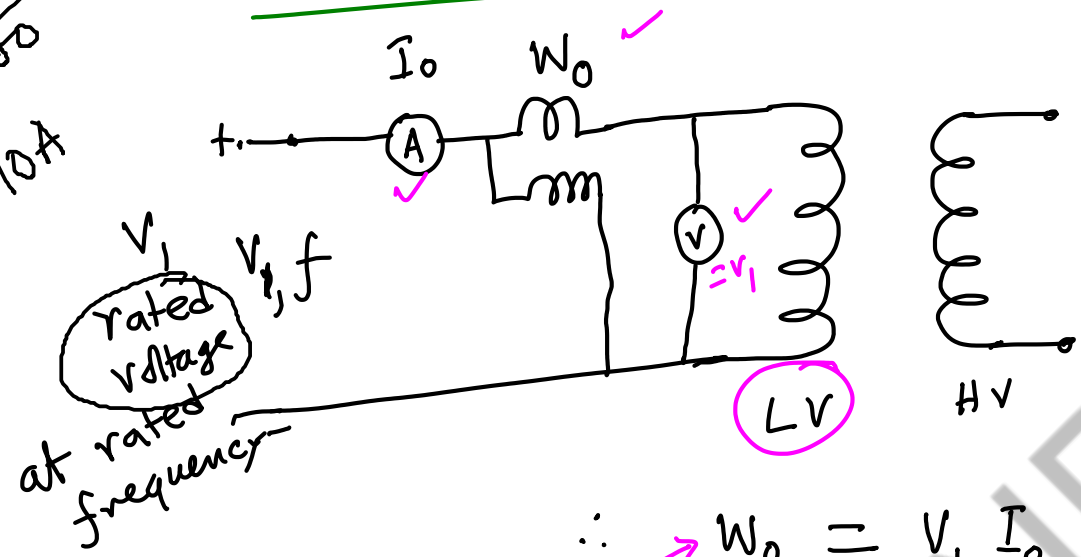


Dec-17

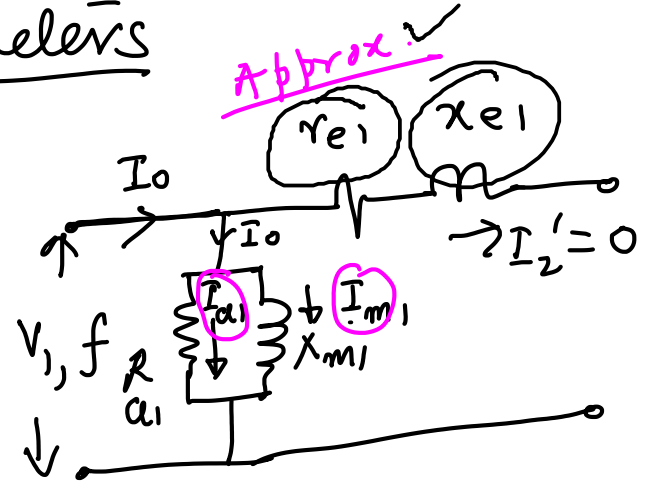
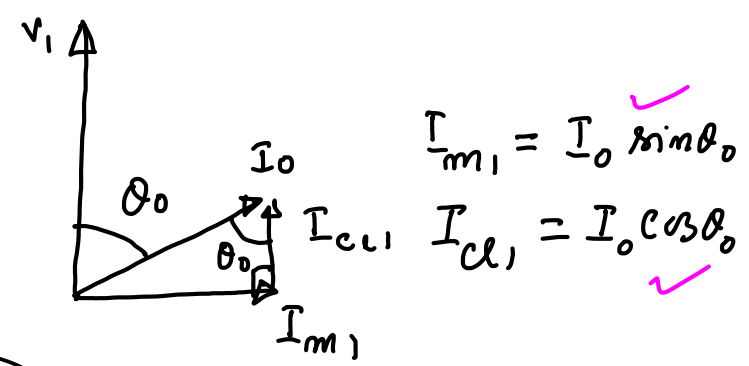
Determination of Equivalent Ckt. parameters

Open Circuit Test & S.C Test or no load

200V/100V, 50Hz
1KVA
 $I_{HV} = \frac{1000}{200} = 5A$
 $I_{LV} = 10A$



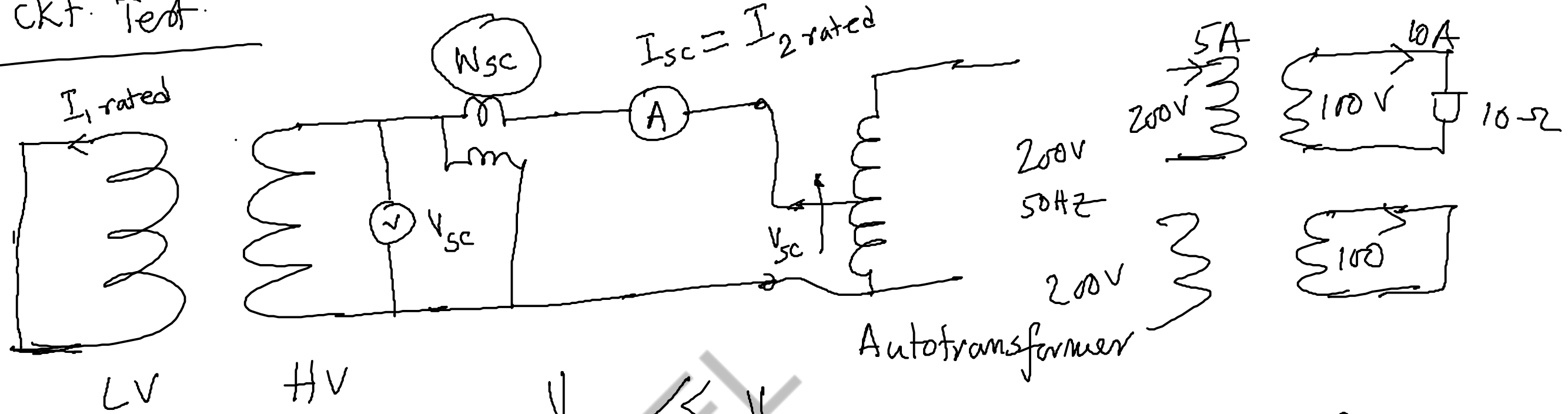
$R_{e1} = \frac{V_1}{I_{e1}}$
 $X_{m1} = \frac{V_1}{I_{m1}}$



$\therefore W_0 = V_1 I_o \cos \theta_0$
 $I_o \cos \theta_0 = \frac{W_0}{V_1} = I_{e1}$
 $\cos \theta_0 = \frac{W_0}{V_1 I_o}$ from this θ_0 is known
 practically $\therefore$ records the core loss
 The loss $I_o^2 R_{e1} \ll$ core loss
 as flux is rated & I_o is only about 2 to 5% rated current.

I know also R_{e2} & X_{m2}

Short ckt. Test.



$$1 \text{ kVA} \quad \frac{100}{200 \text{ V}} \\ 10 \text{ A} / 5 \text{ A}$$

$$V_{sc} \ll V_{\text{HV rated}}$$

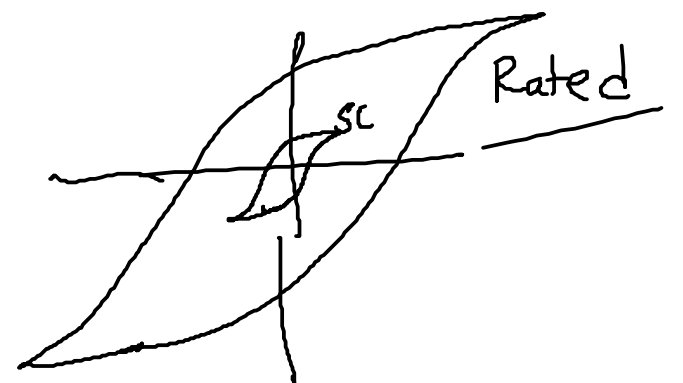
Note during S.C test

Core loss $\ll$ winding Cu loss ($I^2 r$)

$$\phi_{\text{max (sc)}} = \frac{V_{sc}}{\sqrt{2} \pi f N_{\text{HV}}} \ll \frac{\phi_{\text{max rated}}}{\sqrt{2} \pi f N_{\text{HV}}}$$

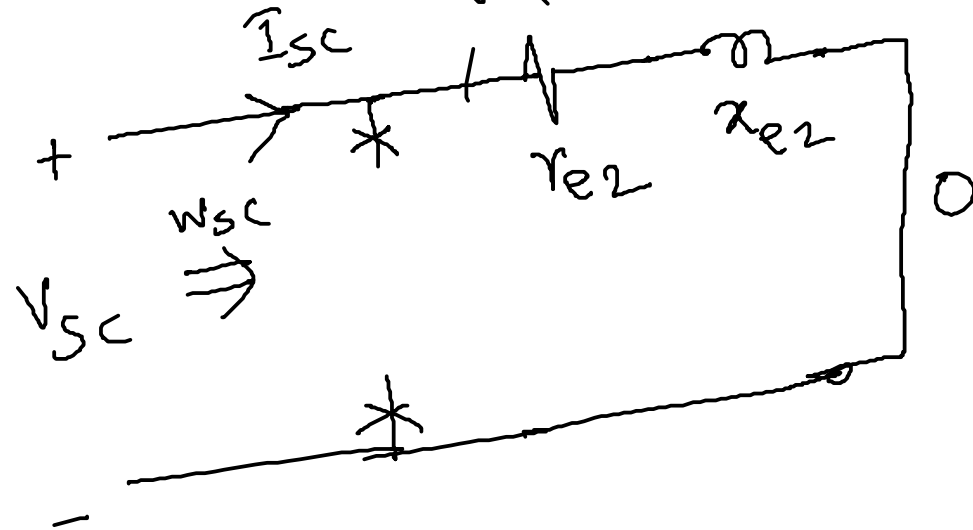
$$\phi_{\text{max (sc)}} \ll \phi_{\text{max rated}} \\ B_{\text{max sc}} \ll B_{\text{max rated}}$$

$$W_{sc} \approx \text{crl } \frac{Cu\text{-loss}}{I_1^2 r_1 + I_2^2 r_2} \\ = I_1^2 r_{e1} = I_2^2 r_{e2}$$



SC Test

Equivalent ckt ref. HV side



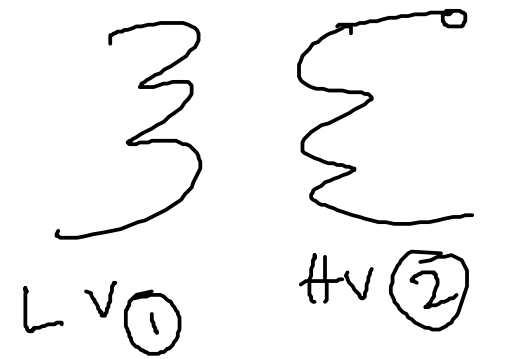
during S.C Test

Core loss << Cu loss (iron)

$$W_{sc} \approx I_{sc}^2 r_{e2} \quad \therefore r_{e2} = W_{sc} / I_{sc}^2$$

$$\frac{V_{sc}}{I_{sc}} = \sqrt{r_{e2}^2 + x_{e2}^2} \Rightarrow x_{e2} \text{ can be found out.}$$

