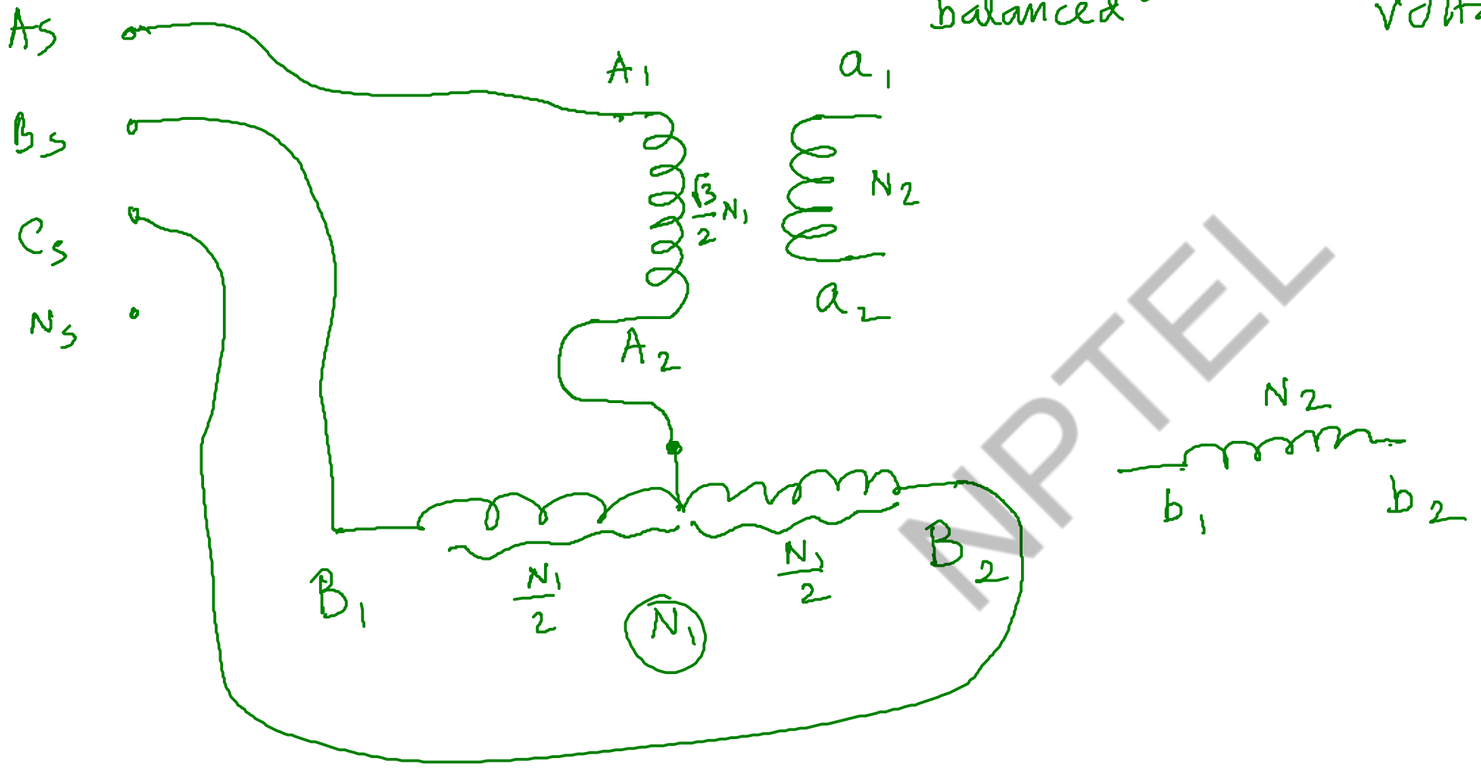
Phase conversion :

Scott connection : uses Two nos of 1-ph. tfo

3 ph voltage balanced ⟶ 2 ph. balanced voltage.

Dec 45



primary turns of tfo B = N_1

Then primary turns of tfo A = $\frac{\sqrt{3}}{2} N_1$

Volt per turn of tfo B = $\frac{V_{LL}}{N_1}$

$$|V_{b_1 b_2}| = \frac{V_{LL}}{N_1} \times N_2$$

$$= \frac{N_2}{N_1} V_{LL}$$

NPTEL

$a_A = \frac{\sqrt{3}\,N_1}{2\,N_2}$

$A_1O \equiv V_{LL}\frac{\sqrt{3}}{2}$

$\therefore$ voltage/turn of ffo B $= \frac{V_{LL}\sqrt{3}/2}{\sqrt{3}/2\,N_1} = \frac{V_{LL}}{N_1}$

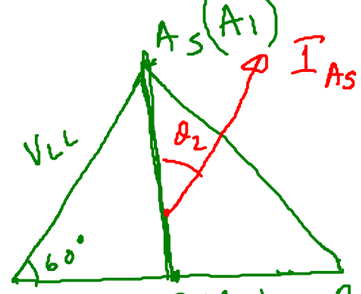
voltage/turn must be same for ffo A and ffo B $= \frac{V_{LL}}{N_1}$

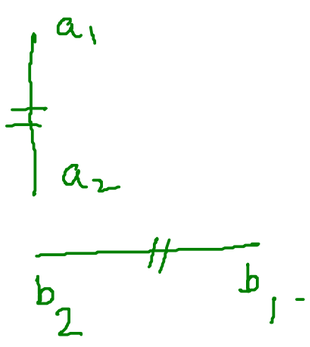
$I_{AS} = \frac{2\,N_2}{\sqrt{3}\,N_1} I_a$

