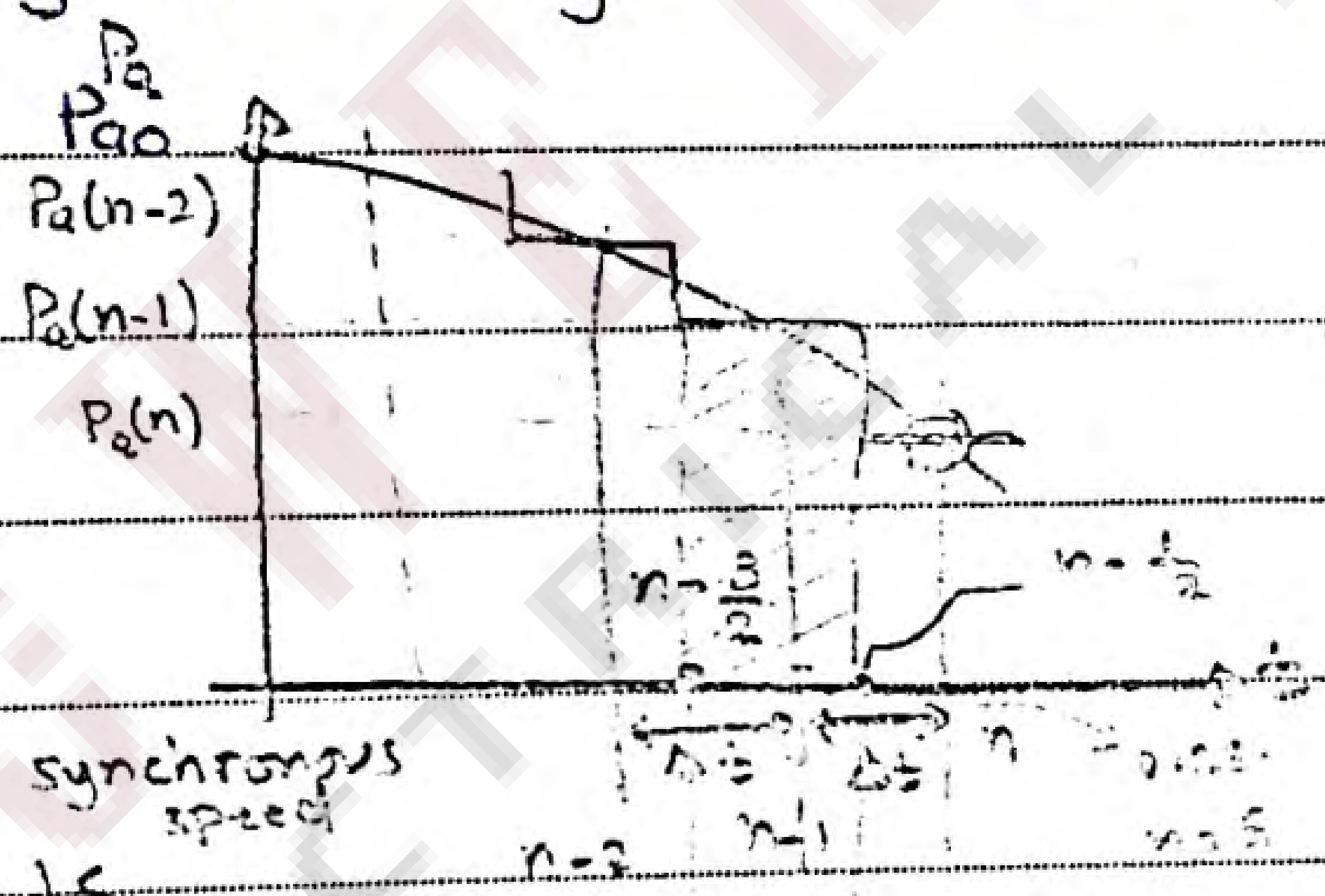






- Fault at most severe ~~condition~~ position
- Fault time 0.1 sec 0.2 sec

(relay operating time + Circuit Breaker clearing time) 50msec 50msec



$P_a^{0^-} = 0.$

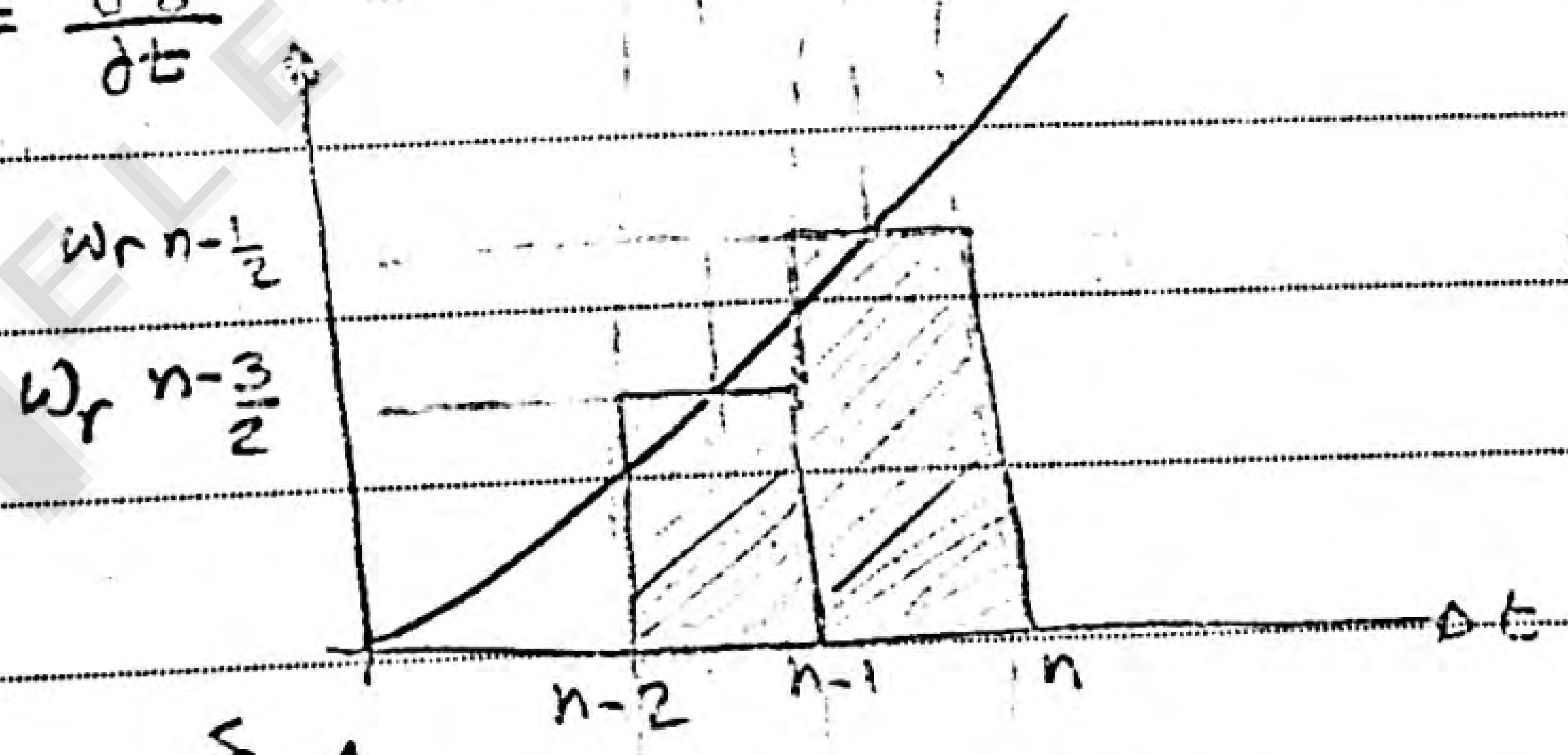
$P_a^{0^+} = P_{ao}$

take average.

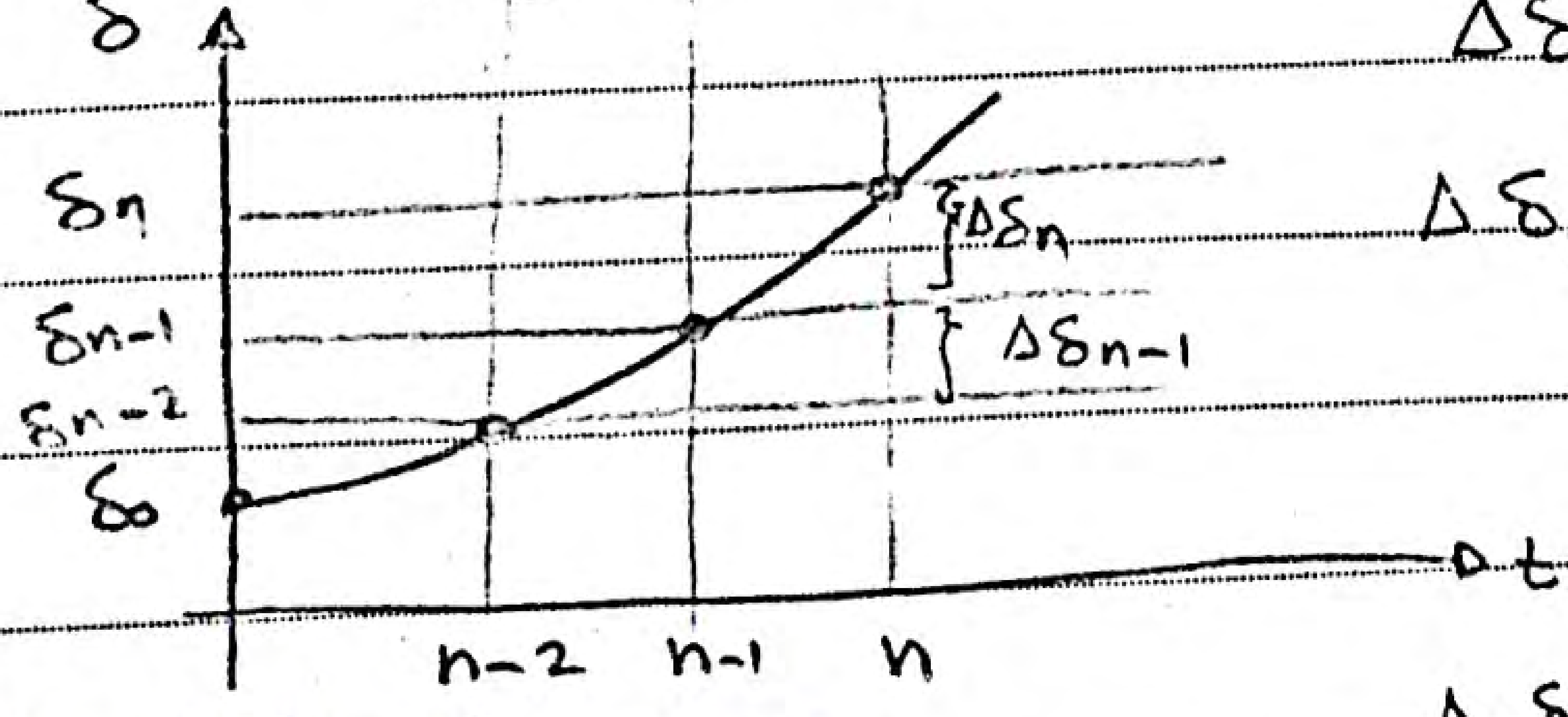
$$\frac{d^2\delta}{dt^2} = P_a \times \frac{180f}{H}$$

deviation synchronous speed

$$\omega_r = \frac{d\delta}{dt}$$



$$\omega_{r\,n-\frac{1}{2}} - \omega_{rm-\frac{3}{2}} = \frac{180f}{H} P_{a_{n-1}} \cdot \Delta t$$



This called swing curve

$$\Delta\delta_n = \delta_n - \delta_{n-1} = \omega_{r\,n-\frac{1}{2}}\Delta t$$

$$\Delta\delta_{n-1} = \delta_{n-1} - \delta_{n-2} = \omega_{r\,n-\frac{3}{2}} \cdot \Delta t$$

$$\Delta\delta_n - \Delta\delta_{n-1} = \left(\omega_{rn-\frac{1}{2}} - \omega_{rn-\frac{3}{2}}\right)\Delta t$$

$$\Delta\delta_n - \Delta\delta_{n-1} = \frac{180f}{H}(\Delta t)^2 P_{a_{n-1}}$$

lec # 10

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16/4/2014

$$\Delta\delta_n = \Delta\delta_{n-1} + K P_{a\,n-1}$$

K → electrical degree

Example :

machine 2

$$\frac{H}{180f}\frac{d^2\delta}{dt^2} = 1.6955 - 5.5023 \sin(\delta_2 - 0.755)$$