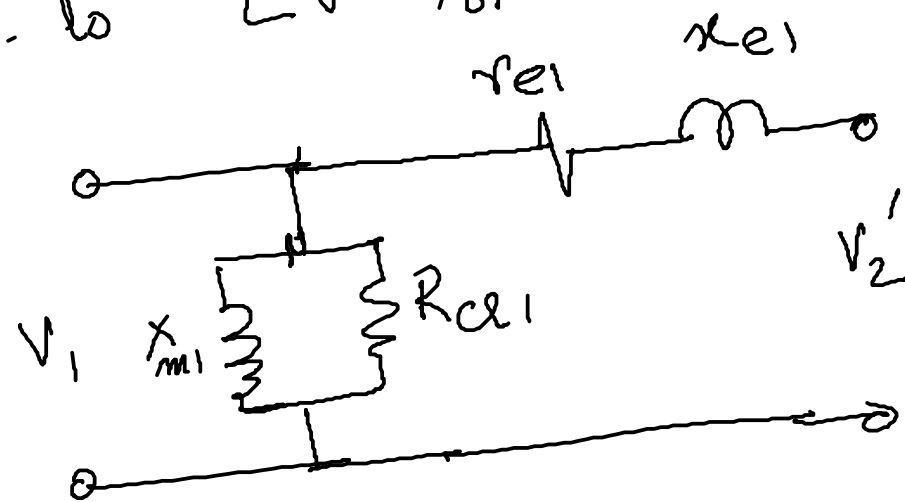
10



o-c test

R_{e1}, X_{m1}

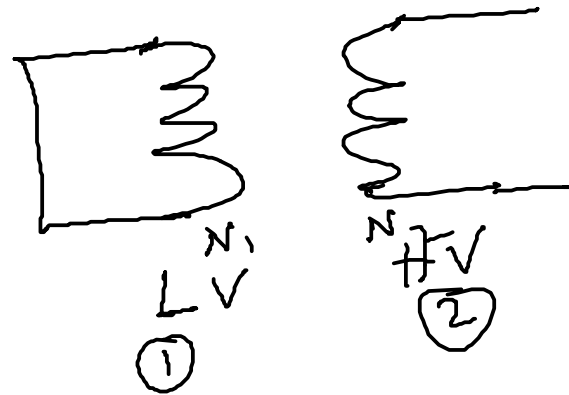
To draw the equiv ckt.
ref. to LV side



where

$$r_{e1} = a^2 r_{e2}$$

$$x_{e1} = a^2 x_{e2}$$

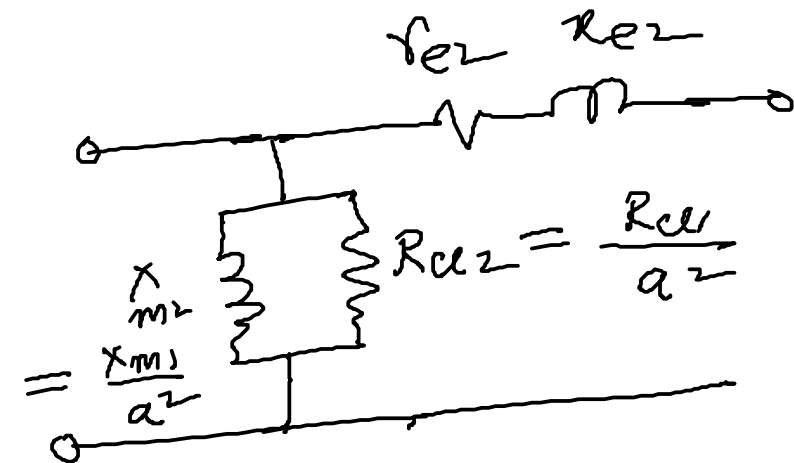


r_{e2} , x_{e2}

$a = \frac{N_1}{N_2}$

dec-18

Equiv. ckt. ref to HV.



1 kVA, 200 V / 100 V, 50 Hz, 1 ph
 5 A 10 A

no restriction
 on carrying out a test
 from a particular side

1, ph, 100 kVA, $\frac{10000 \text{ V}}{I_{Hv}}$ / 100 V, 50 Hz

O.C from HV side (!)

$$\frac{I_{Hv \text{ rated}}}{1000} = \frac{100 \times 10^3}{1000} = 100 \text{ A}$$

$$\frac{100 \text{ A}}{20} = 5 \text{ A}$$

$$I_{Lv \text{ rated}} = 1000 \text{ A}$$

$$5\% \rightarrow 50 \text{ A}$$



O.C Test from LV side



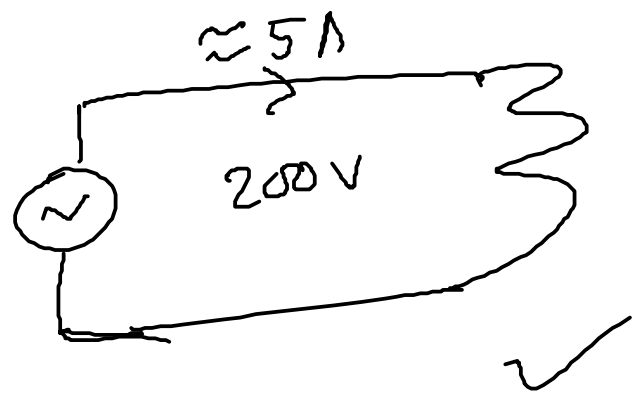
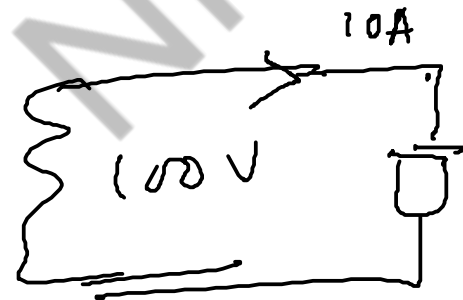
Two comment:-

During O.C test : tfo will have core loss only (!) Rated flux

During S.C test tfo will have only Cu-loss only (!)
flux $\ll$ Rate value

200 V / 100 V, 1 KVA, 50 Hz
5A 10A

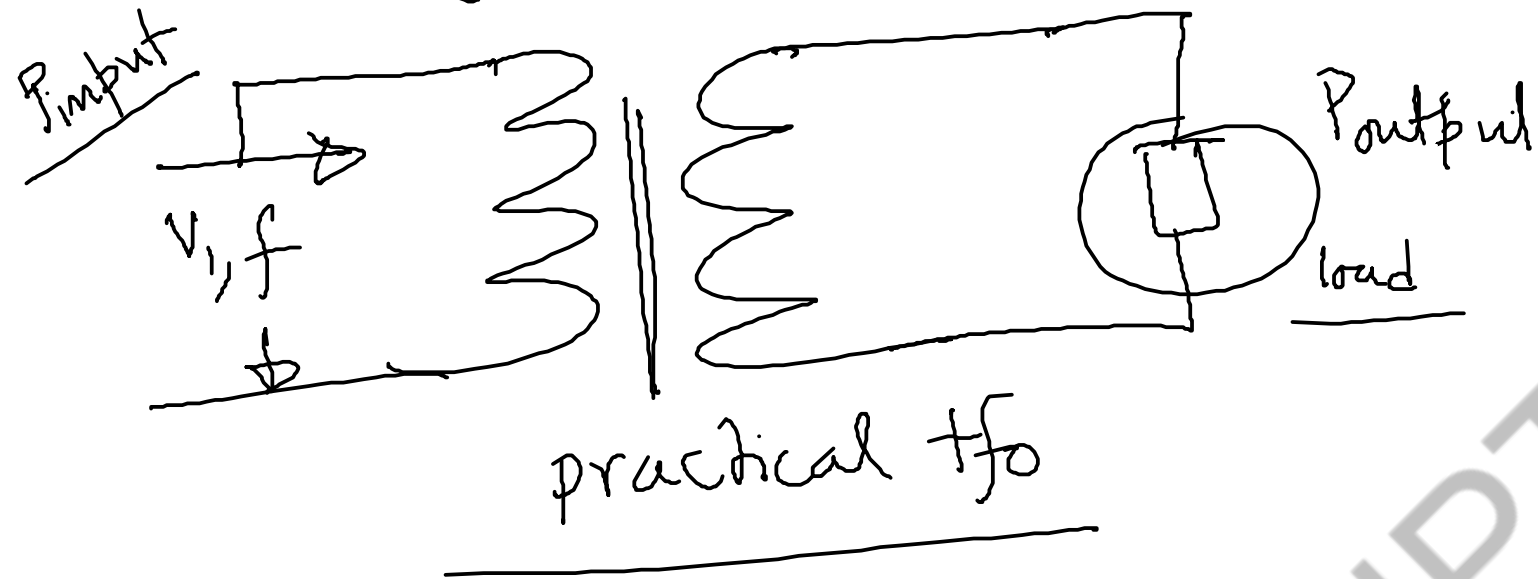
transformer in operation:- under full load condition:-



both the losses are at their rated values.

flux is rated
Cu loss is also rated

- ✓ Efficiency (η)
- Regulation (R)



$$\text{Core loss} = P_{\text{eddy}} + P_{\text{hyst.}}$$

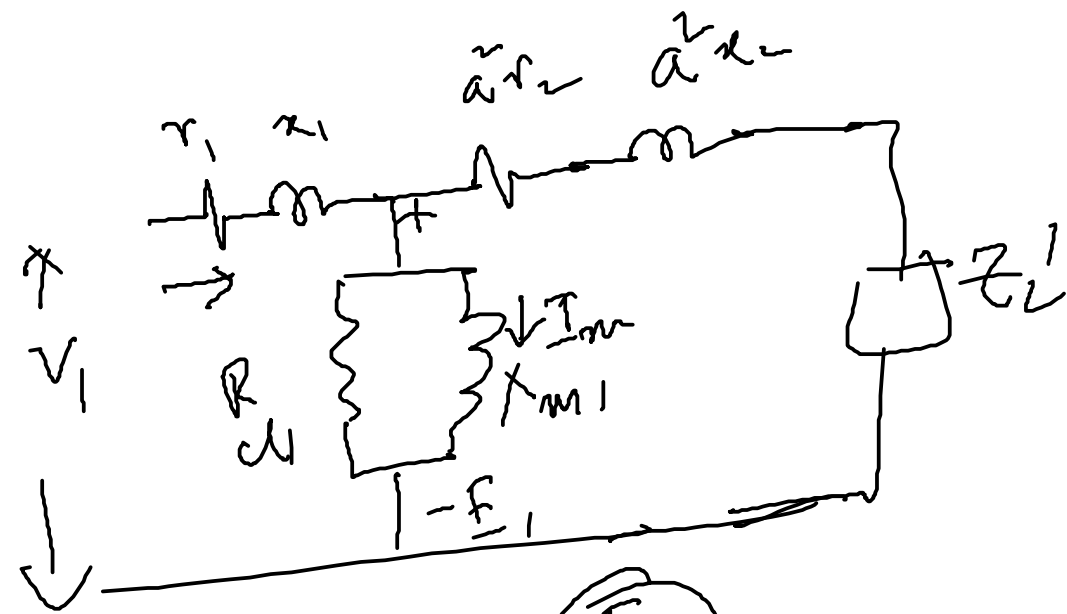
$$\propto k_e (B_{\text{max}})^2 + k_h B_{\text{max}}^{1.6}$$

$$\eta = \frac{\text{Kw output}}{\text{Kw input}} \quad \text{dec-19}$$

$$= \frac{P_{\text{output}}}{P_{\text{input}}} = \frac{P_{\text{output}}}{P_{\text{output}} + (\text{losses})}$$

$$\eta = \frac{P_{\text{output}}}{P_{\text{output}} + \text{core loss} + \text{Cu loss}}$$