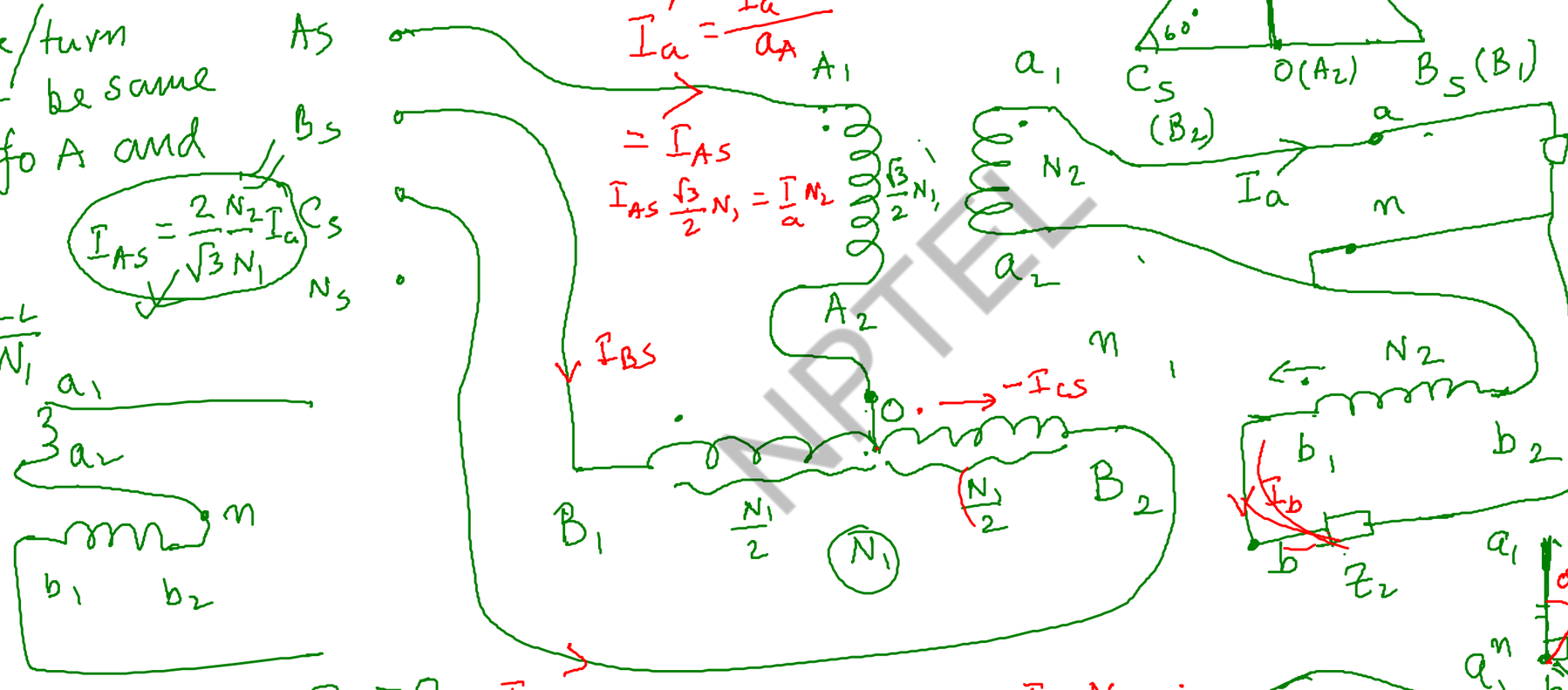
$I_a' = \frac{I_a}{a_A}$

$= I_{AS}$

$I_{AS}\frac{\sqrt{3}}{2}N_1 = I_a N_2$







length of a_1a_2 & b_1b_2 $= \frac{V_{LL}}{N_1}N_2$

$I_{AS} + I_{BS} + I_{CS} = 0$

or $I_{BS} + I_{CS} = -I_{AS}$

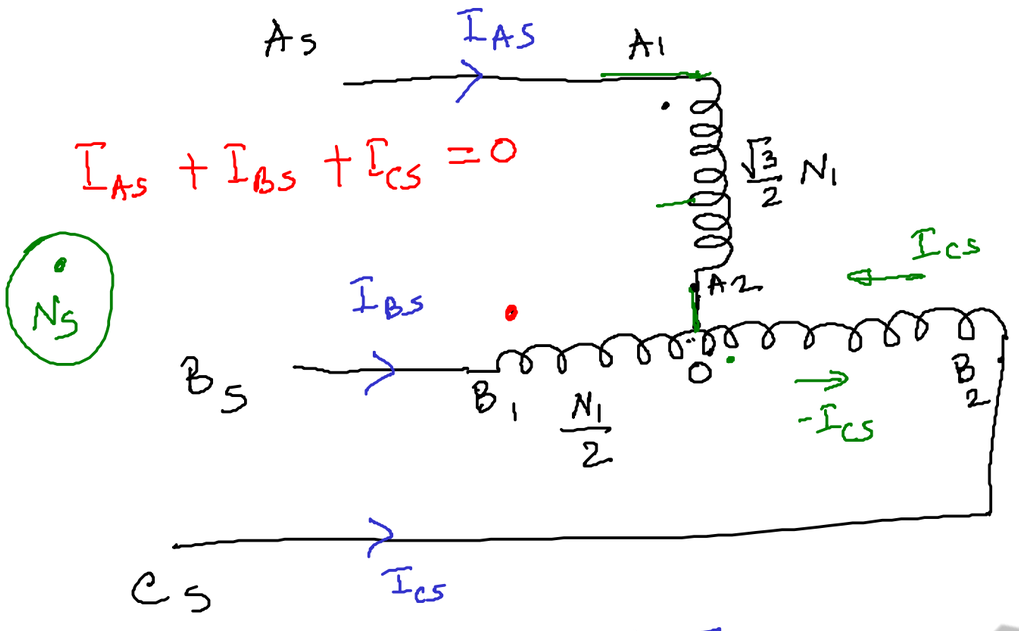
$I_{BS}\frac{N_1}{2} + (-I_{CS})\frac{N_1}{2} = I_b N_2$

or $I_{BS} - I_{CS} = I_b \frac{N_2 2}{N_1}$ (1)

NPTEL

Scott connection

Lec 46

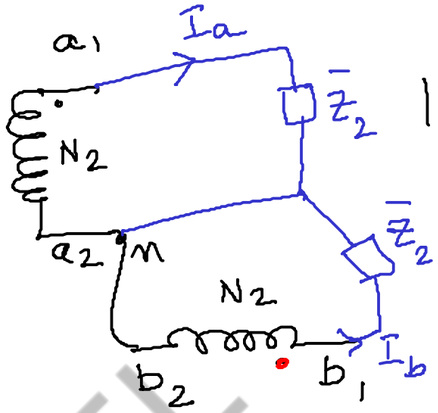


$$I_{AS} + I_{BS} + I_{CS} = 0$$

$$I_{AS}\frac{\sqrt{3}}{2}N_1 = N_2 I_a$$

$$\therefore I_{A_{AS}} = \frac{2N_2}{\sqrt{3}N_1} I_a$$

$$I_{BS}\frac{N_1}{2} + (-I_{CS})\frac{N_1}{2} = N_2 I_b$$



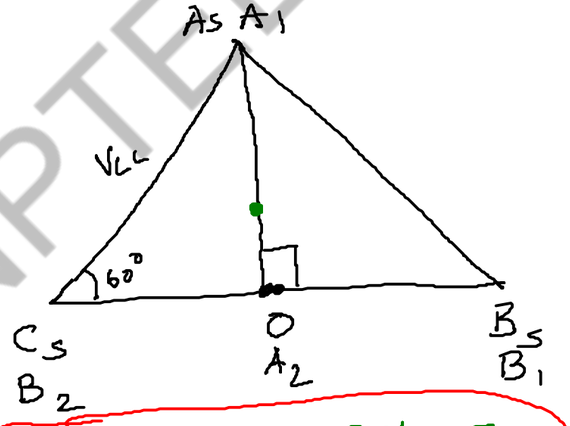
$$|V_{b_1b_2}| = \frac{V_{LL}N_2}{N_1}$$

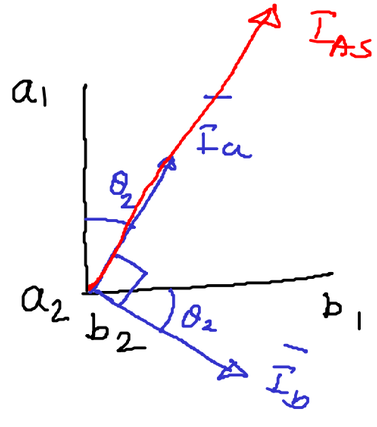
$$|V_{a_1a_2}| = \frac{V_{LL}\frac{\sqrt{3}}{2}N_2}{\frac{\sqrt{3}}{2}N_1} = \frac{V_{LL}N_2}{N_1}$$

$$N_{B_1B_2} = N_1$$

$$N_{A_1A_2} = \frac{\sqrt{3}}{2}N_1$$

$$N_{B_1O} = N_{B_2O} = \frac{N_1}{2}$$





$$\therefore \begin{cases} I_{BS} - I_{CS} = \frac{2N_2}{N_1} I_b \\ I_{BS} + I_{CS} = -I_{AS} \end{cases}$$

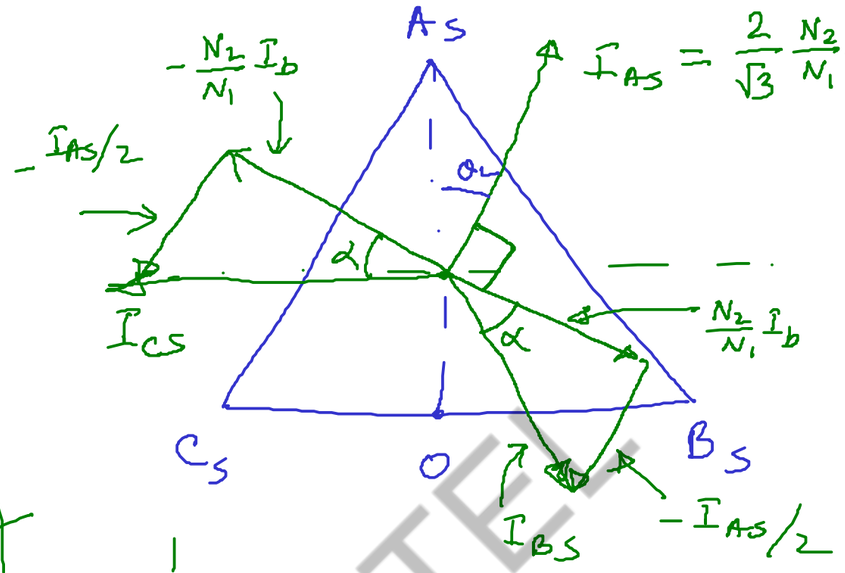
$$\Rightarrow \begin{aligned} I_{BS} &= -\frac{I_{AS}}{2} + \frac{2N_2}{2N_1} I_b \\ I_{CS} &= -\frac{I_{AS}}{2} - \frac{2N_2}{2N_1} I_b \end{aligned}$$