$t_{clearnig} = 0.225$ sec

$E_2 = 1.065 \angle 16.19°$

~~$\Delta t = 0.25$ sec~~

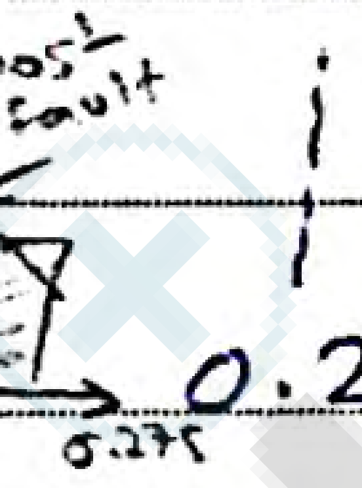
$\Delta t = 0.05$ sec

✱ it $t_{clearing} = 0.25 \begin{cases} 0.25^- \text{ @ fault} \\ 0.25^+ \text{ @ Post} \\ 0.25_{avg} \end{cases}$

$H = 8$ S

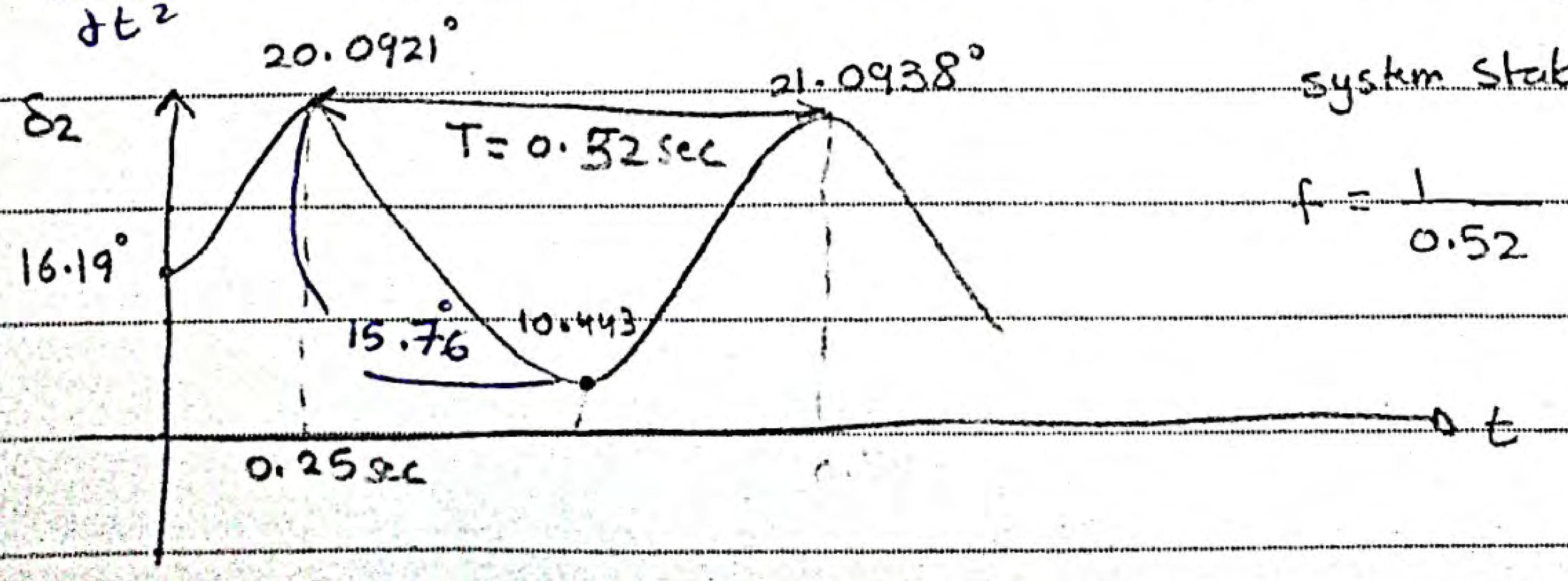
$$K = \frac{180f}{H}\Delta t^2 = \frac{180*60}{8} * 0.05 = 3.375° \text{ electric}$$

| t, s | $(\delta_2-\gamma)°$ | Pmax $\sin(\delta_2-\gamma)$ | $P_a$ | $K P_{a\,n-1}$° | $\Delta\delta_n$ | $\delta_n$ |
|---|---|---|---|---|---|---|
| $0^-$ | | | 0 | | | 16.19° |
| $0^+$ | 15.435 | 1.4644 | 0.231 | | | 16.19° |
| $0_{av}$ | | | 0.1155 | 0.389 | 0.389 | 16.19° |
| 0.05 | 15.824 | 1.5 | 0.1955 | 0.658 | 1.05 | 16.579° |
| 0.1 | 16.87 | | | | | 17.627° |
| 0.2 | | | | | 0.7976 | [illegible] |
| 0.25 | 20.248 | 2.247 | -0.5774 | -1.95 | -1.15 | 21.0921 |
| | | | | | | 19.94 |



After post fault :

$$\frac{d^2\delta}{dt^2} = 1.85 - 0.1804 - 6.4934 \sin(\delta_2 - 0.847)$$



system stable.