B_{max} from remains practically constant
no load full load condition



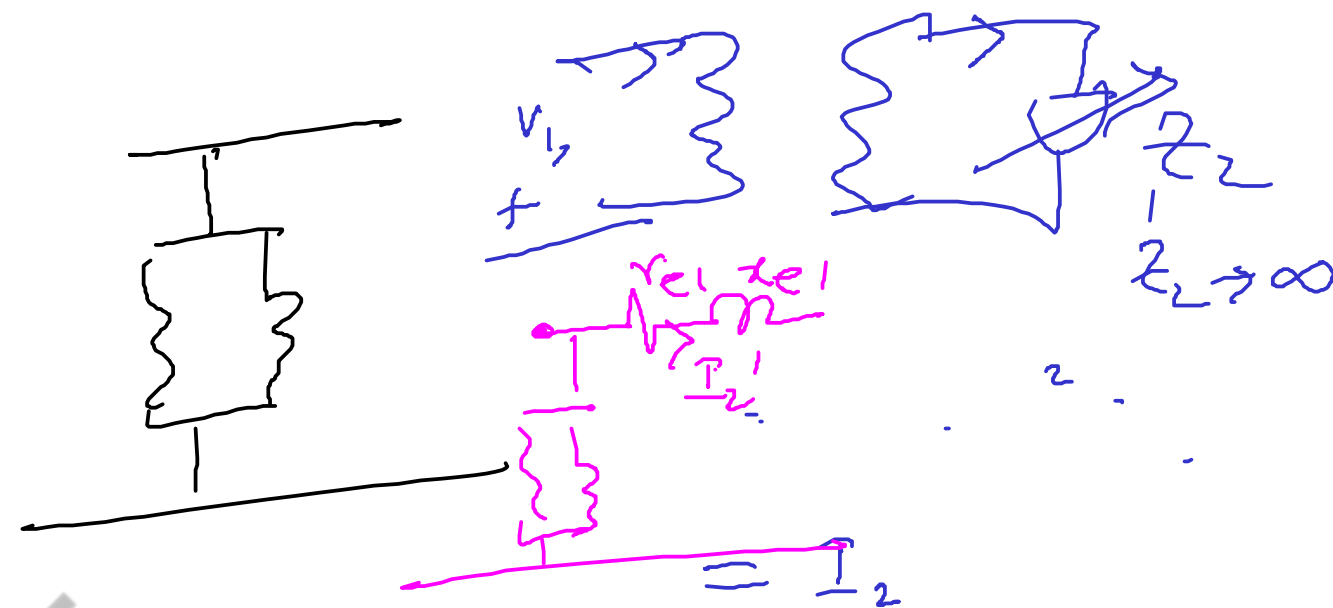
$$P_{max} = \frac{F_1}{4.44 f N_1}$$

$P_{core loss} \approx \text{fixed} = \text{constant loss}$

$P_{cu loss}$ is it fixed?
cu loss at any current I_2

No

$$I_1^2 r_{e1} = I_2^2 r_{e2}$$



P_{output}

$$P_{output} + P_{core loss} + P_{cu loss}$$

Practically remains constant from no load to full load ($\because B_{max} \approx \text{constant}$)

During s.c test wattmeter
reading = Cu loss of the tfo at full load
current

$$P_{\text{core}} = \frac{\text{wattmeter reading during no load test}}{}$$

If the tfo is loaded such that

windings (or coils) carry half the rated current

Then what will be the Cu loss now?

$$\frac{I_{fe1}^2 r_{e1}}{}$$

$$\frac{I_{fe2}^2 r_{e2}}{}$$

$$= \left(\frac{I_{fe1}}{2} \right)^2 r_{e1} = \frac{1}{4} (I_{fe1}^2 r_{e1}) = \frac{1}{4} (P_{\text{Cu loss full load}})$$

$$= \frac{1}{4} (W_{\text{sc test}})$$

Degree of loading $0 \leq x \leq 1$

$x = 0 \rightarrow$ no-load

$x = 1 \rightarrow$ full load

Let

$S =$ rated kVA.

~~Calc~~ Estimate η at " x " degree of loading.

$$\eta_x = \frac{x S \cos \theta \quad \checkmark \text{ P.f of the load}}{x S \cos \theta + \underset{\substack{\text{does not} \\ \text{depend on } x}}{P_{\text{core}}} + x^2 \left(\underset{\substack{\text{at} \\ x=1}}{P_{\text{cu loss full load}}} \right)}$$

Dec-20

degree of loading $x = 0 < x < 1$
 $\uparrow$ no load $\nwarrow$ Rated condition

Core loss = P_{core} (independent on x) = constant
(= wattmeter reading of no load test)

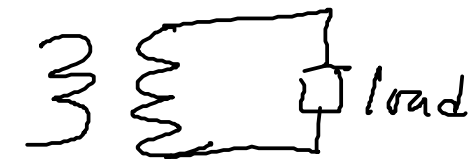
full load cu loss = P_{cufl} (wattmeter reading of S.C Test)

Cu loss depends on "x"

$\text{Cu loss depends on "x"}$
 $\text{Cu loss at "x" degree of loading} = x^2 P_{\text{cufl}}$

Efficient at " x " degree of loading

$$\eta_x = \frac{x S \cos \theta \leftarrow (\text{p.f. of load})}{x S \cos \theta + P_{\text{core}} + x^2 P_{\text{cufl}}}$$

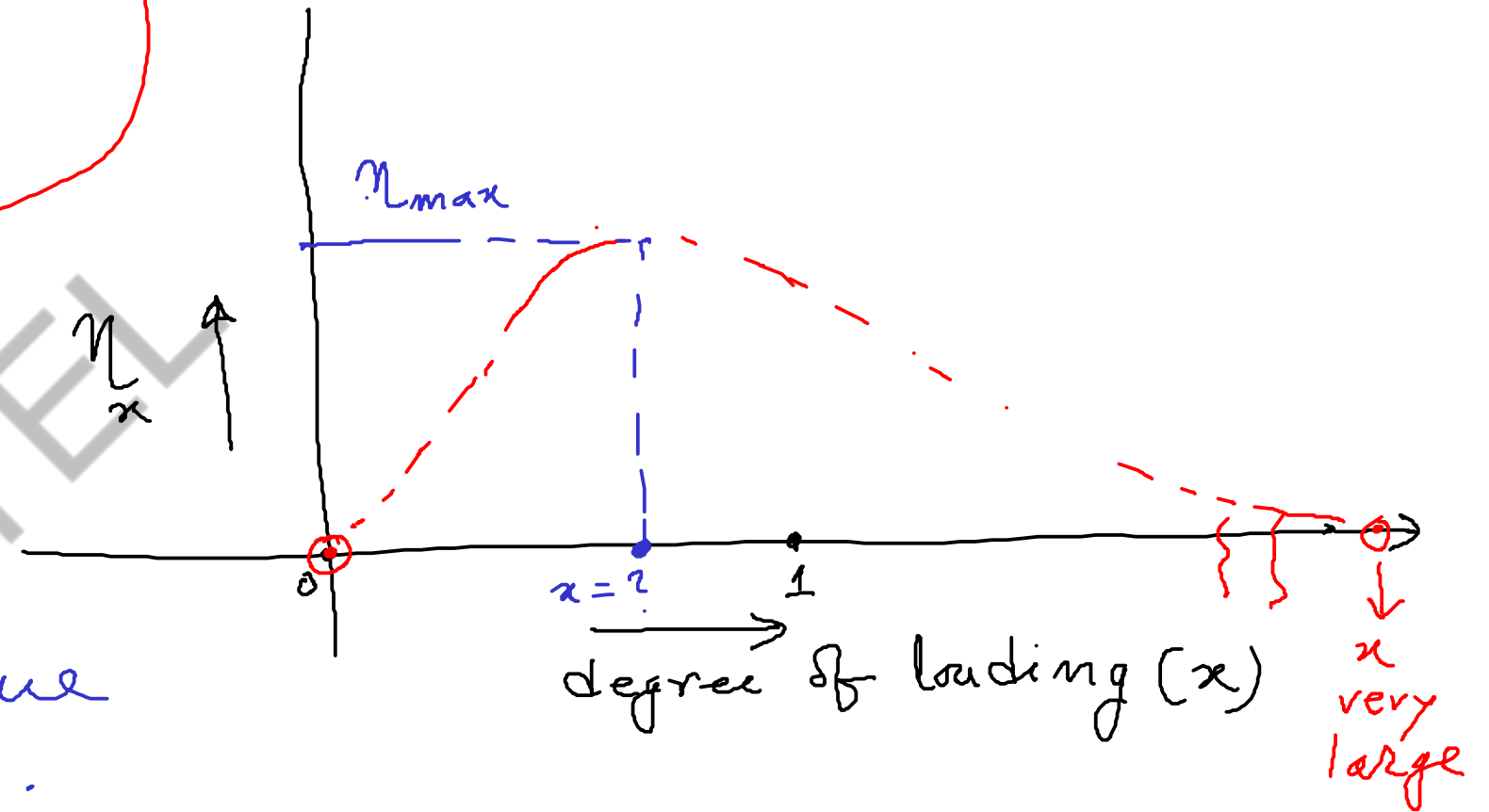


$x = 0 \rightarrow$ no load $\eta_x = 0$

If $x \rightarrow$ very large
($\rightarrow \infty$)

$\eta_x \rightarrow 0$

To find out at what value
of x , η_x will be max.
 $\cos \theta = \text{constant}$



$$\eta_x = \frac{x S \cos \theta \rightarrow \text{constant}}{x S \cos \theta + P_{\text{cone}} + x^2 P_{\text{cufl}}}$$

$$\therefore \frac{d\eta_x}{dx} = 0$$

η_x will be max.^m when denominator is min.^m

$$\eta_x = \frac{S \cos \theta}{\left(S \cos \theta + \frac{P_{\text{cone}}}{x} + x P_{\text{cufl}} \right)}$$

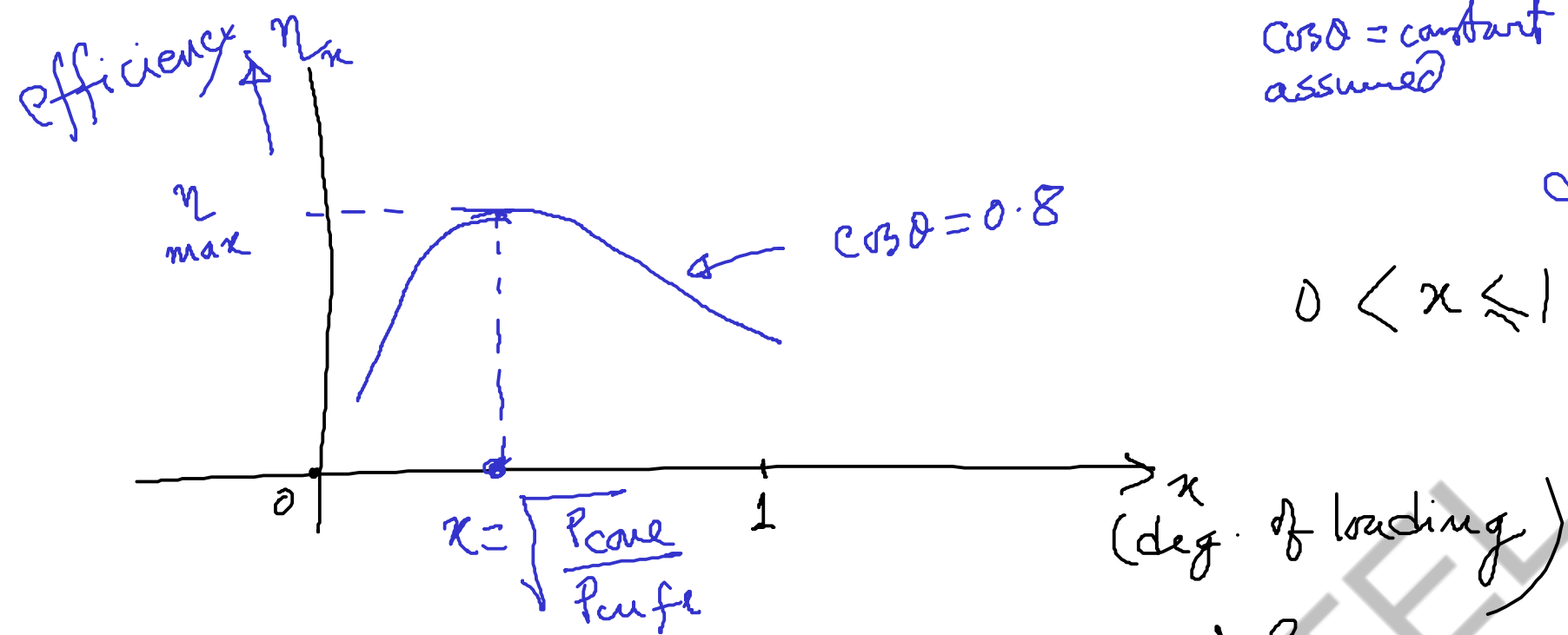
$$\therefore \frac{d}{dx} \left(S \cos \theta + \frac{P_{\text{cone}}}{x} + x P_{\text{cufl}} \right) = 0$$