NPTEL

$$I_{BS} = -\frac{I_{AS}}{2} + \frac{N_2}{N_1} I_b$$

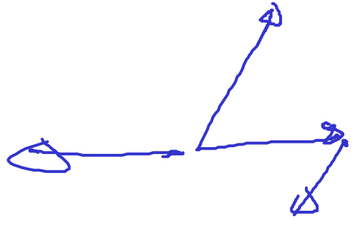
$$I_{CS} = -\frac{I_{AS}}{2} - \frac{N_2}{N_1} I_b$$

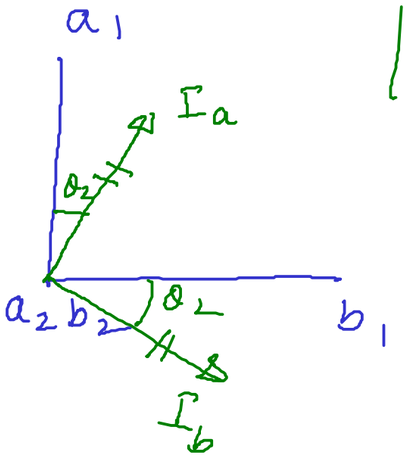
$$\therefore I_{A_{AS}} = \frac{2 N_2}{\sqrt{3} N_1} I_a$$



$$\tan\alpha = \frac{\frac{1}{2}\frac{2}{\sqrt{3}}\frac{N_2}{N_1}|I_a|}{\frac{N_2}{N_1}|I_b|} = \frac{1}{\sqrt{3}} \quad \therefore \alpha = 30^\circ$$

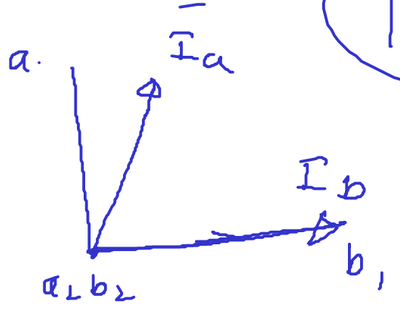
with unbalanced load on 2ndary side:



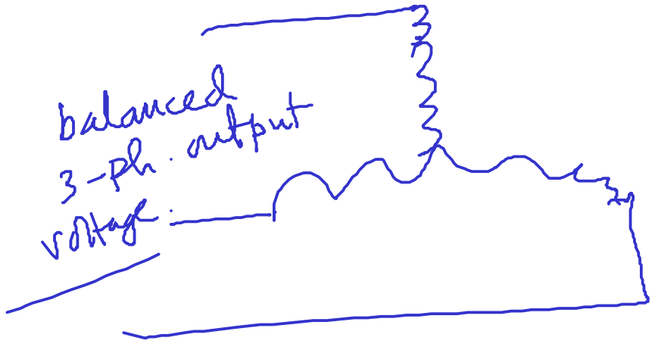


$$|I_a| = |I_b|$$

$$|I_a| = |I_b|$$



NPTEL

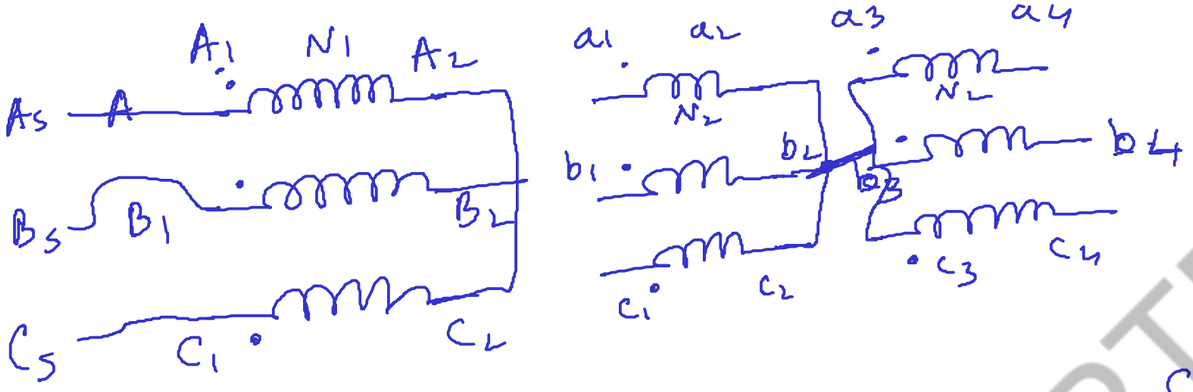


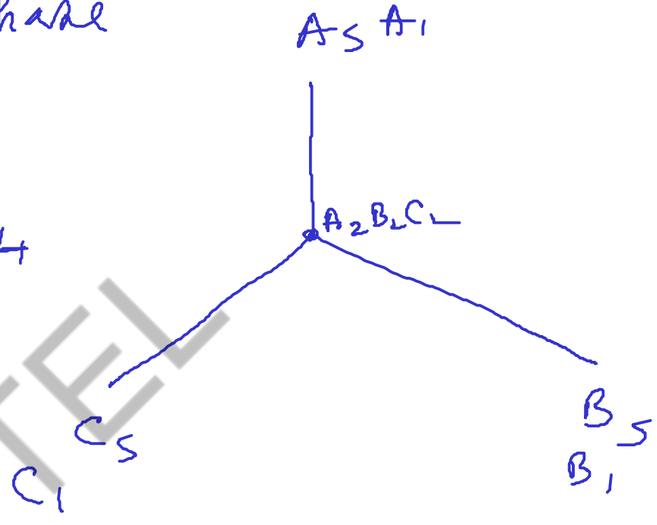
NPTEL

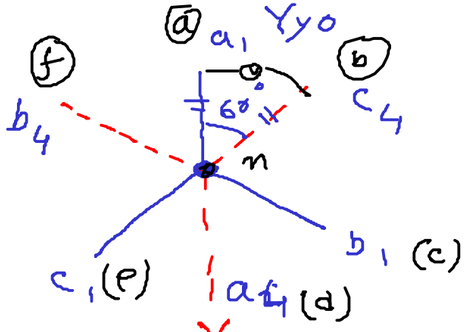
Phase conversion

- 3 phase to 2 phase (Scott connection)
- 3 phase to 6 phase

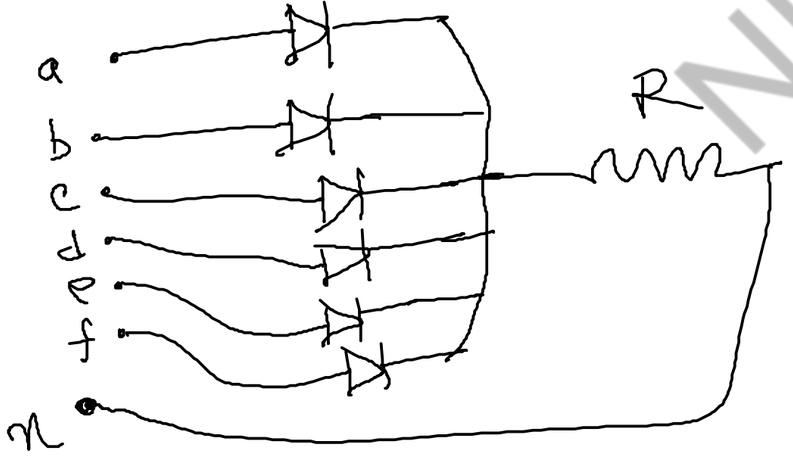
Lec 47

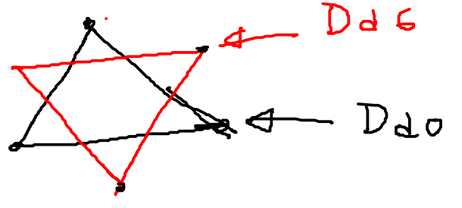


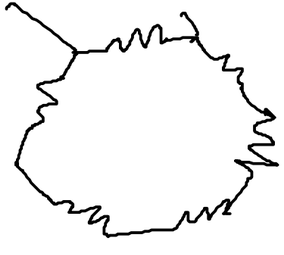




Yy6
balanced
6-ph.
voltage







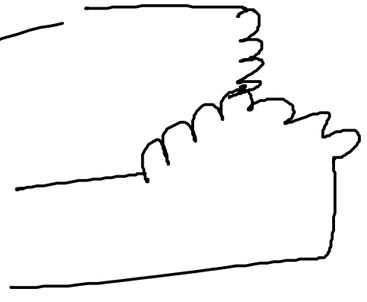
NPTEL

30 KVA, 400 V / 200 V, 3 ph, 50 Hz, tfo

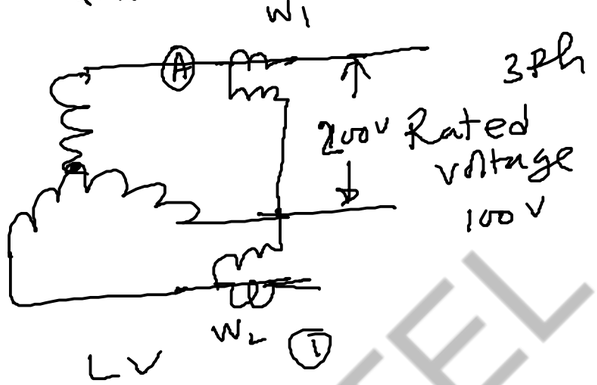
l-l l-l

per phase Equivalent ckt.

