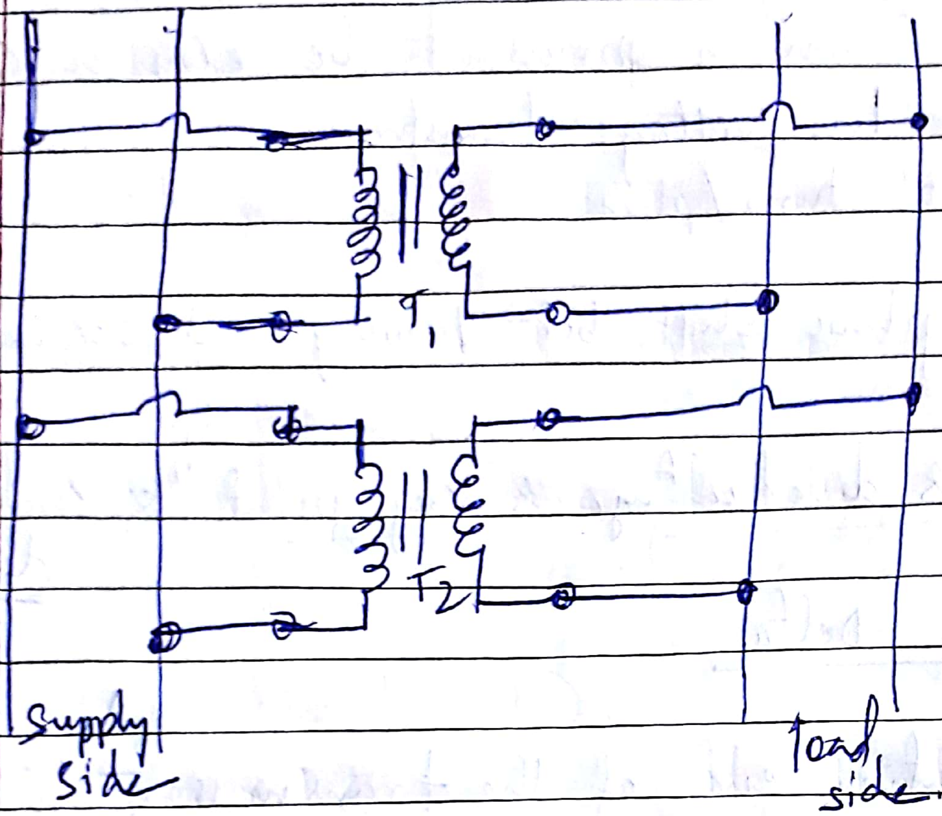
Unit 2

Parallel operation of transformers

Change



Why parallel connection ?
load > KVA Rating, share load, burden on 1 Transformer, spare parts interchangeably & storage easy.

→ primary supply bus bars & secondary load bus bars connected

→ Two or more connected in parallel to carry common load

GoodLuck Page No.

Date

→ if one tfr is of reduced capacity for a particular load we can remove or replace with higher capacity or additional unit is inserted to share load with same connection

→ Additional unit is said parallel with first one
→ Satisfactory operation in parallel condn must be satisfied.

Need of parallel operation

i) load > capacity individual transformer Second unit will share that load.

ii) power system reliable a parallel operation needed. if any one fault occurs, it can be removed & other units in parallel can maintain supply.

iii) According to power demand, transformer in parallel can be switched on or off which reduced tfr losses and makes overall system more efficient & economical.