$f = \frac{1}{0.52}$

lec # 18

Wednesday

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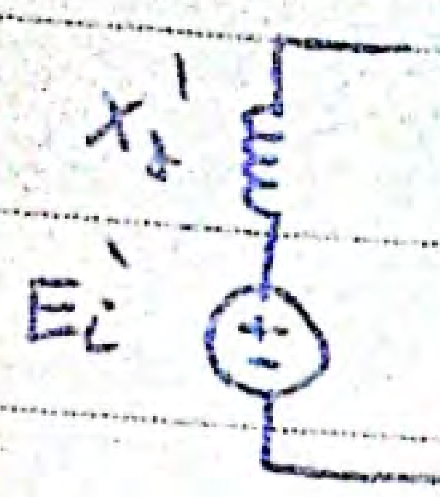
$$f_n = \frac{1}{2\pi}\sqrt{\frac{\overset{377}{\omega_s}\cdot S_P}{\cancel{2H}16}} = 1.935\ Hz \rightarrow T = \frac{1}{F} = 0.517^\circ$$

$$S_P = \frac{dP_e}{d\delta} = \frac{d}{d\delta}\left(0.1804 + 6.4934\ \sin(\delta_2 - 0.847)\right)$$

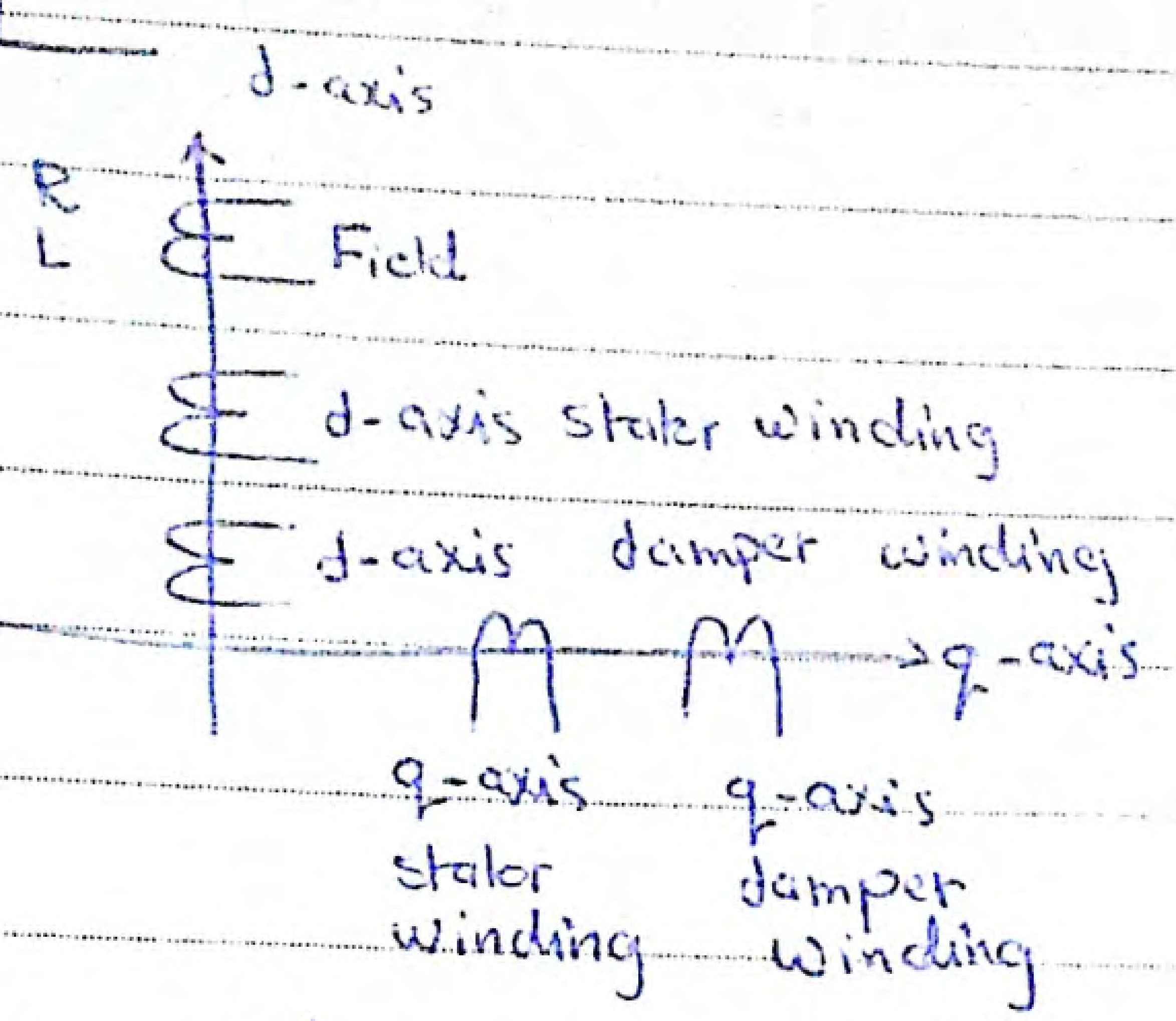
23/3/2014

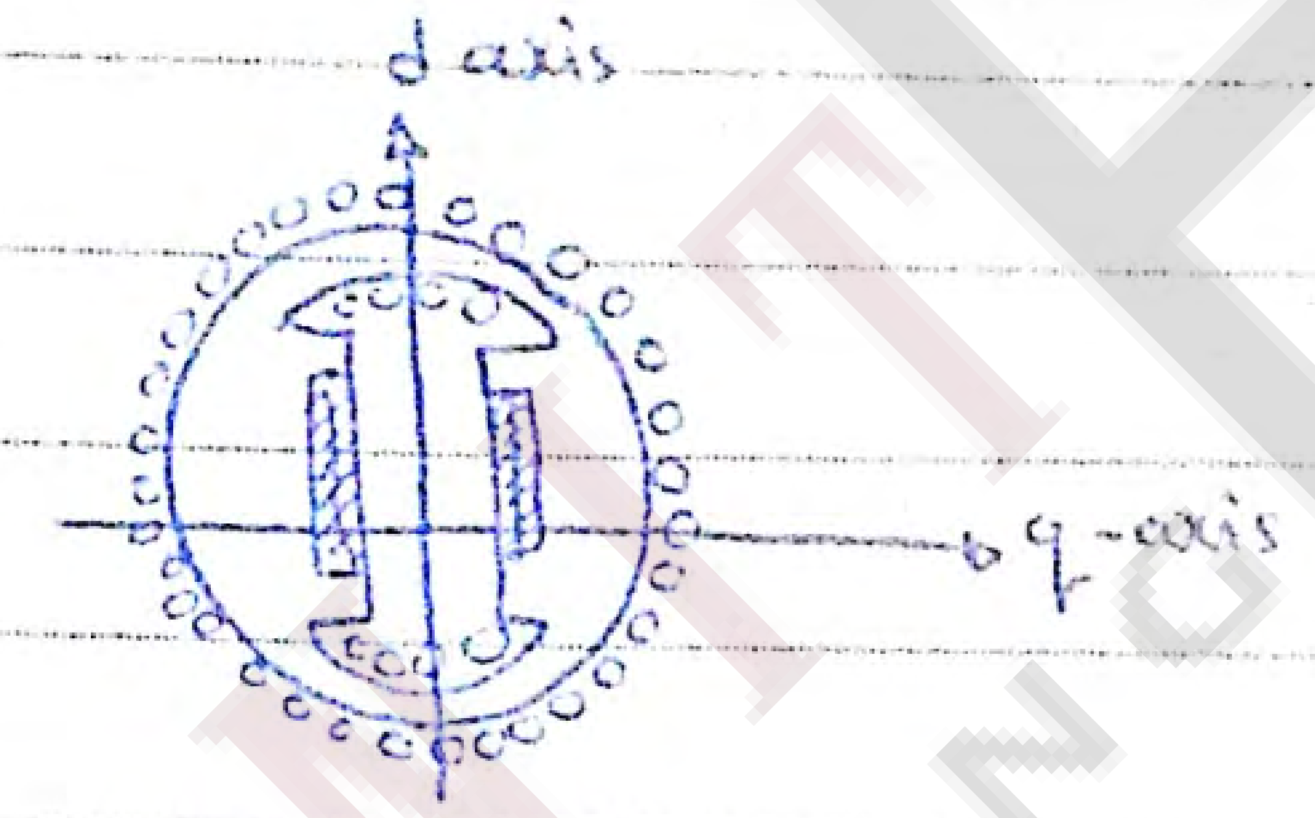
## Computer Programs for Transient Stability Studies:

- very large Number of machines

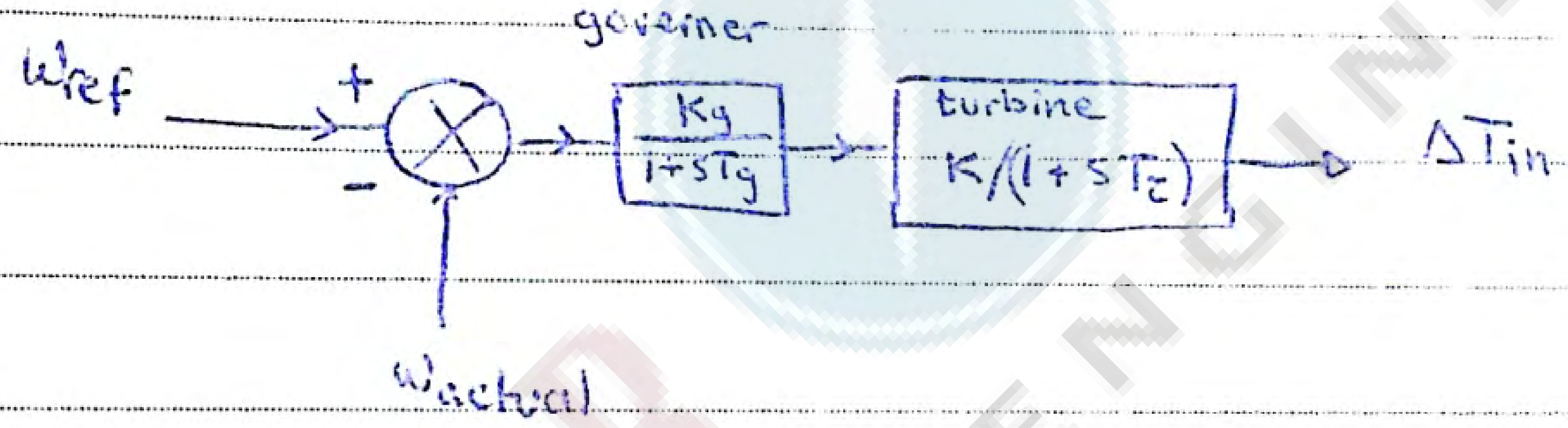


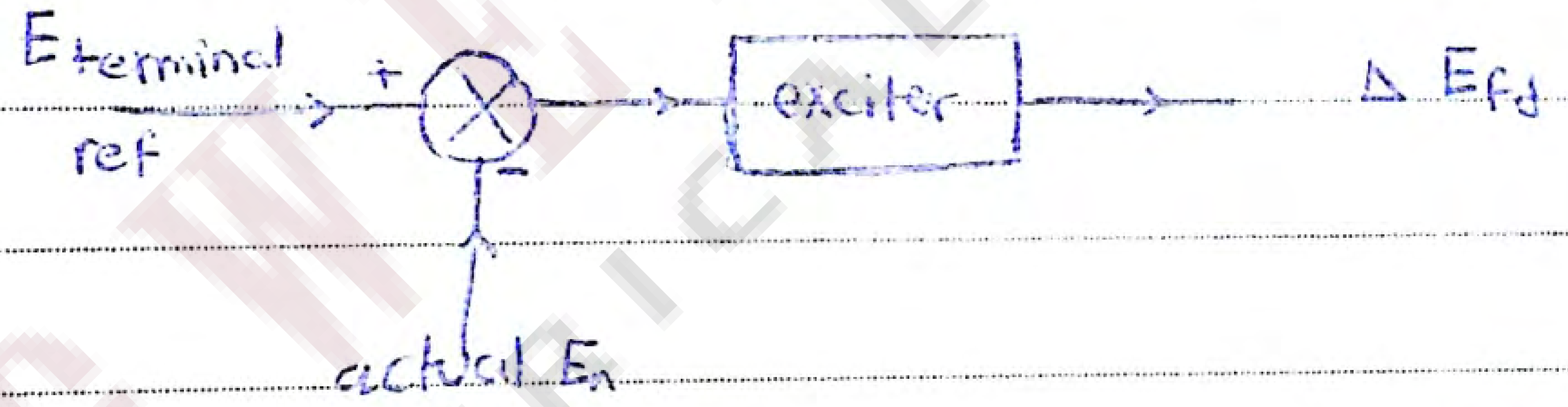
detailed representation of synchronous machine.