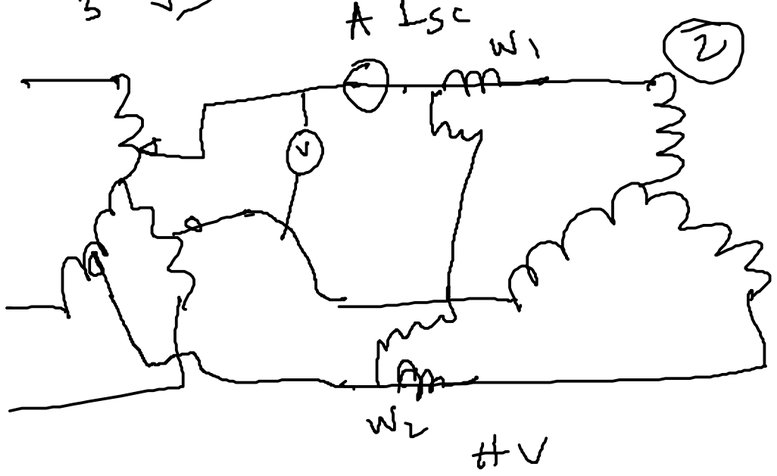
O.C



HV



3-ph variac

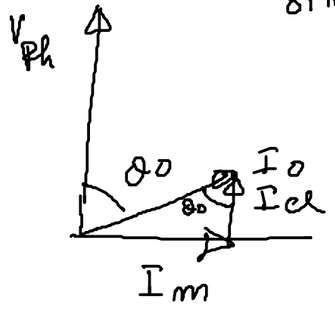


I_0, W_0, V $= W_1 + W_2$

$\sqrt{3} \times 200\, I_0 \cos\theta_0 = W_0$

$\cos\theta_0$ ✓

$\sin\theta_0$ ✓



$I_{cl} = I_0 \cos\theta_0$

$I_m = I_0 \sin\theta_0$

$R_{cl1} = \frac{V}{I_{cl}}$

$X_{m1} = \frac{V}{I_m}$

$I_{HV\,rated} = \frac{30000}{\sqrt{3} \times 400} \approx 43A$

$W_1 + W_2 = \text{Cu-loss} = 3 I_{sc}^2 r_{e2} = W_{sc}$

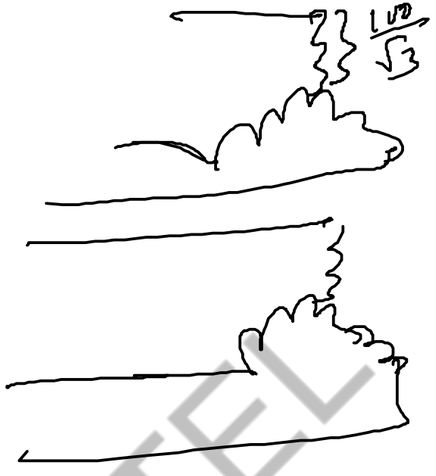
r_{e2} ✓ r_{e2} ✓

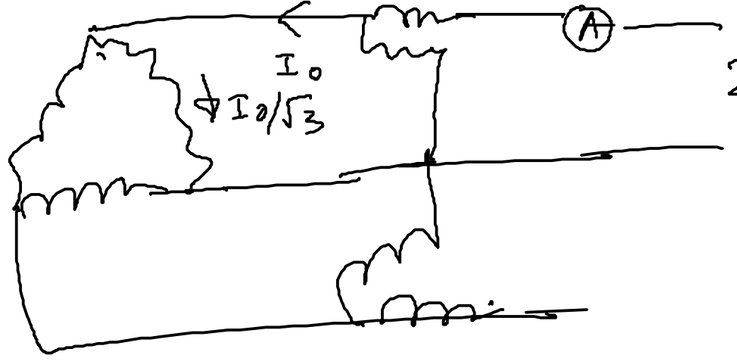
$Z_{e2} = \frac{V_{sc}}{\sqrt{3}\, I_{sc}}$

$x_{e2} = \sqrt{Z_{e2}^2 - r_{e2}^2}$

NPTEL

30 KVA, 400V/200V,





O-C

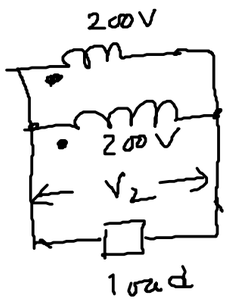
$$\frac{(W_1 + W_2)}{3} = 200\left(\frac{I_0}{\sqrt{3}}\right)\cos\theta_0$$

NPTEL

Parallel operation of transformers

Lec-48

400V/200V, 1ph tfo 50Hz 100KVA trf A.
50KVA trf B

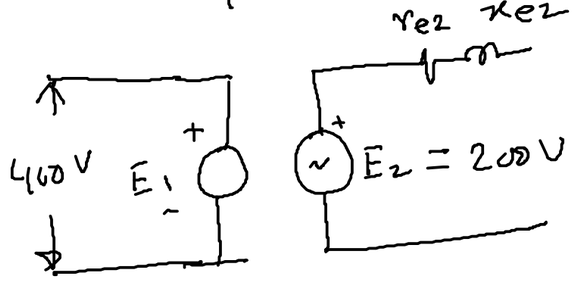


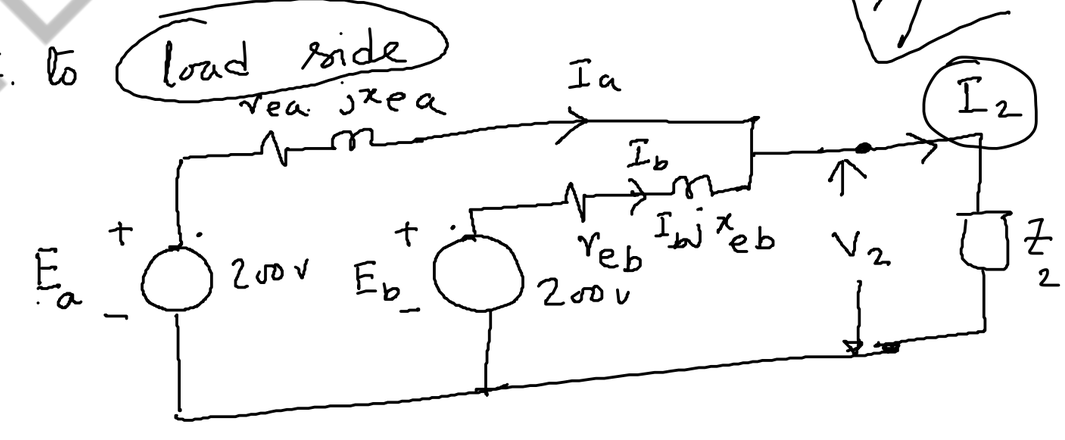
400V/200V,

3ph, 6.6 KV/440 V, 50Hz, 150KVA

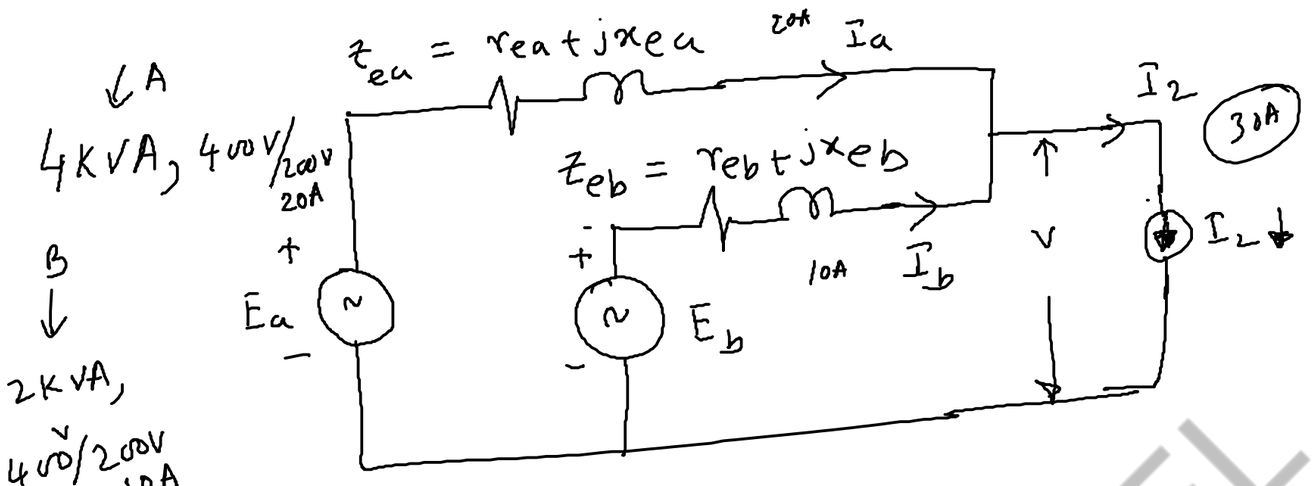
✓ Polarity must be same while connecting tfo in parallel