$$\therefore -\frac{P_{\text{cone}}}{x^2} + P_{\text{cufl}} = 0 \quad \text{or} \quad x^2 P_{\text{cufl}} = P_{\text{cone}}$$

$$\boxed{x^2 P_{\text{cufl}} = P_{\text{cone}}} \quad \checkmark$$

η_x will be max.^m when variable loss (Cu-loss) = fixed loss (cone loss)

$$x = \sqrt{P_{\text{cone}} / P_{\text{cufl}}} \quad \checkmark$$



$\cos \phi = \text{constant}$
assumed

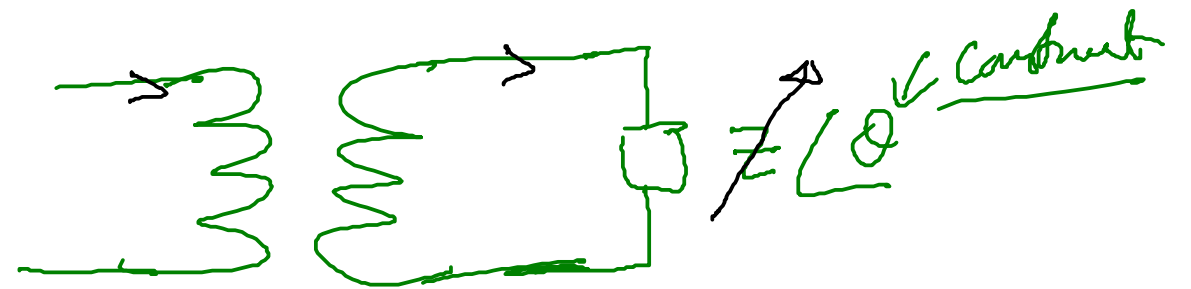
$S = 10 \text{ kVA}$ (rated kVA)

deg. of loading at $\max^m \eta$

$$= \sqrt{\frac{P_{\text{core}}}{P_{\text{cufl}}}} = 0.7 \text{ (say)}$$

if the tfo is operated
at $0.7 \times 10 = 7 \text{ kVA}$
then $\max^m$ efficiency
will be achieved.

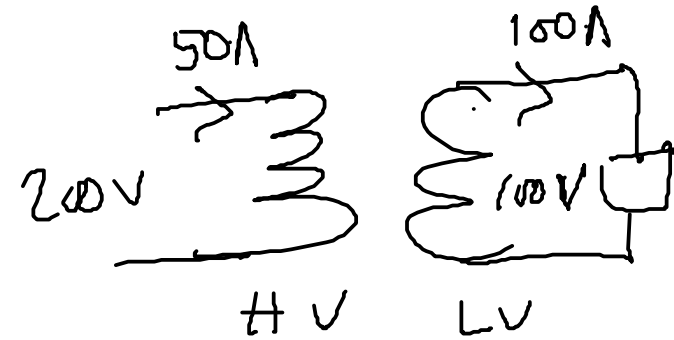
As an user of the tfo
at what value of x
efficiency will be $\max^m \rightarrow$
user's choice.



— 0 —

1ph, 10 KVA, 200 V/100 V, 50 Hz.

$\frac{10000}{200} = 50 \text{ A}$ / 100 A



Dec-21

Suppose this tfo will operated
always at full load condition.

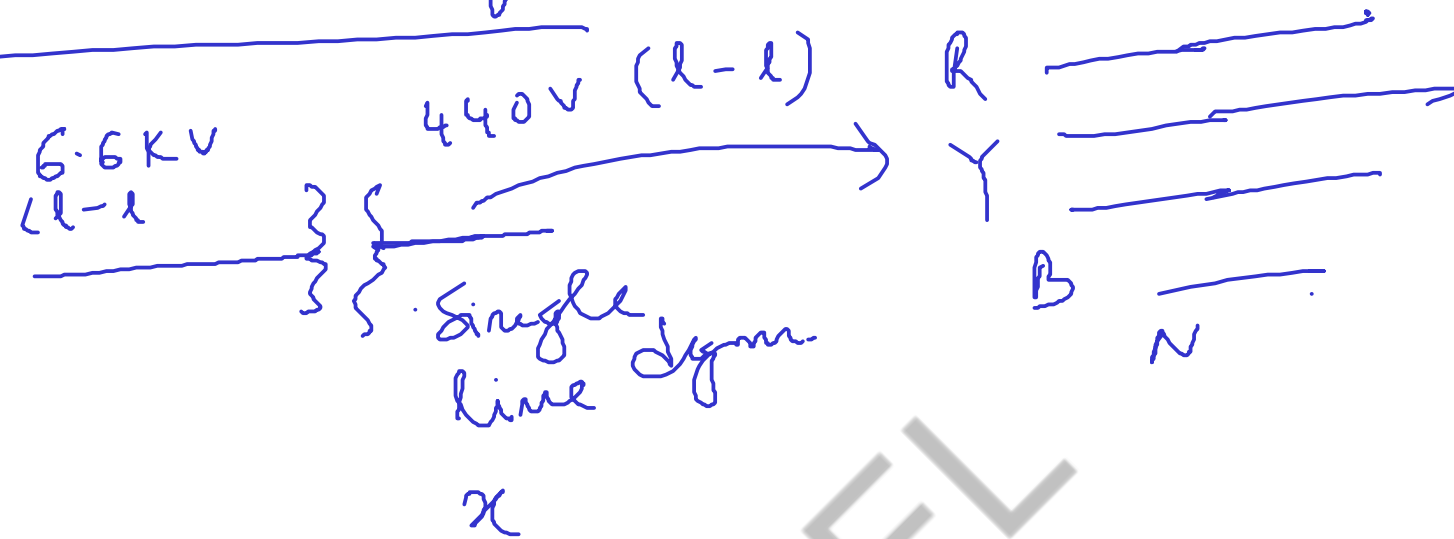
at $x = 1$, $\eta_{\max}$ should occur.

$$P_{\text{core}} = P_{\text{cu fl}}$$

$$\downarrow x = \sqrt{\frac{P_{\text{core}}}{P_{\text{cu fl}}}} = 1$$



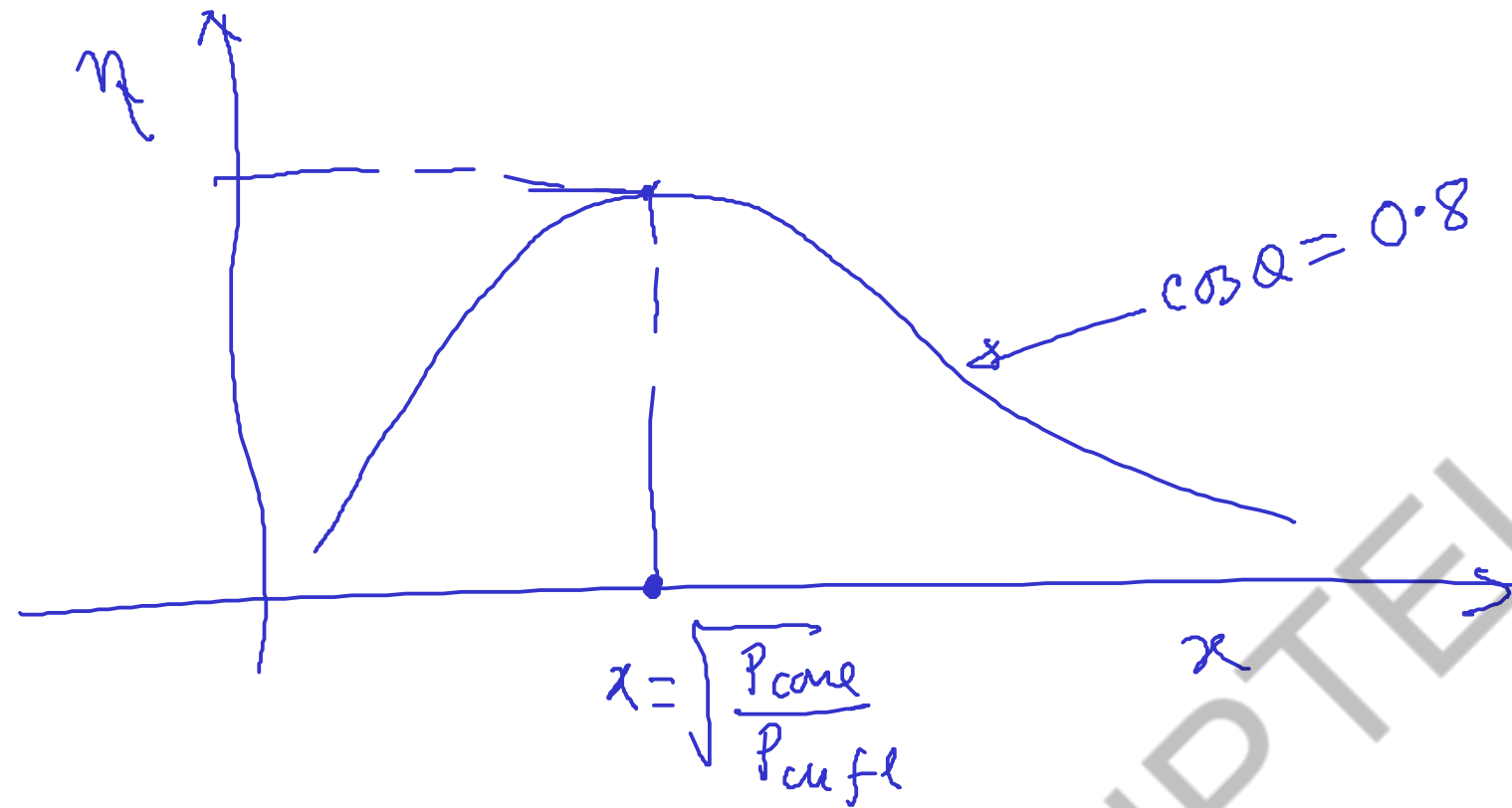
A distribution tfo



Energy efficiency
or "all day efficiency" η
energy

$$= \frac{\text{Energy delivered to load in a day (in 24 hrs)}}{\text{Input Energy over 24 hrs}}$$

Before this is calculated
let us go back to power efficiency expression
once more to highlight another interesting point