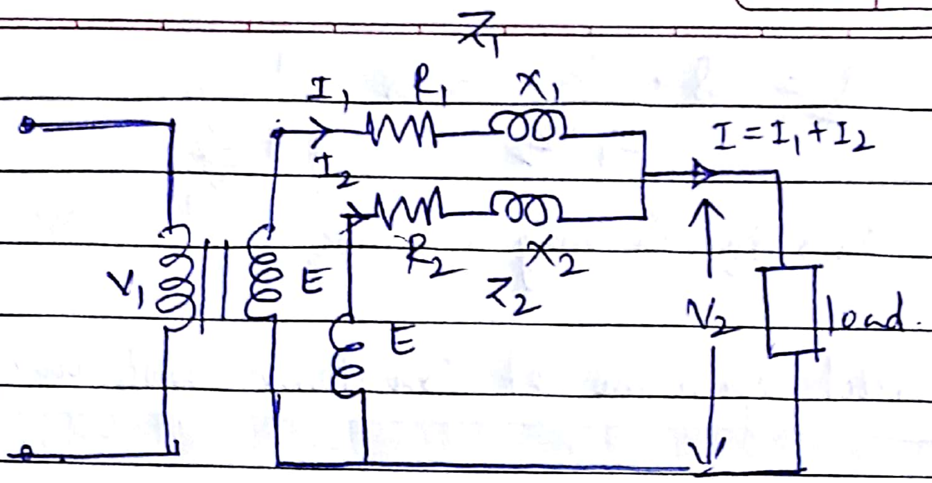
iv) when no of transformer are connected in parallel, cost of Stanby unit is much less

Conditions of parallel operation

1) Supply system and frequency. Suit
2) Same polarity
3) Voltage Ratio Same of both
4) %Z equal in magnitude & X/R Same (avoid circulating c/n & operation at different p.f.).
5) $Z_{eq} \propto 1/KVA$ (Individual) (if different KVA rating to avoid Circulated c/n).

2nd explanation
0 degree phase displacement or 180 phase difference & series closed circuit.

Load Sharing in Case of ~~Ideal~~ or similar tfr with equal voltage Ratio



→ no load secondary vtg same $E = E_1 = E_2$ (In phase)

→ equivalent impedance

$$\frac{1}{Z_{eq}} = \frac{1}{Z_1} + \frac{1}{Z_2} \quad \therefore Z_{eq} = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

→ w.k.T $I_1 Z_1 = I_2 Z_2 = I Z_{eq}$.

$$I_1 = \frac{I \cdot Z_{eq}}{Z_1} = \frac{I Z_2}{Z_1 + Z_2} \quad \& \quad I_2 = \frac{I Z_{eq}}{Z_2} = \frac{I Z_1}{Z_1 + Z_2}$$

Multiply by V_2

$$V_2 I_1 = V_2 I \frac{Z_2}{Z_1 + Z_2} \qquad V_2 I_2 = V_2 I \cdot \frac{Z_1}{Z_1 + Z_2}$$

$V_2 I \times 10^{-3}$ is Q, ie combined load in KVA.