Equivalent circuit ref. to load side

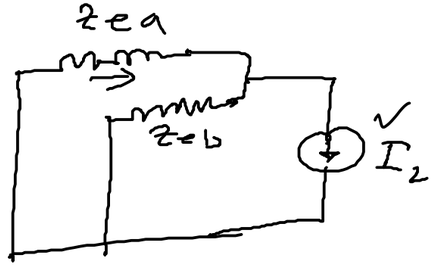




NPTEL



Suppose load current $\underline{I_2}$ is known



$$\underline{I_a} = \frac{E_a - E_b}{Z_{ea} + Z_{eb}} + I_2 \frac{Z_{eb}}{Z_{ea} + Z_{eb}}$$

$$\underline{I_b} = \frac{E_b - E_a}{Z_{ea} + Z_{eb}} + I_2 \frac{Z_{ea}}{Z_{ea} + Z_{eb}}$$

In case $\underline{E_a = E_b}$

$$\underline{I_a} = \frac{Z_{eb}}{Z_{ea} + Z_{eb}} I_2$$

$$\underline{I_b} = \frac{Z_{ea}}{Z_{ea} + Z_{eb}} I_2$$

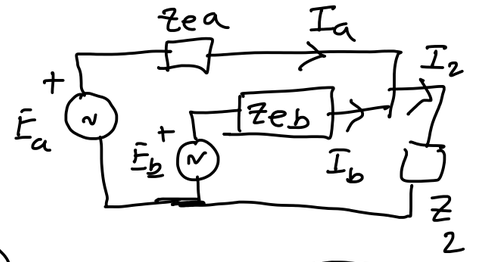
$$\frac{\underline{I_a}}{\underline{I_b}} = \frac{Z_{eb}}{Z_{ea}}$$

— o —

NPTEL

Lec-49

$$\frac{I_a}{I_b} = \frac{Z_{eb}}{Z_{ea}} \Rightarrow \frac{|I_a|}{|I_b|} = \frac{|Z_{eb}|}{|Z_{ea}|} = \frac{2}{1}$$



transformer A : 400V/200V, 50Hz, 4 KVA (10A / 20A)

B : 400V/200V, 50Hz, 2 KVA (5A / 10A)

$E_a = E_b = 200\,V$

current shared by transformer $\propto \frac{1}{\text{leakage impedance}}$

$\therefore |Z_{eb}| = 2|Z_{ea}|$

$I_2 : I_a : I_b = 3 : 2 : 1$

$I_2 = 30A$, $I_a = 20A$, $I_b = 10A$

$\frac{I_a}{I_b} = \frac{2}{1}$

$\frac{|Z_{eb}|}{|Z_{ea}|} = \frac{1}{2}$

Transformer leakage impedance $\propto \frac{1}{KVA}$

NPTEL

$$Z_{ea} = r_{ea} + jx_{ea} \quad | \quad Z_{eb} = r_{eb} + jx_{eb}$$

$$|Z_{ea}| = \sqrt{r_{ea}^2 + x_{ea}^2} \qquad |Z_{eb}| = \sqrt{r_{eb}^2 + x_{eb}^2}$$

$$Z_e \propto \frac{1}{S}$$

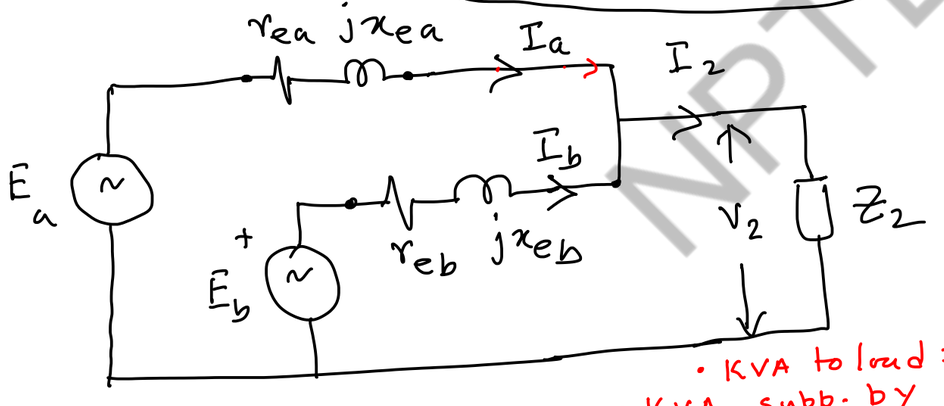
$$|Z_{ea}| = K \frac{1}{S_a}$$

$$|Z_{eb}| = K \frac{1}{S_b}$$

Quality of the leakage impances.

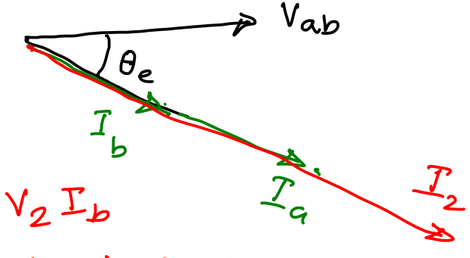
If $\frac{x_{ea}}{r_{ea}} = \frac{x_{eb}}{r_{eb}}$

$$\tan^{-1}\frac{x_{ea}}{r_{ea}} = \tan^{-1}\frac{x_{eb}}{r_{eb}} = \theta$$



$E_a = E_b$

voltage across Z_{ea} = $E_a - E_2$ = voltage across Z_{eb} = V_{ab}



- KVA to load = $V_2 I_2$
- KVA supp. by trf A = $V_2 I_a$
- KVA supp. by trf B = $V_2 I_b$

$V_2 I_a + V_2 I_b = V_2 I$ ← algebraic sum.

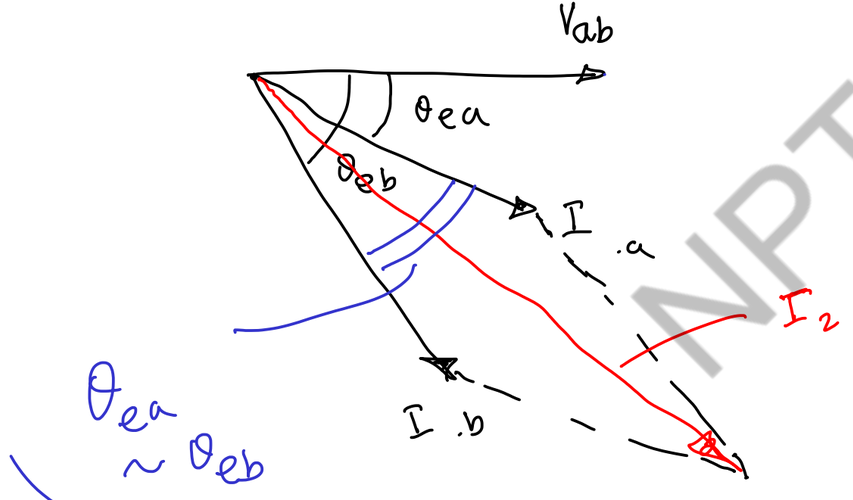
NPTEL

Suppose $\tan^{-1}\frac{x_{ea}}{r_{ea}} = \theta_{ea} \neq \tan^{-1}\frac{x_{eb}}{r_{eb}} = \theta_{eb}$