- representation of controllers





| | classical study | Computer study |
|---|---|---|
| $t = 0.25$ | $\delta = 21.09°$ | $\delta = 20.9°$ |
| $t = 0.75$ | $\delta = 21.09°$ | $\delta = 20.8°$ |

## Factors Affecting Transient Stability:

$$\underset{\text{constant}}{\frac{H}{180f}} \frac{d^2\delta}{dt^2} = \underset{\text{constant}}{P_a - P_e}$$

H ↑ , acceleration ↓

$$\Delta\delta_n = \Delta\delta_{n-1} + \frac{180f}{H}(\Delta t)^2 P_{a\,n-1}$$

lec # 19

Wednesday
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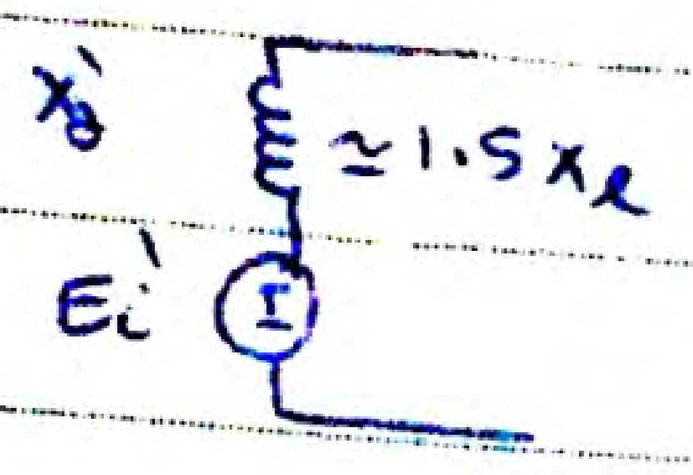
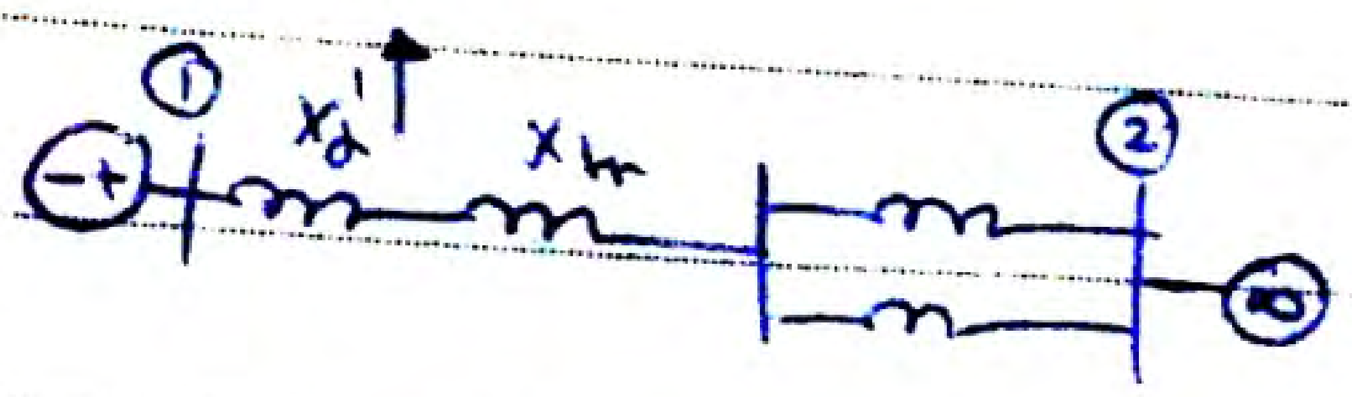
$$H = \frac{\underline{K.E.\ \text{stored at synchronous speed}}}{S_{machine}} = \frac{\frac{1}{2}\overset{\text{mass}}{\textcircled{J}}\,\omega_{sm}^2}{S_{machine}}$$



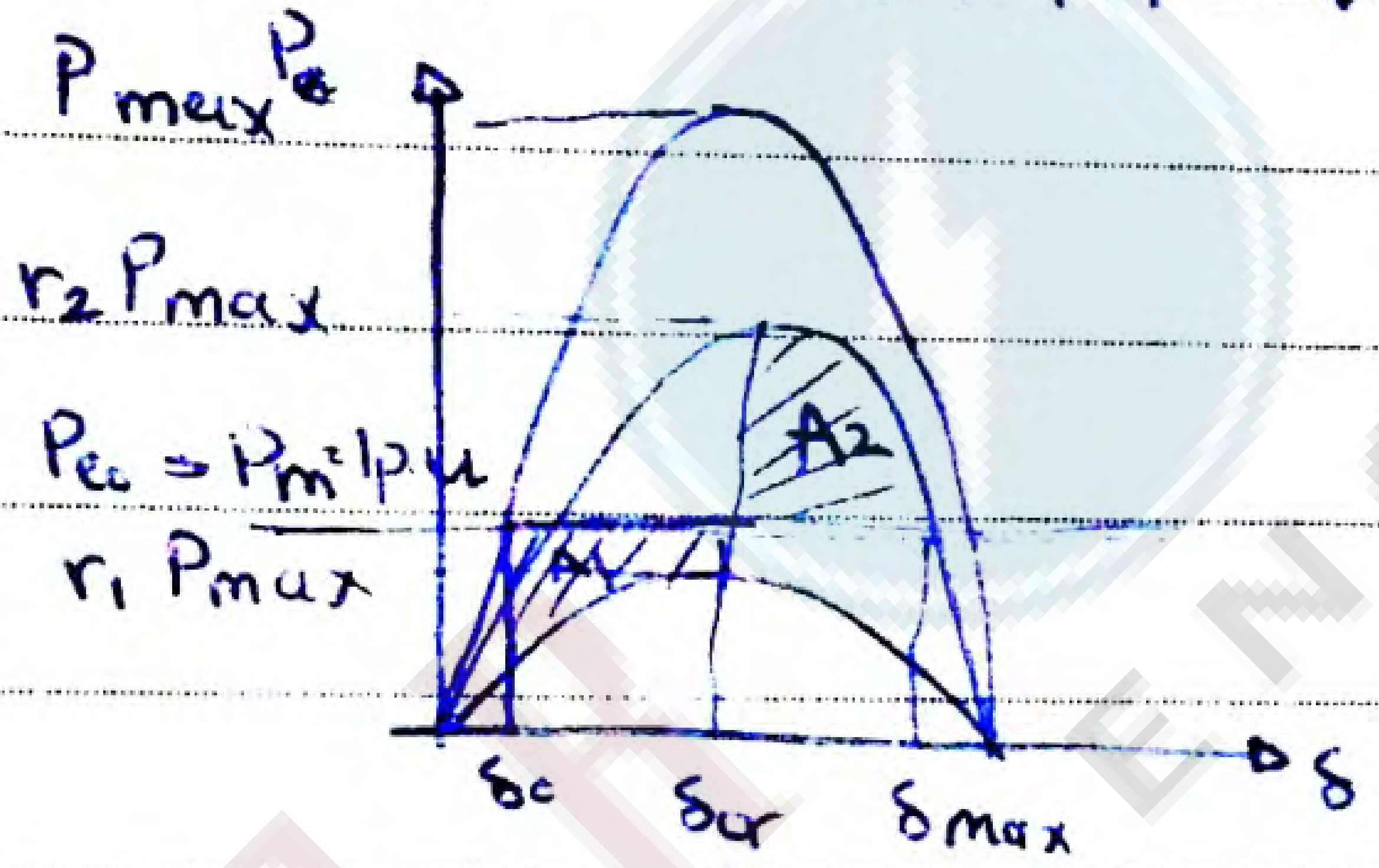
$H\downarrow$ $\underline{\underline{x_d'\uparrow}}$