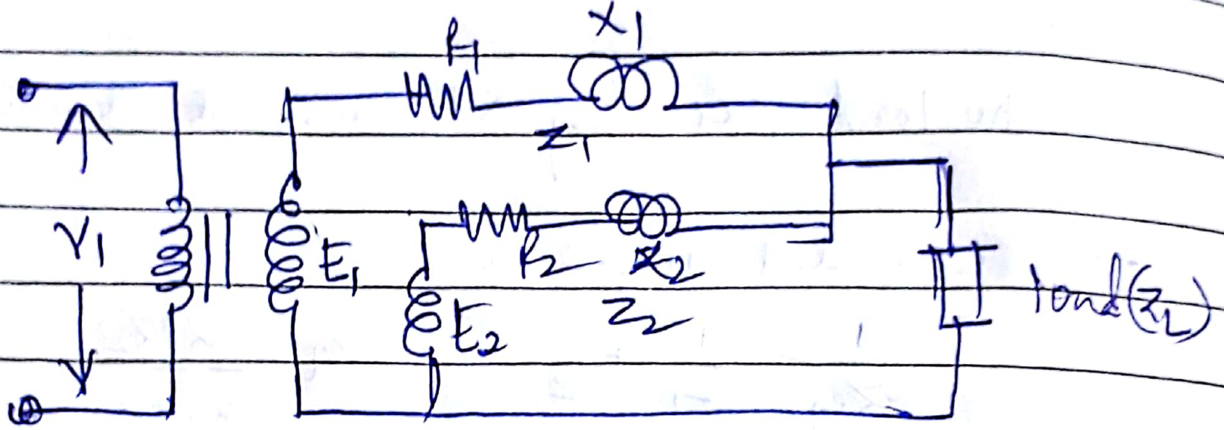
KVA Carried by each tfr

$$Q_1 = Q \frac{Z_2}{Z_1 + Z_2} = Q \cdot \frac{1}{1 + \frac{Z_1}{Z_2}}$$

$$Q_2 = Q \cdot \frac{Z_1}{Z_1+Z_2} = Q \cdot \frac{1}{1+\frac{Z_2}{Z_1}}$$

Q_A & Q_B in mag & phase.

parallel operation of Transformer with unequal Ratio (voltg)



Voltage Ratio of 1 > 2. | $E_1 > E_2$.

$$V = E_1 - E_2$$

$$I_C = \frac{E_1 - E_2}{Z_1 + Z_2}$$

circuit dg we have

$E_1 = V_2 + I_1 Z_1$ & $E_2 = V_2 + I_2 Z_2$ $I_L = I_1 + I_2$

$$V_2 = I_L Z_L = (I_1 + I_2) Z_L$$

$$E_1 = (I_1 + I_2)Z_L + Z_1 I_1 \quad \text{—— (a)}$$

$$E_2 = (I_1 + I_2)Z_L + I_2 Z_2 \quad \text{—— (b)}$$

Subtract a & b

$$E_1 - E_2 = I_1 Z_1 - I_2 Z_2$$

$$I_1 = \frac{(E_1 - E_2) + I_2 Z_2}{Z_1}$$

Substitute this in (b)

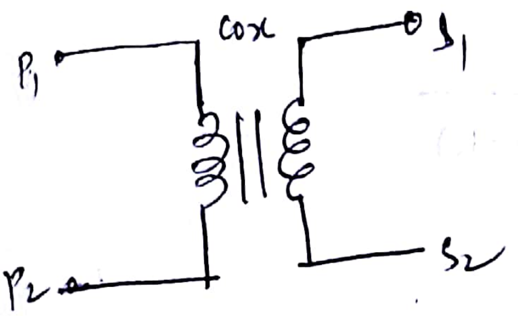
$$E_2 = I_2 Z_2 + \left[\left\{ \frac{(E_1 - E_2) + I_2 Z_2}{Z_1} \right\} + I_2 \right] Z_L$$

$$* \quad I_1 = \frac{E_1 Z_2}{Z_L (Z_1 + Z_2)} + \frac{E_1 - E_2}{Z_1 + Z_2} \qquad I_2 = \frac{E_2 Z_1}{Z_L (Z_1 + Z_2)} - \frac{E_1 - E_2}{Z_1 + Z_2}$$

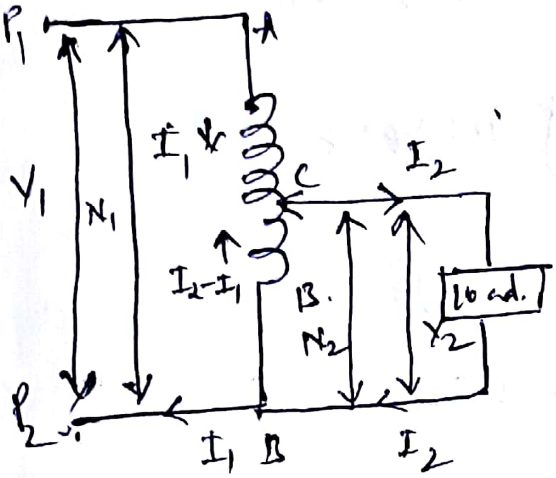
Two transformers A & B are connected in parallel to a load of $(2 + j1.5)\,\Omega$. Their impedances in secondary terms are $Z_A = (0.15 + j0.5)\,\Omega$ and $Z_B = (0.1 + j0.6)\,\Omega$. Their no load terminal voltages are $E_A = 207\angle 0^\circ$ V and $E_B = 205\angle 0^\circ$ V. Find the power output and p.f of transformer.