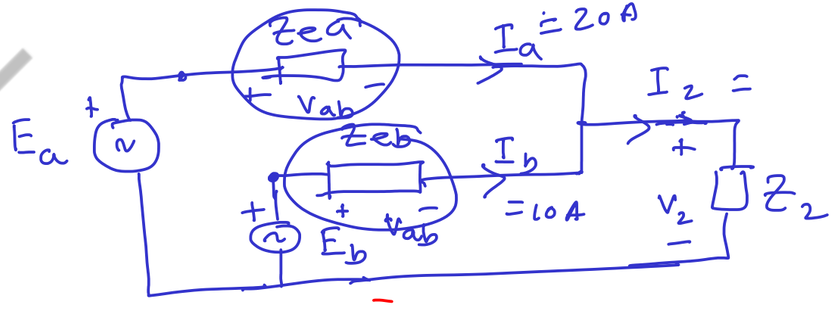
but $Z_e \propto \frac{1}{s}$

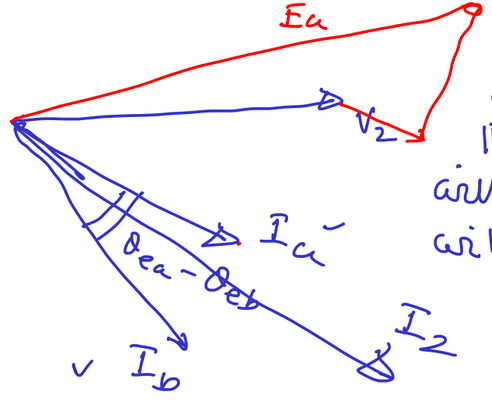
$$\frac{|I_{ea}|}{|I_{eb}|} = \frac{|Z_{eb}|}{|Z_{ea}|}$$

$$I_2 = I_{ea} + I_{eb}$$



$\theta_{ea} \sim \theta_{eb}$





Power factors at which the transformers will operate will be different

NPTEL

leakage impedance (Ω) of tfo $\propto \frac{1}{S}$

→ p.u values of the leakage impedance should be same

p.u value of leakage imp. of tfo A

$$\frac{|I_a|\,|Z_{ea}|}{V_2} = Z_{p.u\,(a)}$$

p.u value of leakage impedance of tr B.

$$\frac{|I_b|\,|Z_{eb}|}{V_2} = Z_{pu\,(b)} .$$

NPTEL

for successful & effective parallel operation of transformers

1. Voltages of HV & LV side should be same. (for 3 ph l-l voltage ratings should be same)
2. $Z_e \propto \frac{1}{S}$ or $Z_{p.u}$ of the tfo should be same
   (Z_e → leakage impedance)
3. The qualities of the leakage impedances should be same ⇒ tfo. will operate at same p.f.
4. The transformers must belong to same vector group.

3-ph. tfo →

Dy1 Yd1 Yz1

NPTEL

Small transformers few KVAs
200V/100V, 50Hz

1-ph. tfo

$$V_1 \approx E_1 = 4.44 f \Phi_{max} N_1$$

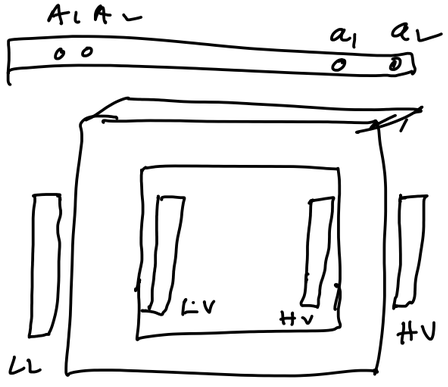
- specific magnetic loading (B_{max}) Tesla
- specific electric loading

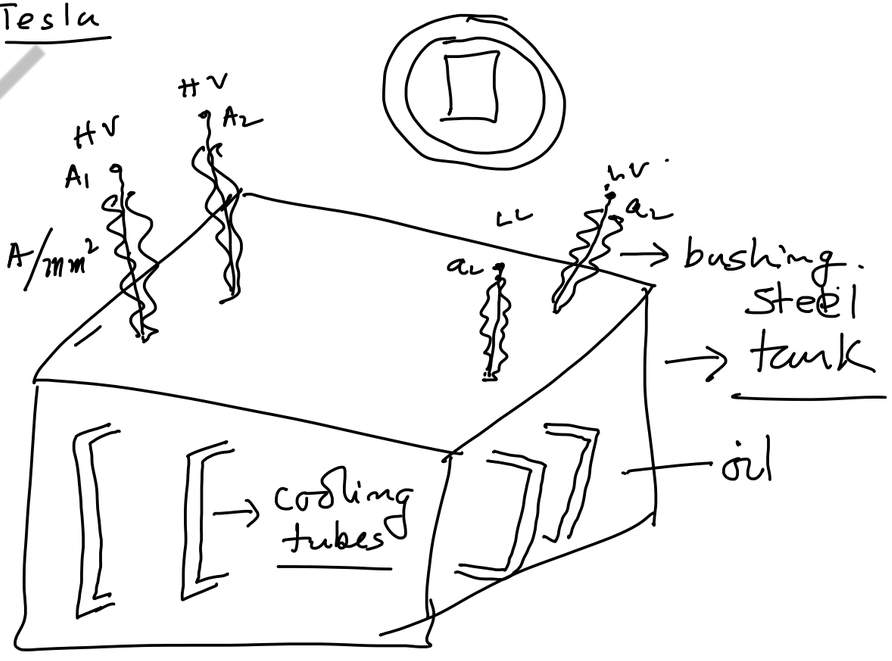
δ = current density of Cu (or Al) 2.5 to 3 A/mm²

LV side a_1 = cross section of wire
HV side a_2 = " " " of wire

δ = same both for LV & HV side.

Let I_1 be the current rating of side 1, (LV side) $I_1 = \delta a_1$
HV side (rated) $I_2 = \delta a_2$





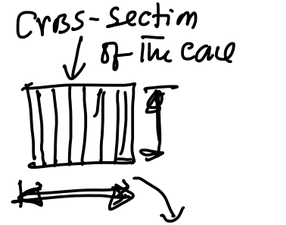
NPTEL

1 ph. tfo

$$S \simeq 4.44 f \varphi_{max} N_1 I_1 \times 10^{-3}$$

$B_{max} \simeq 1\ T$

$\delta = 2.5$ to $3\ A/mm^2$



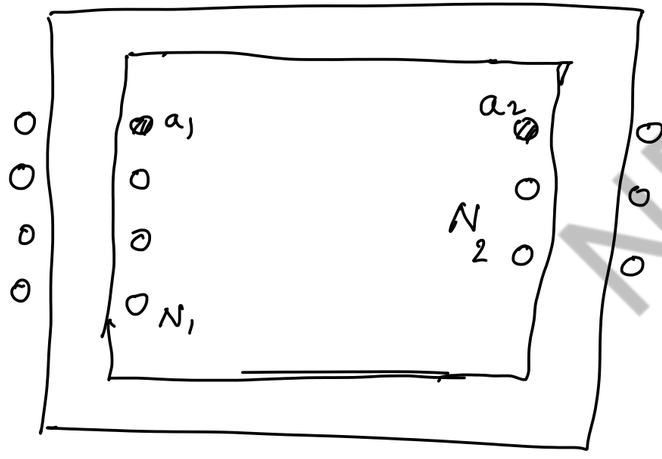
$$= 4.44 f B_{max} A_{i\,(net)} N_1 \delta a_1 \times 10^{-3}$$

$$S = 4.44 f B_{max} s_f A_{i\,gross} N_1 a_1 \delta \times 10^{-3}$$

$N_1 a_1 = A_w K_w / 2$

$A_{i\,net} = s_f A_{i\,gross}$

s_f = stack factor (0.95)



A_w = window area

window space factor:-

$$K_w = \frac{\text{Area used by Cu}}{A_w} = \frac{(N_1 a_1 + N_2 a_2)}{A_w} \simeq 0.35$$

$N_1 I_1 = N_2 I_2$

$\therefore N_1 a_1 \delta = N_2 a_2 \delta \quad \therefore N_1 a_1 = N_2 a_2$

$$K_w = \frac{2 N_1 a_1}{A_w}$$

$\therefore N_1 a_1 = \frac{K_w A_w}{2}$

NPTEL

$$S = 4.44 f B_{max} \delta_f A_{i\,(gross)} \delta \frac{k_w A_w}{2} \times 10^{-3}$$

$$S = 2.22 f \delta_f k_w A_{i\,gross} A_w B_{max} \delta \times 10^{-3}$$

output Eq^n

↘ decides the physical dimension.