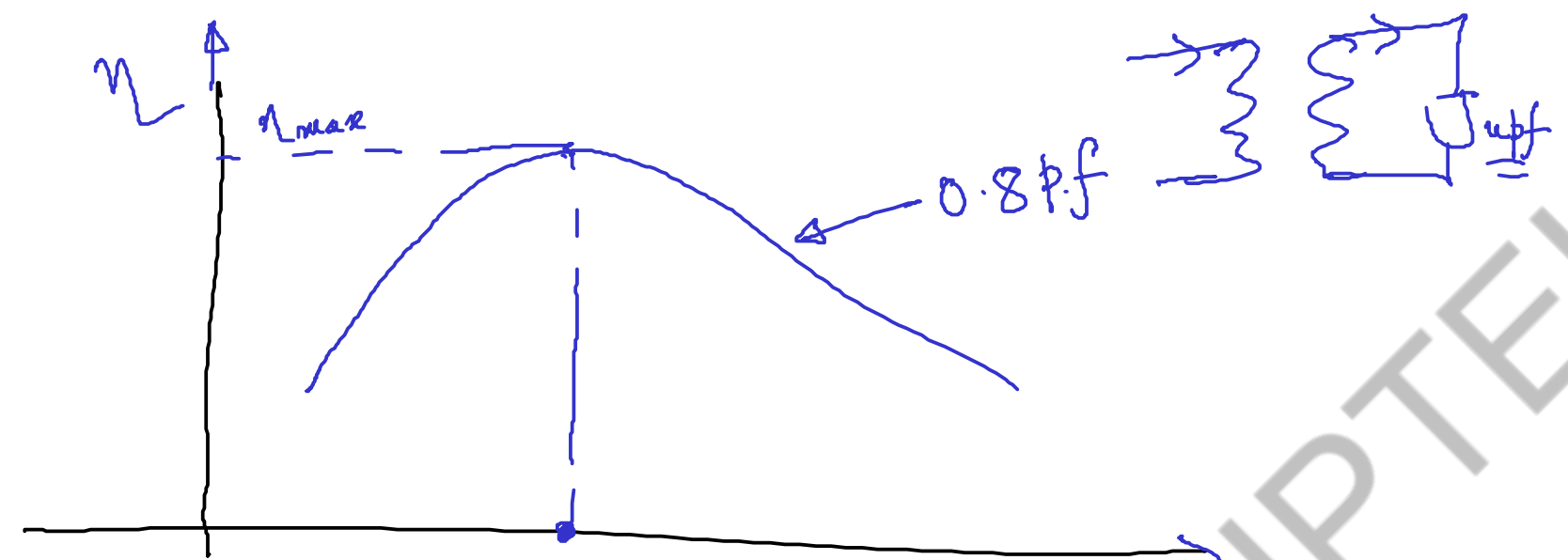
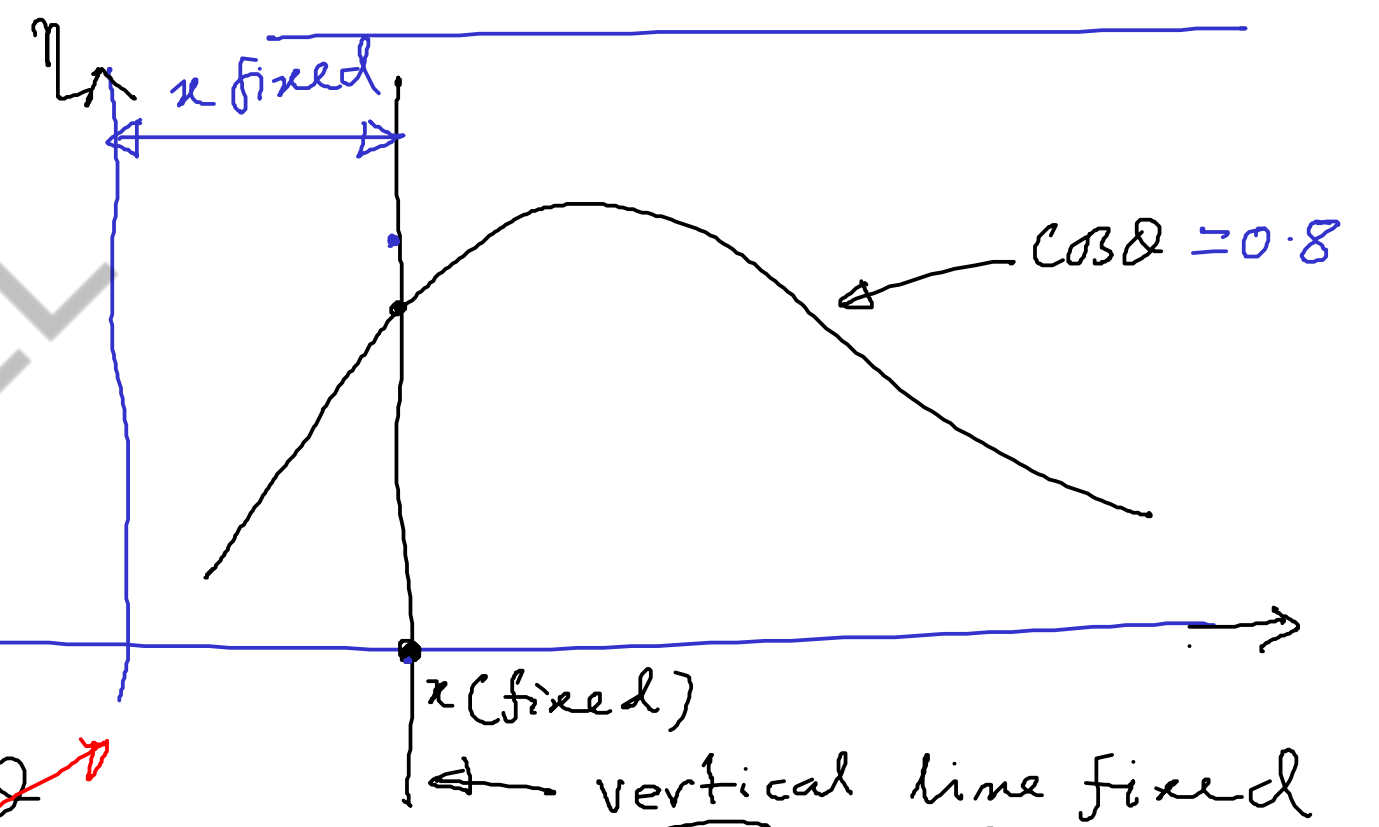
$$\eta_x = \frac{x S \cos \phi}{x S \cos \phi + x^2 P_{cufl} + P_{cone}}$$

What will be plot
of η vs x

if $\cos \phi = \underline{\underline{0.6}}$

$$\eta_x = \frac{xS \cos \theta}{xS \cos \theta + x^2 P_{cufl} + P_{core}}$$

What happens
if $\cos \theta$ also varies



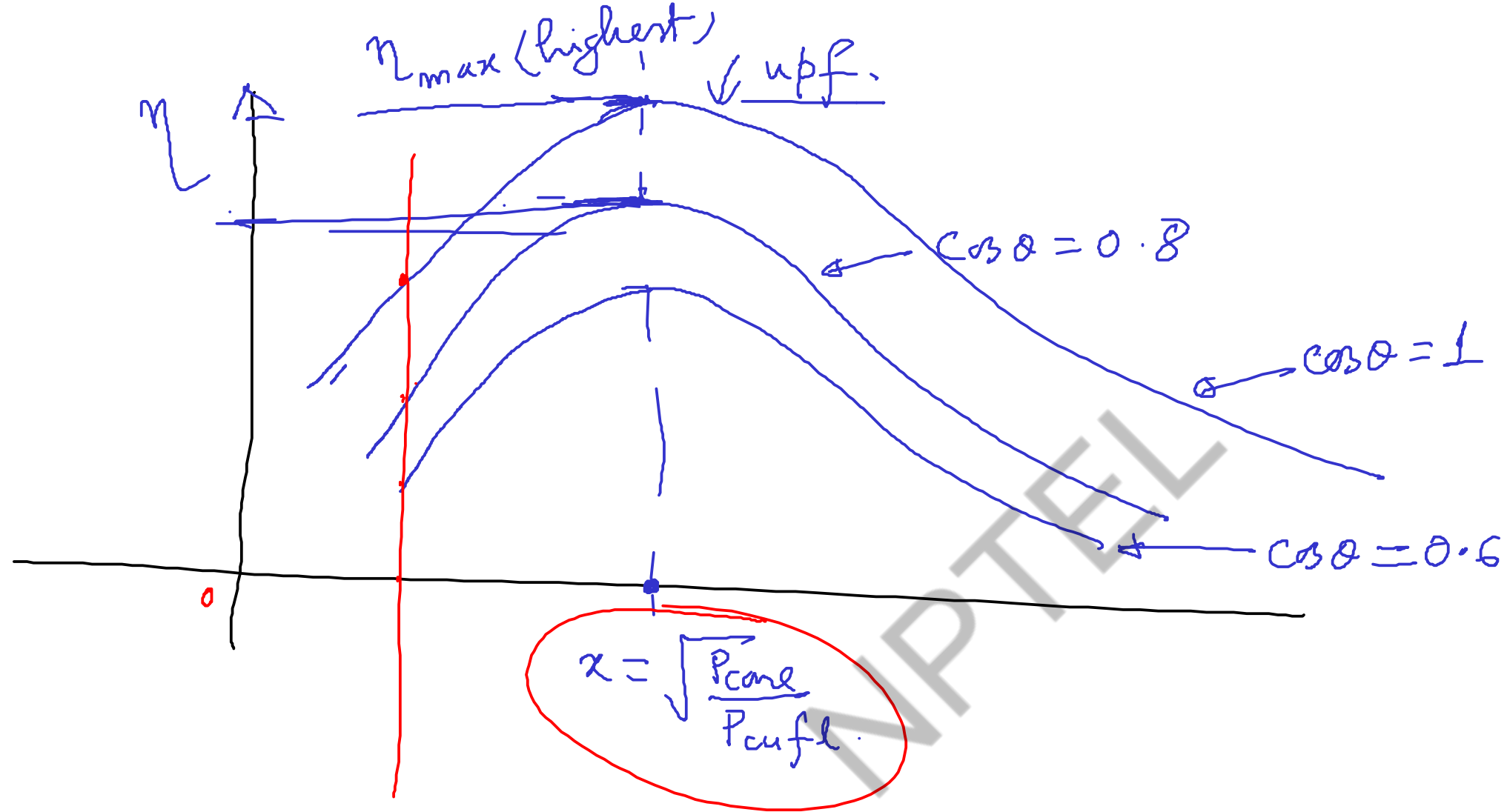
$$\frac{d\eta}{d\theta} = 0$$

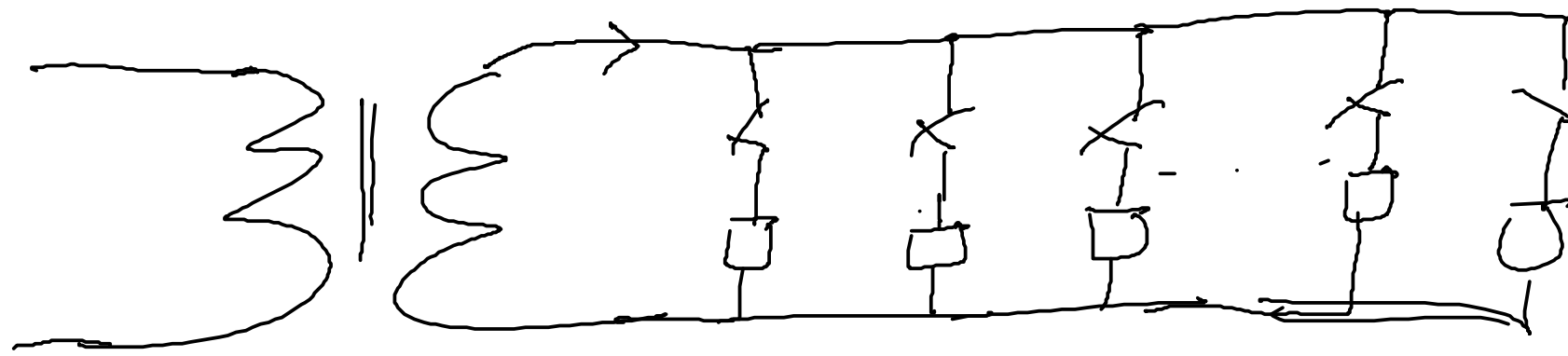
show that η will be max^m

$$\eta = \frac{\cancel{xS \cos \theta}}{\cancel{xS \cos \theta} + \cancel{x^2 P_{cufl}} + P_{core}}$$

fixed fixed fixed

when $\cos \theta = 1$





Energy efficiency
or all day efficiency

distribution
tfo

η
all day

$$= \frac{\text{Energy (kwhr) supplied to load}_{\text{in a day}}^{\text{(over 24 hr)}}}{\text{Input Energy to tfo in a day (over 24 hrs)}}$$



In dist. tfo primary must be kept energised for 24 hrs. $\textcircled{S} \text{KVA} \rightarrow \text{Rated KVA}$