↳ mass increased



$$\left|\frac{1}{x_d' + x_{tr} + x_{//TL}}\right| = |Y_{12}|\downarrow$$

$P_{max} = E_i' E_2' |Y_{12}|$ ↓ , $P_e\downarrow$ , accelaration ↑, H ↓



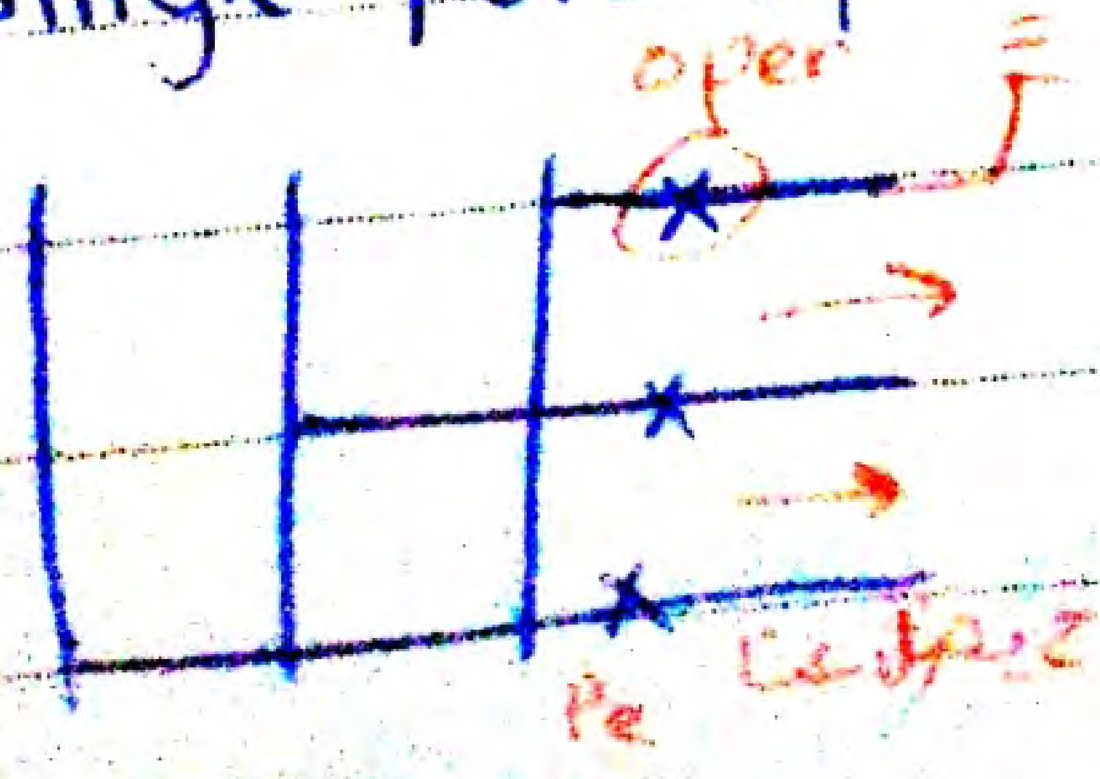
$P_{max}\downarrow$ , $\delta_0$ increase , $\delta_{max}$ decreases ,
$\delta_{cr}$ will decrease.

$\boxed{**}$ we try to increase $P_{max}$.