Let all the linear dimensions of the transformer is increased by a factor of 'x' keeping B_{max} & δ constant

∴ KVA of the tfo will increase by a factor of (??) x^4 ✓

Area will be increased by a factor of x^2

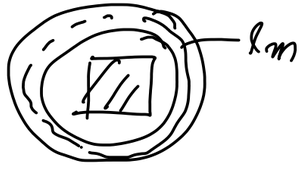
To show that Losses will increase by a factor of x^3 ✓

NPTEL

Lec 52

Cu - loss :- $I_1^2 r_1 + I_2^2 r_2$

$= \delta^2 a_1 \cancel{x} \rho \frac{N_1 l_{m1}}{\cancel{a_1}} + \delta^2 a_2 \cancel{x} \frac{\rho N_2 l_{m2}}{\cancel{a_2}}$



Culoss $\propto$ vol. of Cu.

$\therefore$ Culoss increases by a factor $\frac{x^3}{x^3}$

Core loss :- " . - - - - x^3

$P_{total\ loss}$ ✓ S

$S_{surface}$ ✓ $P_{total\ loss}$

surface area through which heat is dissipate } $S_{surface}$

$x^4 S$

x^3 $P_{total\ loss}$

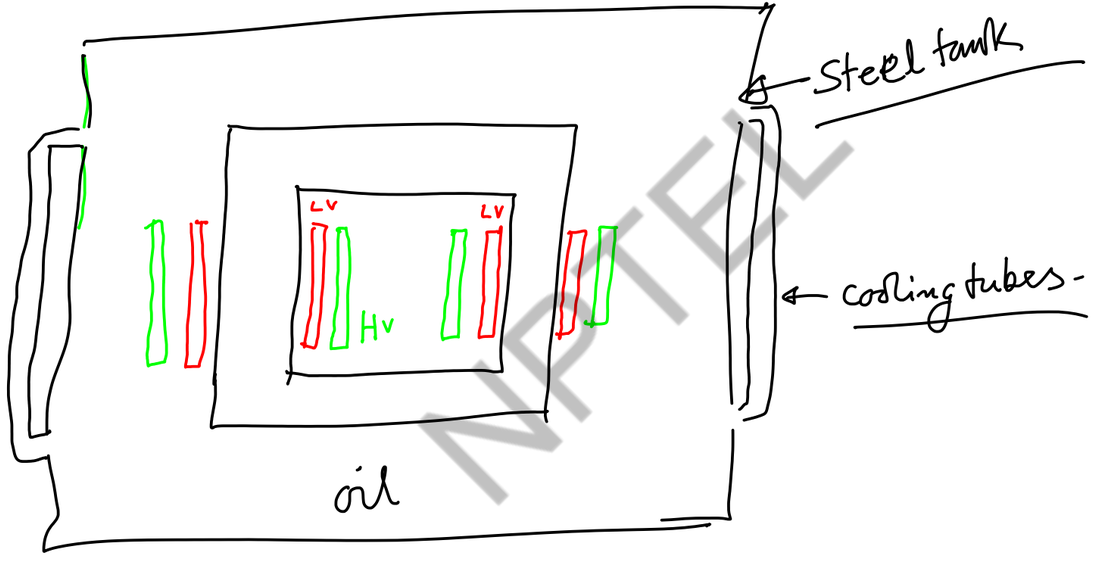
x^2 $S_{surface}$

$\frac{x^3 P_{total\ loss}}{\cancel{x^2} S_{surface}}$

NPTEL

Area available to dissipate the losses in a large transformer will be less.

Hence temp. rise will be more.



$P_{loss} = S_{surface} \lambda \theta_{temp}$

(λ: emissibility)

$\theta_{temp\ rise} = \frac{P_{loss}}{S_{surface}}$

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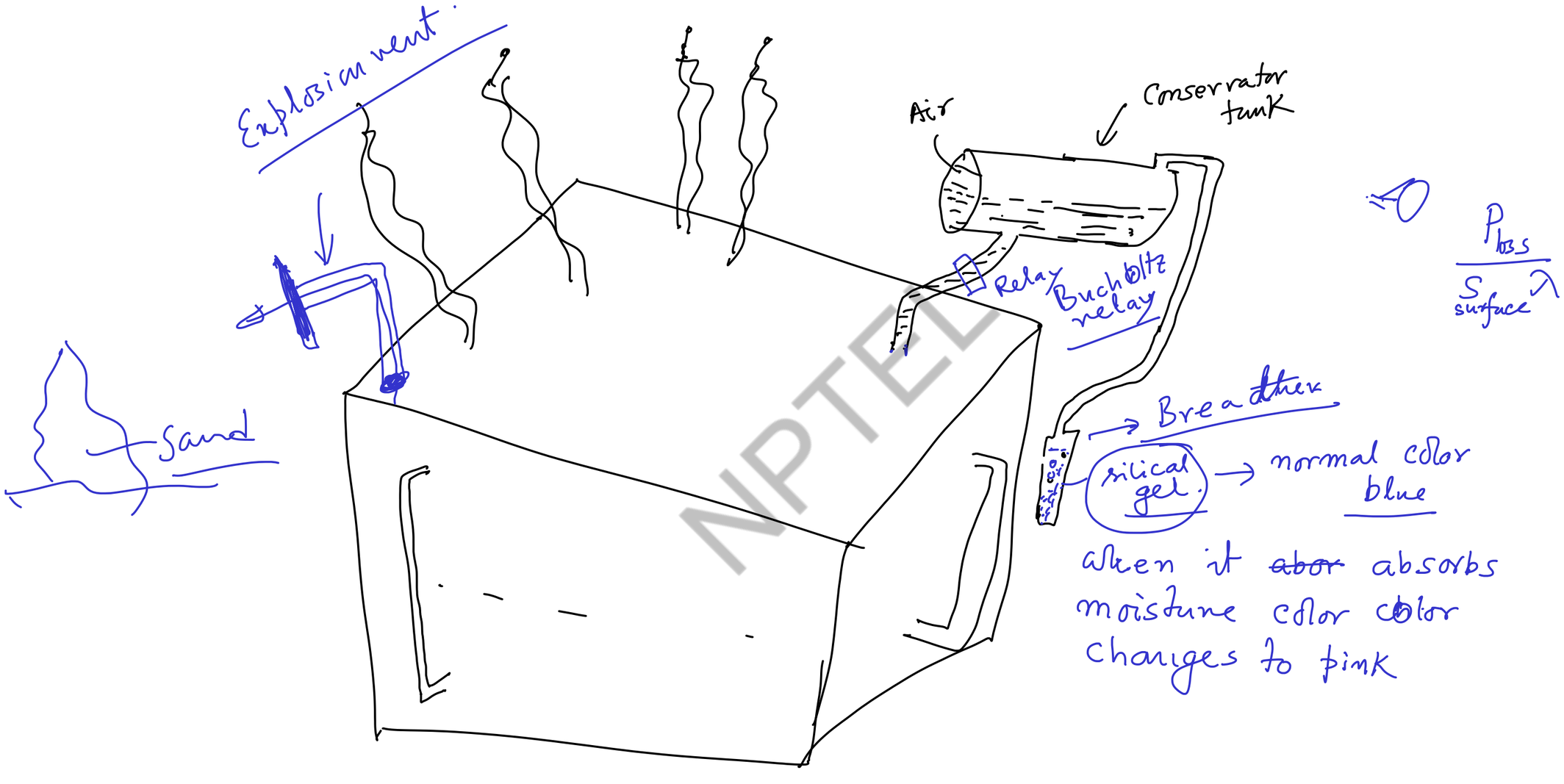
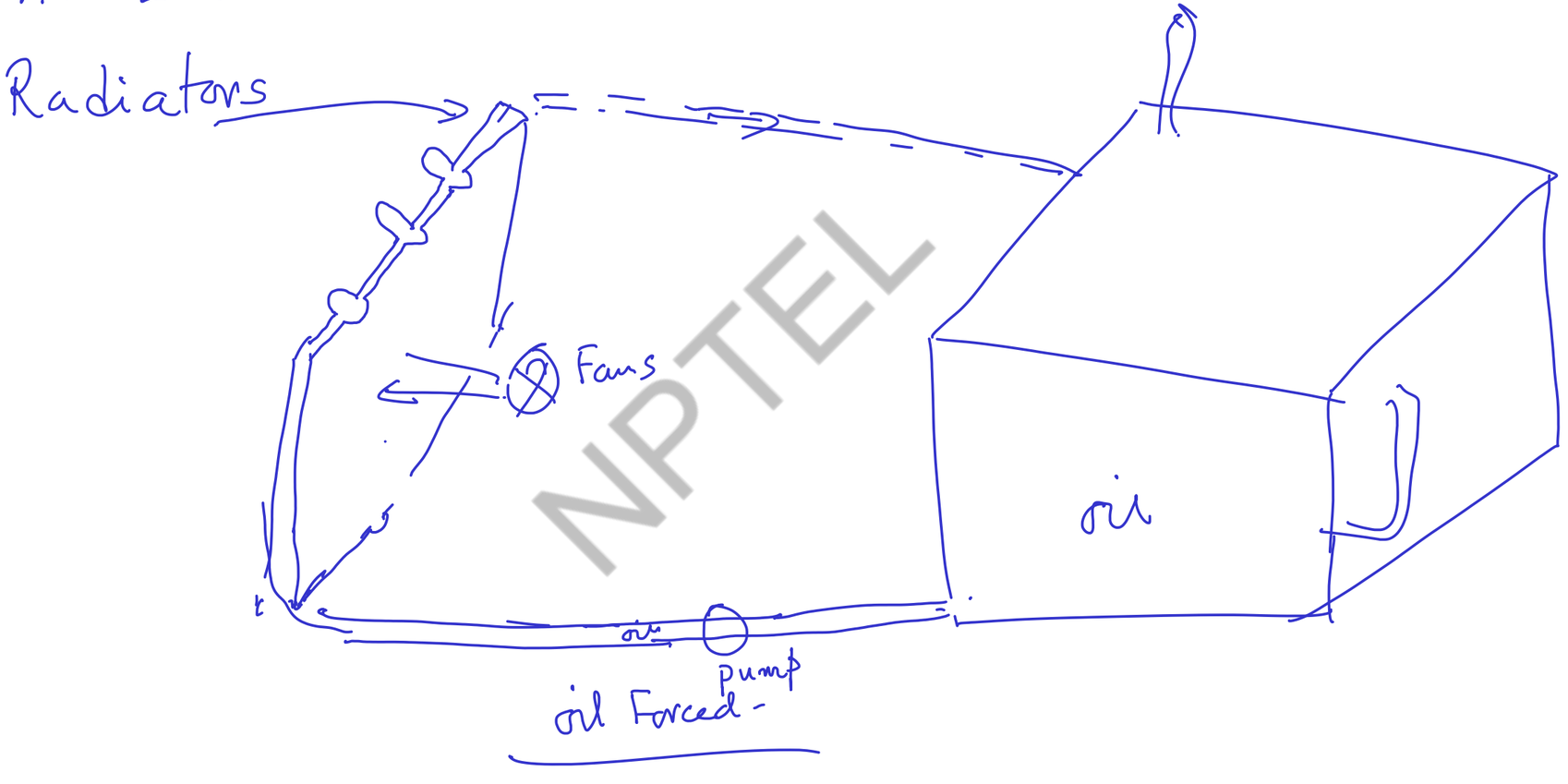