What, How, which
Why, When, where

Auto transformer



Power transfer
electrically isolated
Induction



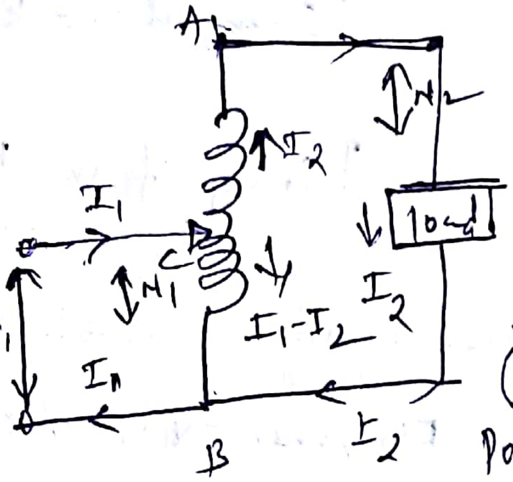
i) Step down Autotransformer

$N_2 < N_1$, $V_2 < V_1$

$AB = N_1$, $BC = N_2$

$K < 1$

$$K = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}$$



electrically connected
conduction
& induction
Power transfer

ii) Step up autotransformer

$N_2 > N_1$; $V_2 > V_1$

$AB = N_2$, $BC = N_1$

$K > 1$

(5)

Copper Saving in autotransformer (step down auto)

$K = I_1/I_2 = N_2/N_1$

$I_2 = I_1/K$, $N_2 = kN_1$

$W_{TW} \propto [N_1 I_1 + N_2 I_2]$

$W_{AT} \propto [(N_1 - N_2) I_1 + N_2 [I_2 - I_1]]$

$$\text{Ratio } \frac{W_{TW}}{W_{AT}} = \frac{N_1 I_1 + N_2 I_2}{[(N_1 - N_2) I_1 + N_2 [I_2 - I_1]]} = \frac{N_1 I_1 + N_2 (I_1/K)}{[N_1 I_1 - N_2 I_1 + N_2 I_1/k - N_2 I_1]}$$

$$\frac{W_{TW}}{W_{AT}} = \frac{N_1 I_1 + K N_1 (I_1/K)}{N_1 I_1 + K N_1 (I_1/K) - 2(K N_1) I_1}$$

$$= \frac{2 N_1 I_1}{2 N_1 I_1 - 2 K N_1 I_1} = \frac{1}{(1-k)}.$$

$W_{AT} = (1-k)\, W_{TW}$.

$\therefore$ Saving in $Cu = W_{TW} - W_{AT} = W_{TW} - (1-k) W_{TW} = k W_{TW}$

Saving of $Cu = K W_{TW}$ → Step down.

Saving of $Cu = \frac{1}{K} W_{TW}$ → Step up.

Power transfer in autotransfer (step down)

I/p power $= V_1 I_1$; o/p power $= V_2 I_2$.

P_t = Power transfer. Inductively

$= (N_2)[I_2 - I_1]$

$= K N_1 \left[\frac{I_1}{k} - I_1\right] = N_1 I_1 - K N_1 I_1 = (1-k) V_1 I_1$

$= (1-k)$ I/p power

Remaining $P_c = k$ (I/p power)

P_c = (load power o/p) $- P_t$

\# gives more output ($C \& I$) → Higher η.