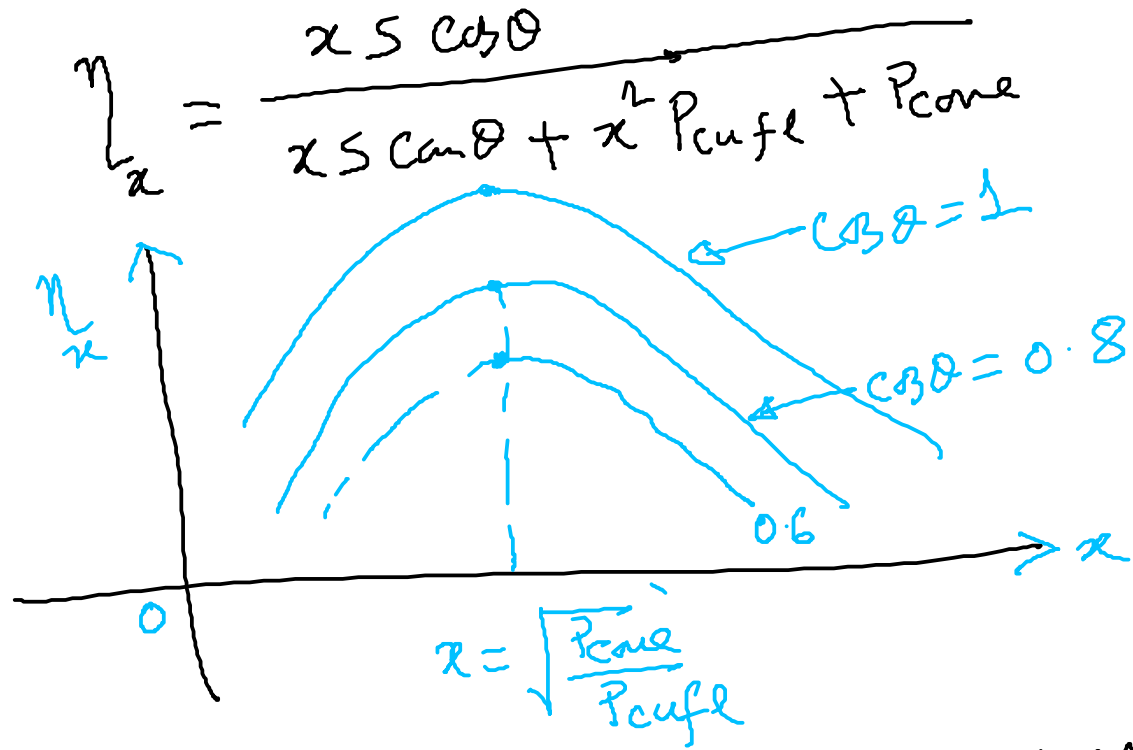
time intervals hrs	distr. tfo deg. of loading	p-f of load	Cu loss	Core loss
T_1	x_1	$\cos \theta_1$	$x_1^2 P_{cufl}$	P_{core}
T_2	x_2	$\cos \theta_2$	$x_2^2 P_{cufl}$	P_{core}
T_3	x_3	$\cos \theta_3$	$x_3^2 P_{cufl}$	P_{core}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
T_n	x_n	$\cos \theta_n$	$x_n^2 P_{cufl}$	P_{core}
$T_1 + T_2 + \dots + T_n$ <u>24 hrs</u>				

$\eta =$
all day efficiency

Energy output
(KWh)

$$\eta = \frac{(x_1 S \cos \theta_1 \times T_1 + x_2 S \cos \theta_2 \times T_2 + \dots + x_n S \cos \theta_n \times T_n)}{(x_1^2 P_{cufl} T_1 + x_2^2 P_{cufl} T_2 + x_3^2 P_{cufl} T_3 + \dots + x_n^2 P_{cufl} T_n) + 24 P_{core} + x_1^2 P_{cufl} T_1 + x_2^2 P_{cufl} T_2 + x_3^2 P_{cufl} T_3 + \dots + x_n^2 P_{cufl} T_n}$$

$$T_1 + T_2 + T_3 + \dots + T_n = 24 \text{ hr}$$

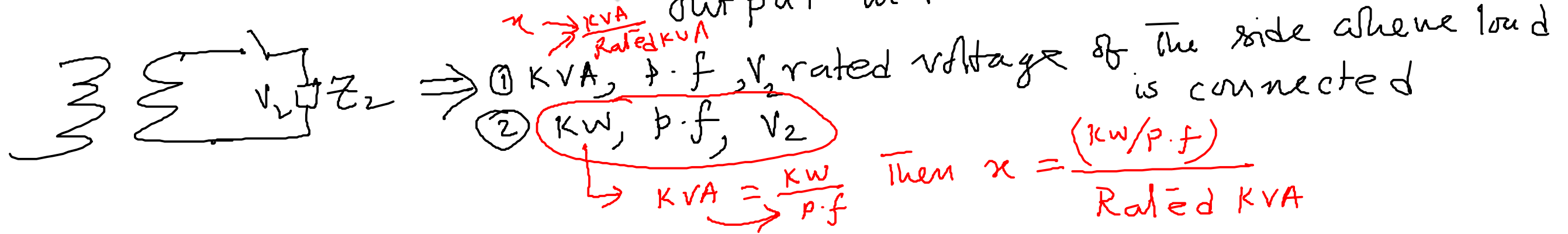


η
all day
(energy)

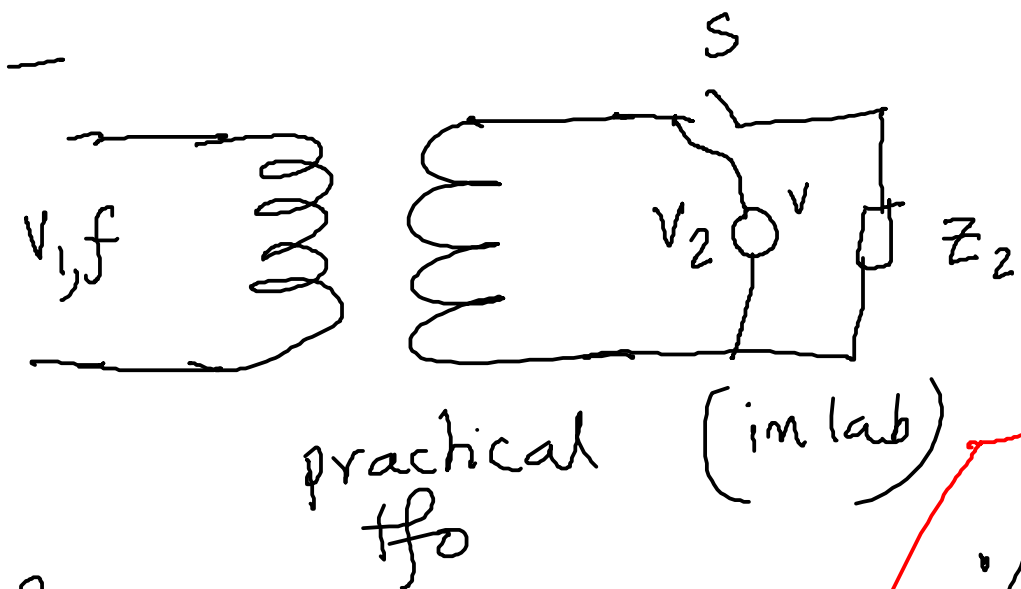
$$= \frac{\sum_{i=1}^N \boxed{x_i} S_i \cos \theta_i T_i}{\sum_i x_i S_i \cos \theta_i T_i + \sum_i x_i^2 \boxed{P_{cufl}} T_i + 24 \boxed{P_{core}}}$$

(kW hr)
(kW hr)
(T₁ + T₂ + ... + T_N = 24)

Loading : $\begin{cases} S \text{ kVA} \\ x = \text{degree of loading } (0 \leq x \leq 1) \end{cases}$
delivering kVA = xS at p.f.



Regulation :-



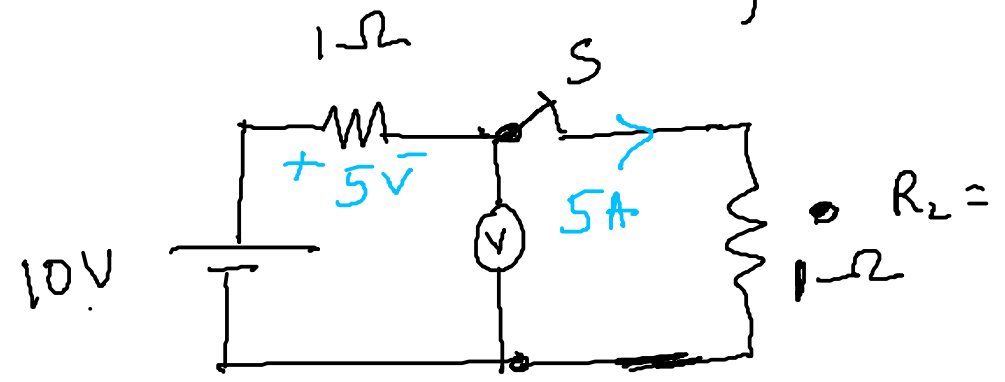
S opened: V_{20} = Reading of voltmeter

for a particular load (Z_2)

close S, V_2 = Reading of voltmeter

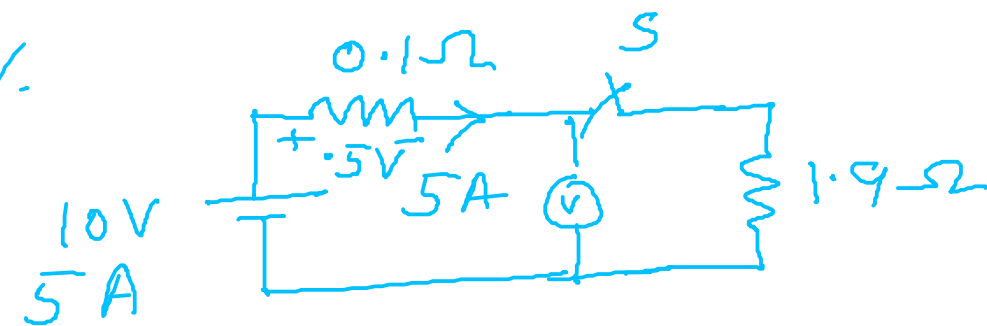
$$\% R = \frac{|V_{20}| - |V_2|}{|V_{20}|} \times 100$$