1. Use of thyristor exciter
to change
$t_{cr}$ + (0.5 - 1.5 cycle).

2. Use of solenoid valves on turbines
$t_{cr}$ + ( 1 - 2 cycles)

3. Single pole operation



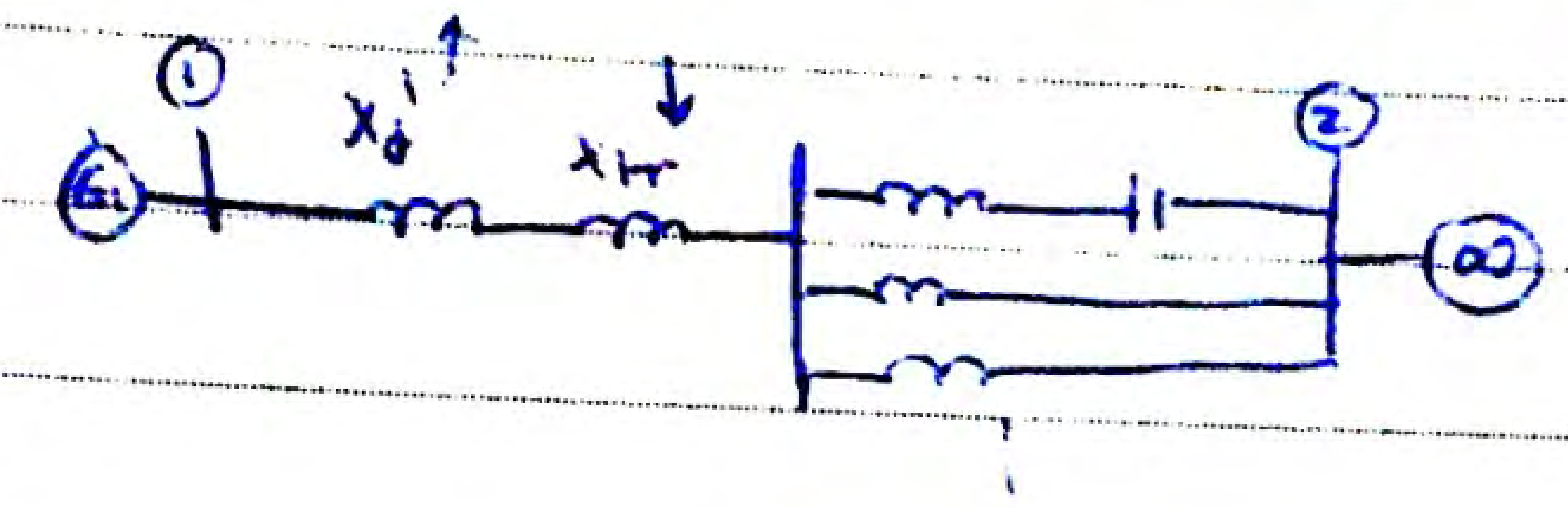
phase اللي
صار عليه الـ fault
بس هوي اللي
يفتح

$t_{cr}$ + ( 2-5 cycles)

lec # 19

Wednesday
23/4/2014

4. Fast fault clearing times
- more TL's in //el
- use series compinsation (reduce $\overset{z}{\text{impedance}}$ & increase $\overset{y}{\text{admattence}}$)
- reduce transformer impedance.

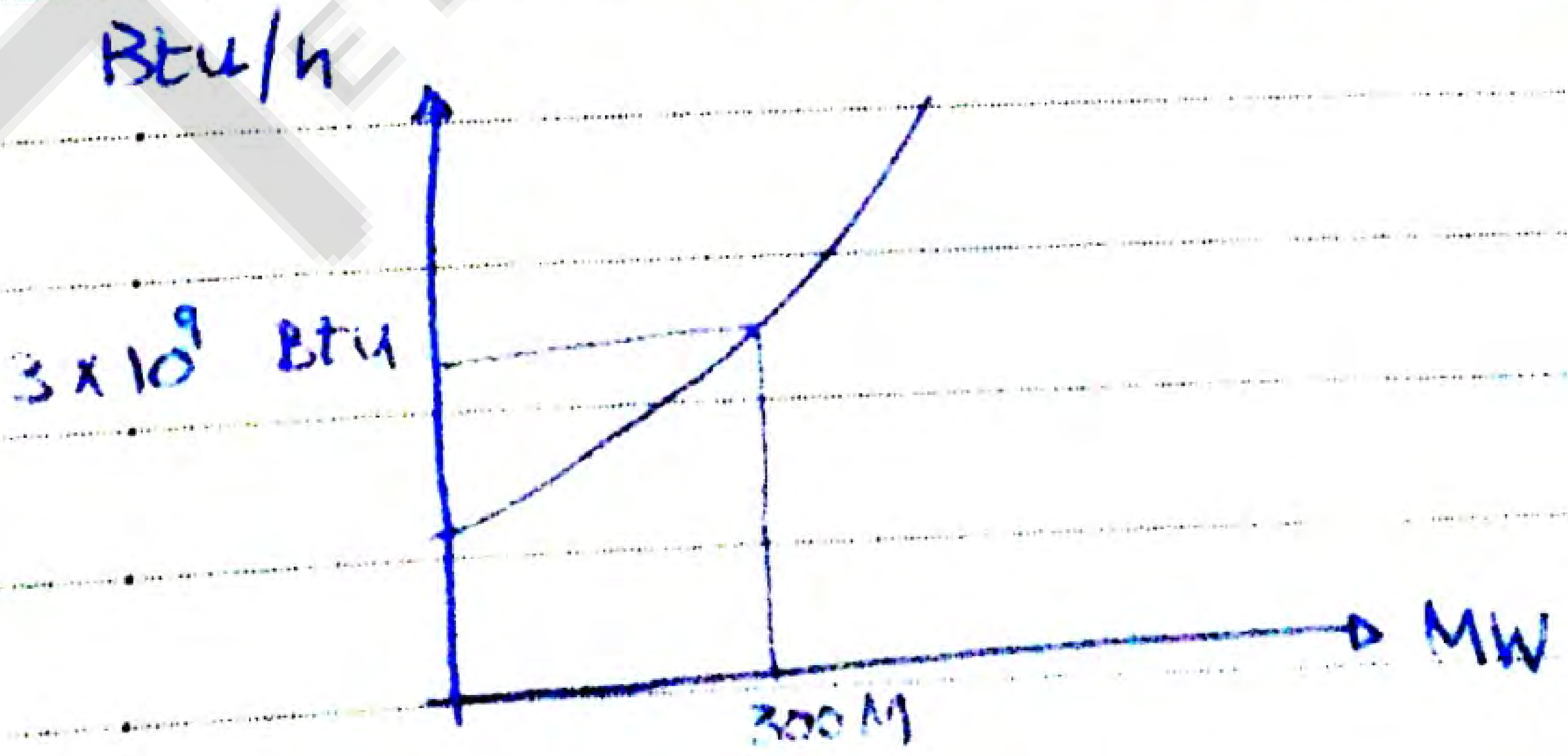


--- ☺ Seconed

Economic Operation of Power Systems:
supply power
constant V & F
in reliable & <u>economic</u> manner

Regulatory bobies:
- reduce price
- reduce fuel consumption

coal
generation: nuclear
↑
Fuel cost gas (5$ /MBtu)
heavy fuel (12-14 $ / MBtu)
Diesal (20 $/ MBtu)



lec #19

wednesday

23/4/2014

$$1\,W = \frac{1\,J}{1\,Sec}$$

1000 Ws = 1kJ

Btu = 1.055056 kJ

1kJ = 0.94782 Btu

1kWh

1000 W . 3600s

1kW = 3600 kJ

= 3412.152 Btu

Britsh thermal unit