Explosion vent
Air
Conservator tank
Relay
Buchholtz relay
Breather
silical gel
normal color blue
when it absorbs moisture color color changes to pink
Sand
P_{loss}
$S_{surface}$
NPTEL

Lec-53.

AN → air natural

ANOL → air natural & oil natural



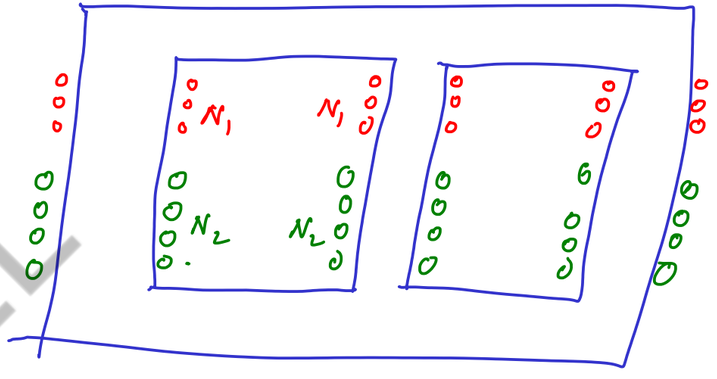
oil Forced-

NPTEL

output equn. of 3-phase core type tfr.

$$S = 3 V_{ph1} I_{ph1} \times 10^{-3}$$

$$\approx 3 \times 4.44 f B_{max} (s_f A_{i\,gross}) N_1 \delta a_1$$



$$N_1 I_1 = N_2 I_2$$

$$K_w = \frac{2 N_1 a_1 + 2 N_2 a_2}{A_w}$$

Show that

$$\rightarrow \boxed{S = 3.33 f B_{max} \delta s_f K_w A_{i\,gross} A_w}$$

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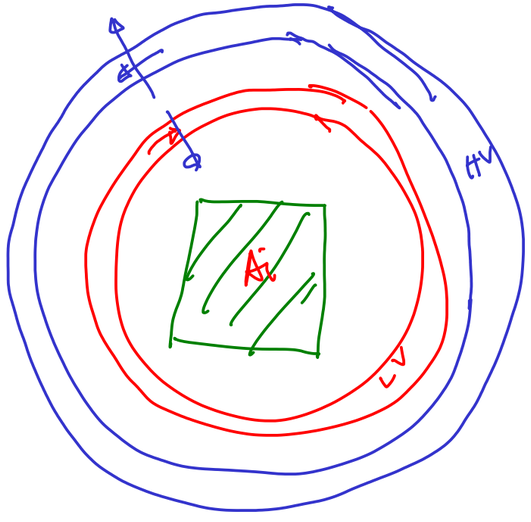
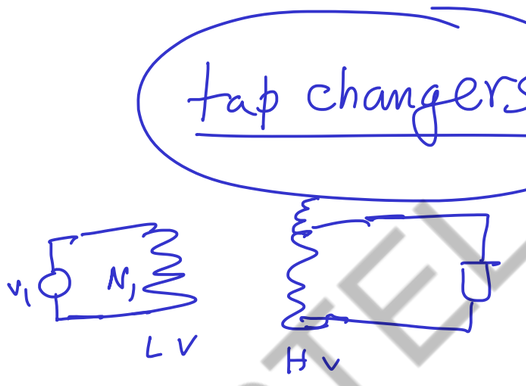
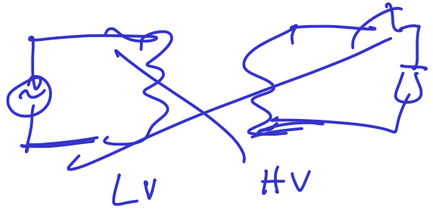
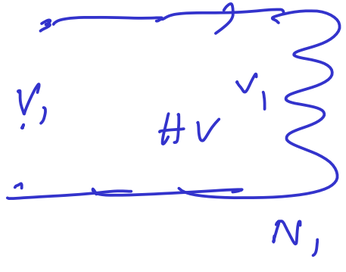
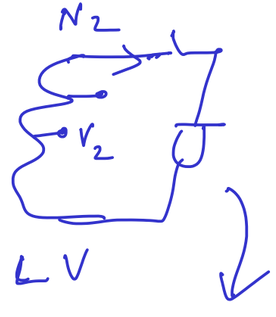


tap changers.



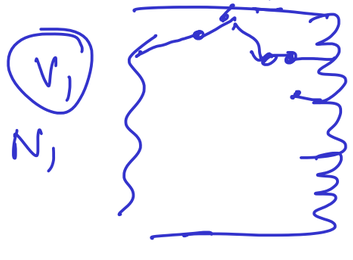


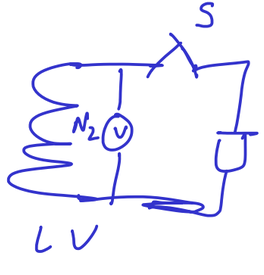


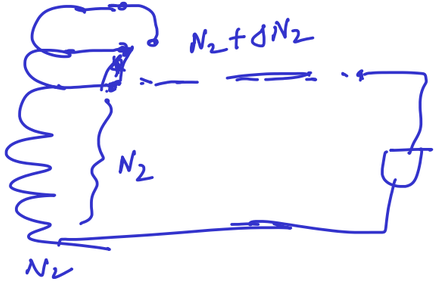


ON Load tap changers should be on which side?

Ans:- on HV side?







NPTEL