when load is Z_2



5A
= rated
current
of the battery

$$R = \frac{(10 - 5) \times 100}{10} = 50\%$$

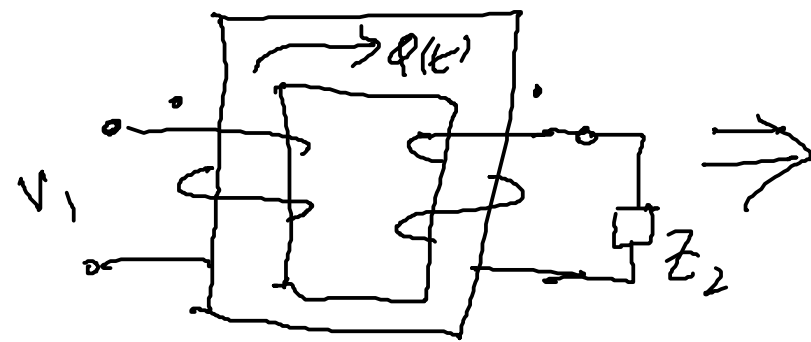
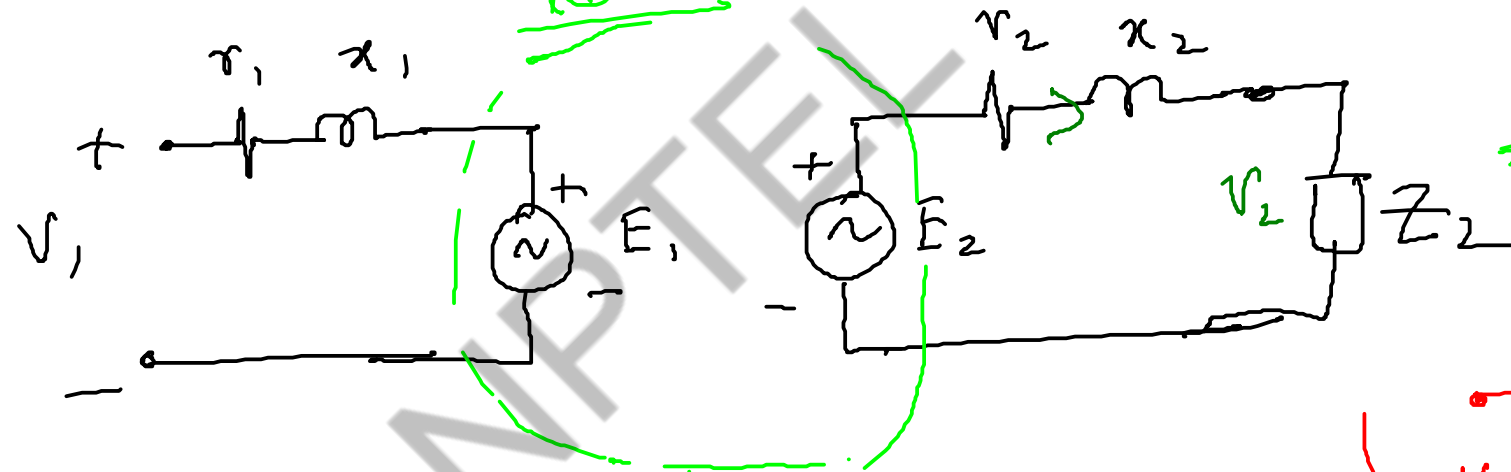
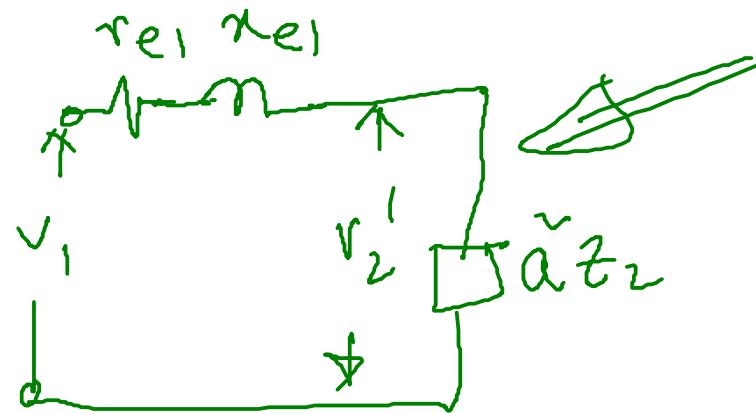
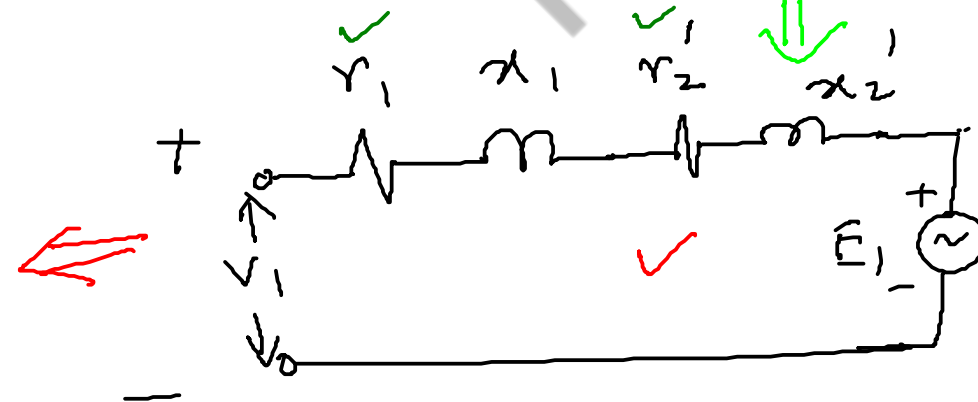
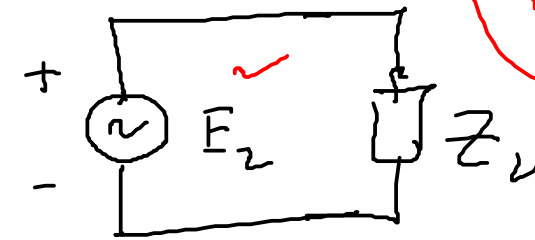
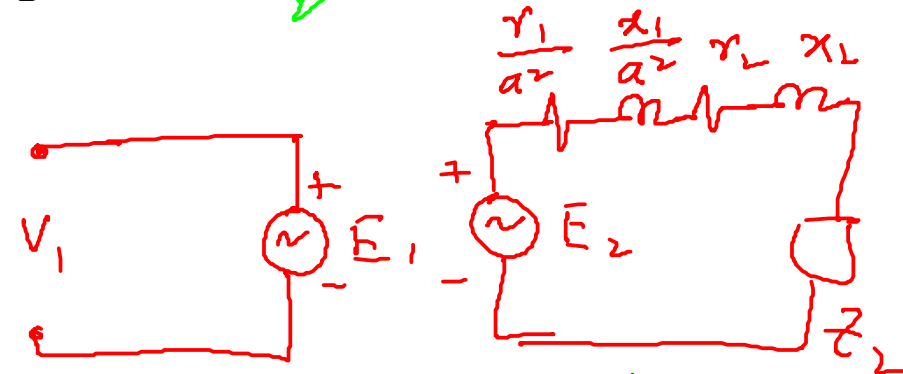


$$\begin{aligned} & \frac{10 - 9.5}{10} \times 100 \\ &= \frac{.5}{10} \times 100 \\ &= 5\% \end{aligned}$$

Regulation :- To obtain an approximate expression for Regulation of a transformer.

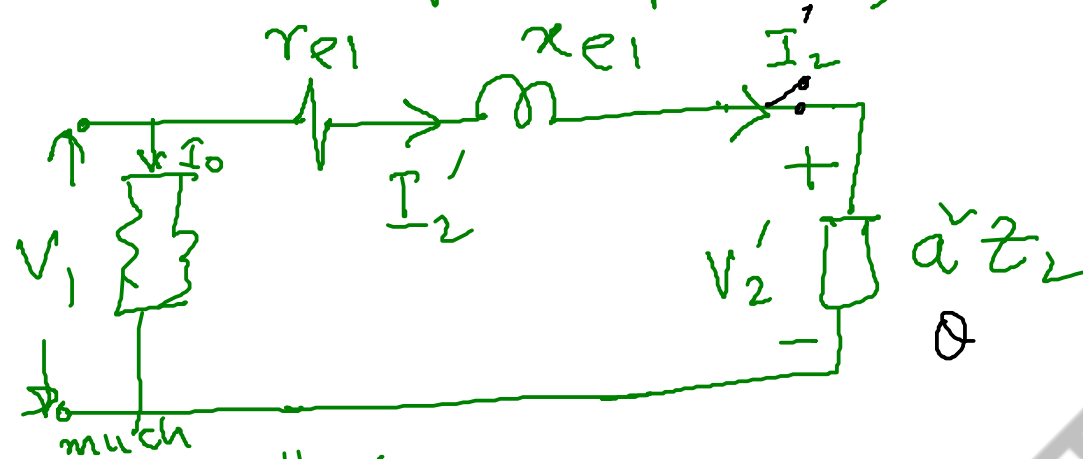
Dec-24

Reviewing quickly the equivalent ckt (approx) A neglect the no load current

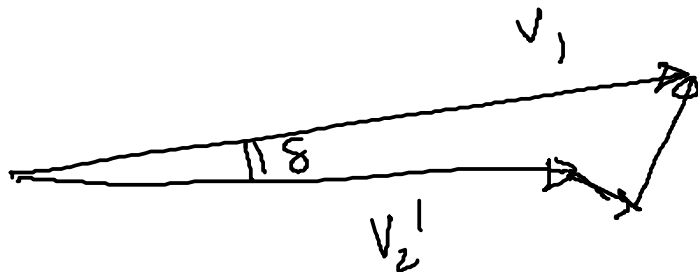
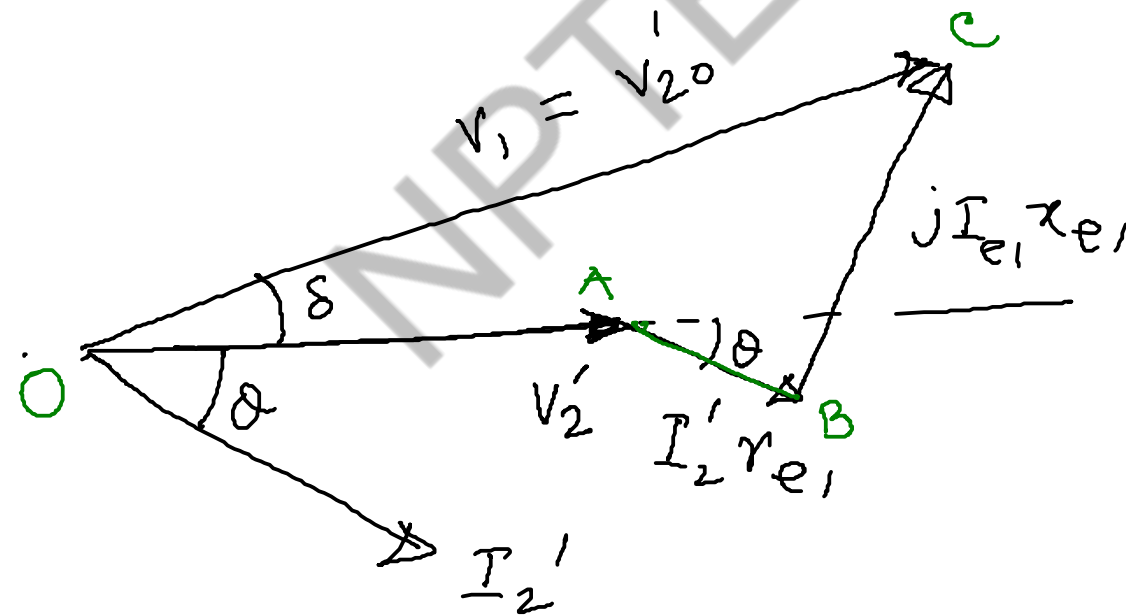


Expression for regulation :-

Equiv. ckt. ref. to primary side



r_{e1}, x_{e1} are much smaller compared to V or V_2' .
Then δ will be also small



$$R = \frac{|V_{20}| - |V_2|}{|V_{20}|}$$

$$= \frac{a|V_{20}| - a|V_2|}{a|V_{20}|}$$

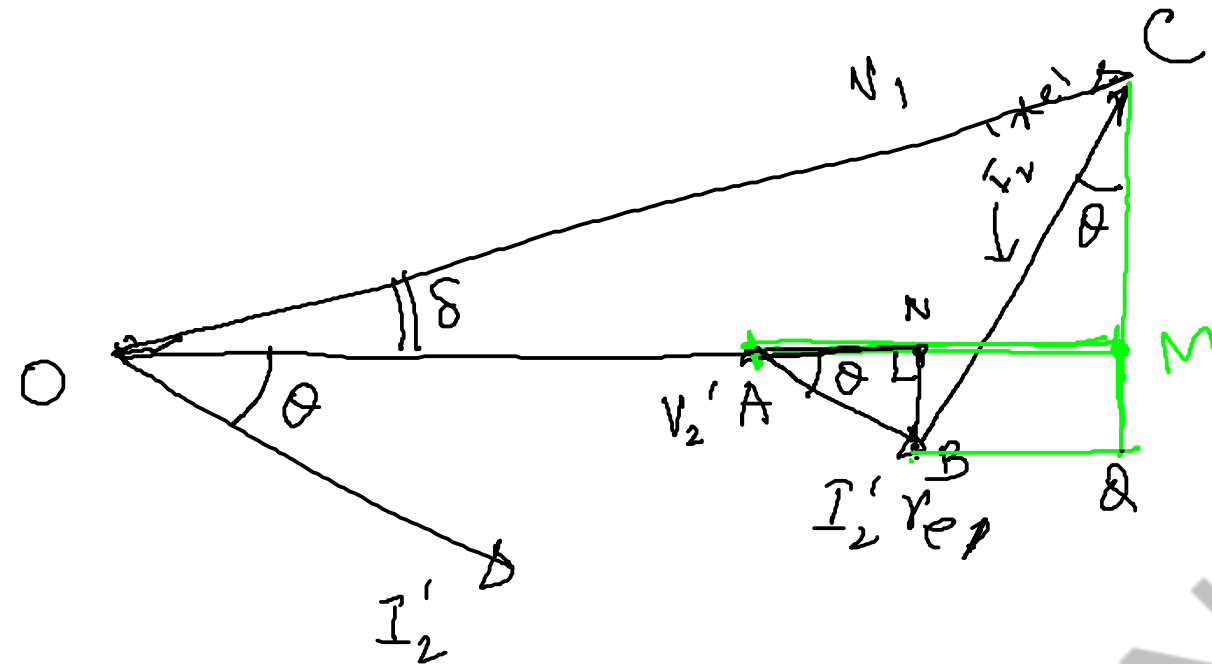
$$= \frac{|V_{20}'| - |V_2'|}{|V_{20}'|}$$

$$= \frac{|V_1| - |V_2'|}{|V_1|}$$

$$= \frac{OC - OA}{OC}$$

$$\frac{N_1}{N_2} = \frac{V_1}{V_2}$$

$$V_{20}' = V_1$$



δ small for a well designed
tfo. $OC \approx OM$

$$Q = \frac{OC - OA}{OC} \approx \frac{AM}{OC}$$

$$OC - OA \approx OM - OA = AM$$

$$\text{now } AM = AN + NM$$

$$= I_2' r_{e1} \cos \theta + B Q$$

$$Q \approx \frac{(I_2' r_{e1} \cos \theta + I_2' x_{e1} \sin \theta)}{|V_1|} \times 100$$

Regulation :-

Note Algebraic equ.

$$R \approx$$

$$\frac{I_2' r_{e1} \cos \theta + I_2' x_{e1} \sin \theta}{|V_1|}$$

for lag. p.f.

$$I_2' \approx I_1$$

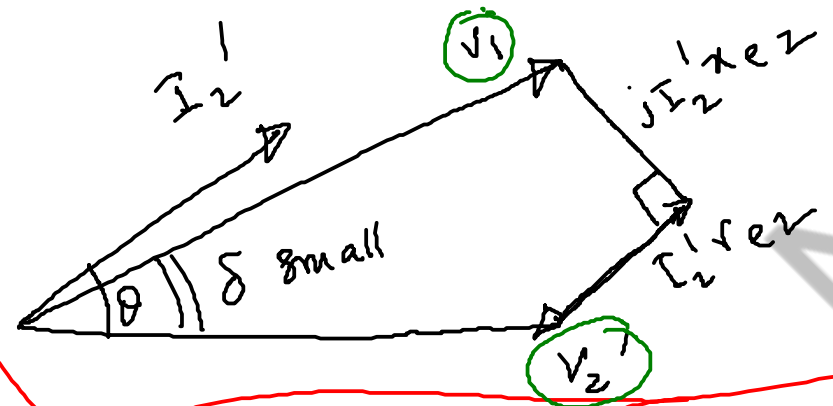
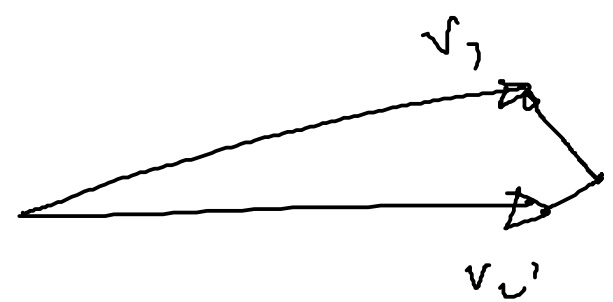
(neglect no load current I_0) $(I_1 = I_0 + I_2')$

$$r_{e1} = r_1 + a^2 r_2$$

$$x_{e1} = x_1 + a^2 x_2$$

$\cos \theta = \text{p.f. of the load}$

$$R = \frac{I_2' r_{e1} \cos \theta \pm I_2' x_{e1} \sin \theta}{|V_1|}$$



+ $\rightarrow$ for lag. p.f.
- for leading p.f.

$$R = \frac{I_2' r_{e1} \cos \theta - I_2' x_{e1} \sin \theta}{|V_1|}$$

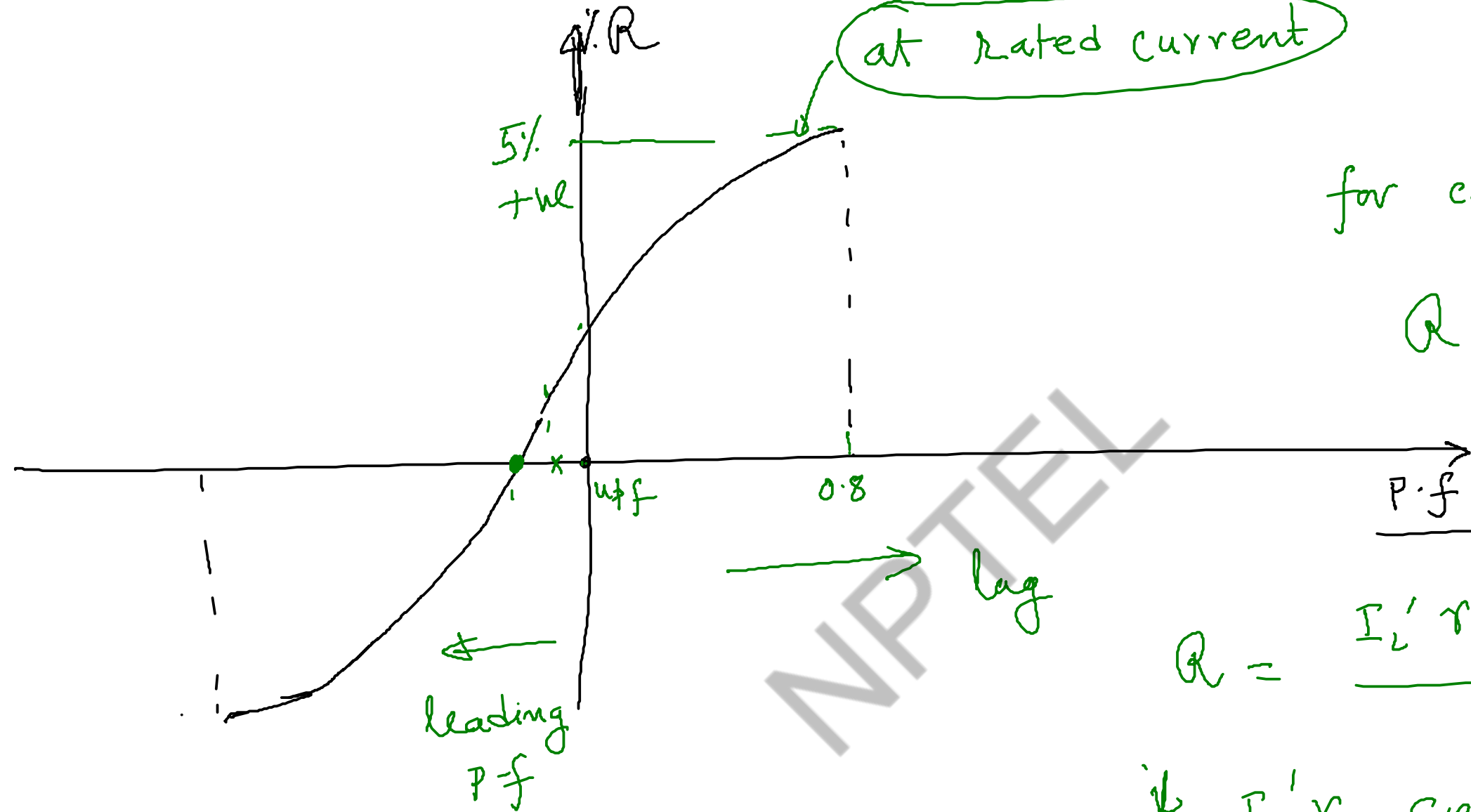
for leading p.f.

$$\% R = \frac{I_2' r_{e1} \cos \theta \pm I_2' x_{e1} \sin \theta}{|V_1|} \times 100$$

$$I_2' = \frac{I_2}{a}$$

$$= \frac{\frac{I_2}{a} (a^2 r_{e2}) \cos \theta \pm \frac{I_2}{a} (a^2 x_{e2}) \sin \theta}{|V_1|}$$

$$= \frac{I_2 r_{e2} \cos \theta \pm I_2 x_{e2} \sin \theta}{\cancel{|V_1|/a}} = \frac{I_2 r_{e2} \cos \theta \pm I_2 x_{e2} \sin \theta}{|V_{20}|}$$



at rated current

for capacitive loading
(leading p.f.)

Q may be -ve



$$Q = \frac{I_2' r_{e1} \cos \theta + I_2' x_{e1}}{|V_1| \text{ finite}} = 0$$

$$\text{if } I_2' r_{e1} \cos \theta + \frac{I_2' x_{e1}}{x \sin \theta} = 0$$

$$\text{or } \tan \theta = -\frac{r_{e1}}{x_{e1}}$$

$$\theta = \tan^{-1} \left(-\frac{r_{e1}}{x_{e1}} \right)$$

$$Q = \frac{\overset{I_1}{\cancel{I_2}''} r_{e1} \cos \phi + \overset{I_1}{\cancel{I_2}'} x_{e1} \sin \phi}{|V_1|} \phi = \underline{2.5\%}$$

at rated current and at 0.8 p.f lag.

$$Q = \frac{I_2' r_{e1}}{|V_1|} \cos \phi + \frac{I_2' x_{e1}}{|V_1|} \sin \phi \rightarrow \text{Algebraic Equn.}$$

p.u resistance

10KVA, $\overset{Pr.}{\downarrow}$ 200V / 100V, 50Hz tfo
50A 100A

$$Q = \overset{r}{\epsilon} \cos \phi + \overset{x}{\epsilon} \sin \phi$$

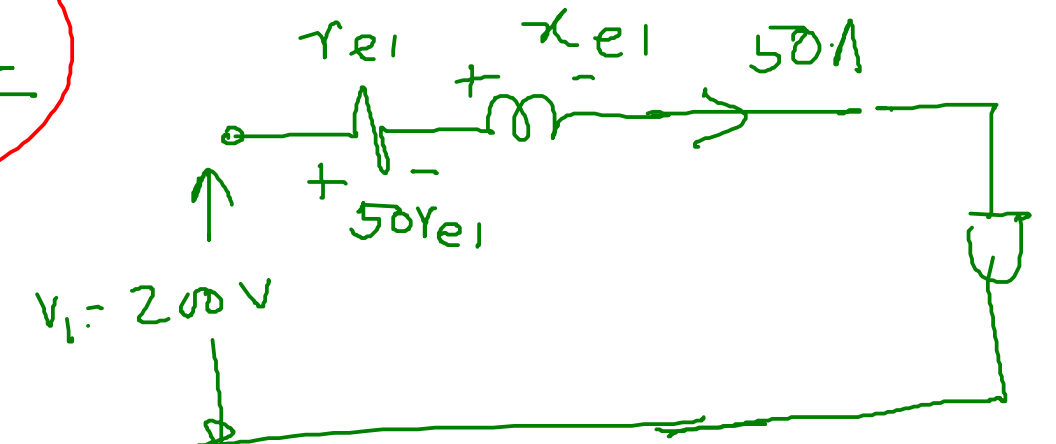
p.u reactance

$$= \frac{I_2' r_{e1}}{200} = \frac{50 \times r_{e1}}{200}$$

resistive

$$\frac{I_2' x_{e1}}{500} =$$

voltage drop in the tfo ref. to pr. side
leakage reactance voltage drop in tfo ref. to pr side



$$10 \text{ kVA}, \quad 200 \text{ V} / 100 \text{ V} \\ 50 \text{ A} \quad 100 \text{ A}$$

$$Q = E_r \cos \theta \pm E_x \sin \theta$$

$$r_{e1} = 2\%$$

$$r_{e1} \text{ p.u.} = .02$$

$$\text{p.u. leakage impedance} = \frac{I_2' Z_{e1}}{V_1}$$

$$Z_{e1} = \sqrt{r_{e1}^2 + x_{e1}^2}$$

$$\frac{50 \times r_{e1}}{200} = .02$$

$$\frac{100 \times r_{e2}}{100} = .02 \quad \checkmark$$

$$r_{e1} (\text{pu}) = \frac{I_2' r_{e1}}{V_1} = \frac{I_1 r_{e1}}{V_1} = \frac{I_1^2 r_{e1}}{V_1 I_1} = \frac{C_u \text{ loss}}{\text{kVA}}$$