VA Rating of Autotfr (Compare VA of Auto & Two wdg)

Step down

$K = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}$ ⇒ VA Rating of Autotransformer

$(VA)_{AT} = V_1 I_1 = V_2 I_2$

Primary AC → $(V_1 - V_2) I_1$ BC → $(I_2 - I_1) V_2$ secondary

If this used as transformer (2 wdg) $(VA)_{TW} = (I_2 - I_1) V_2$

$= V_2 I_2 - kV_2 I_2 k$

$(VA)_{TW} = (V_1 - V_2) I_1 = (I_2 - I_1) V_2$ $= V_2 I_2 (1-k)$.

$(VA)_{TW} = (V_1 I_1 - k V_1 I_1) = V_1 I_1 (1-k)$

$= VA_T (1-k)$

$$\boxed{VA_T = \frac{1}{(1-k)} (VA_{TW})}$$

if $k<1$, $(1-k)<1$, $\boxed{VA_T > VA_{TW}}$

step up

$(VA)_{AT} = V_1 I_L = V_2 I_2$

BC — $V_1 (I_1 - I_2)$ primary; AB — $(V_2 - V_1) I_2$

$(VA)_{TW} = (V_2 - V_1) I_2 = V_1 (I_1 - I_2)$

$= V_1 I_1 - V_1 I_2 = V_1 I_1 \left[1 - 1/k\right]$

$(VA_{TW}) = \left[\frac{k-1}{k}\right] (VA)_{AT}$

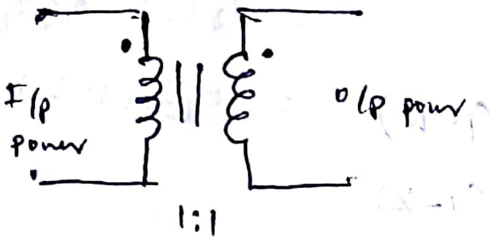
$VA_{(AT)} = \left[\frac{k}{k-1}\right] (VA)_{TW} = \left[\frac{1}{1 - 1/k}\right] (VA)_{TW}$

As $k>1$, $\left[1 - 1/k \text{ is less than one}\right]$

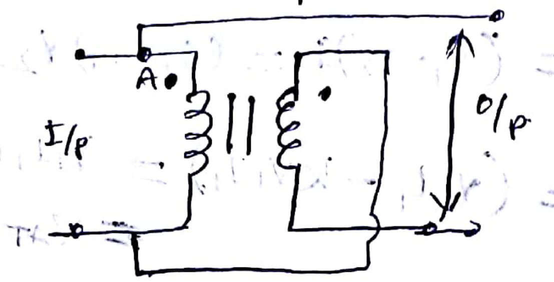
$$\boxed{VA_{AT} > (VA)_{TW}}$$ [Induction & conduction]

Conversion of two wdg tfr to Auto tfr

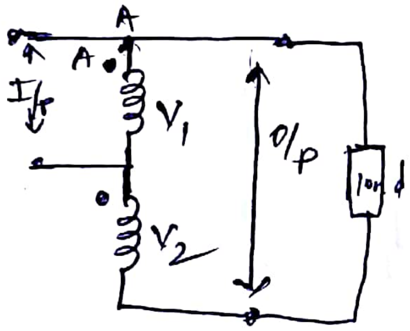
Two wdg tfr



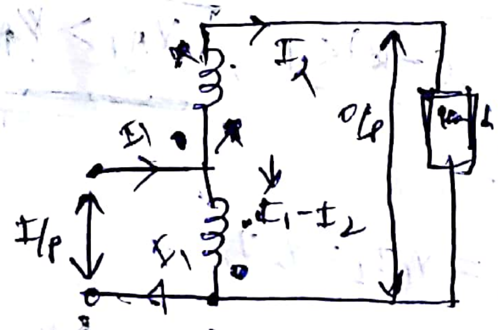
Additive polarity Connection



(dont discuss)



Auto transfr.



V_1 I/p

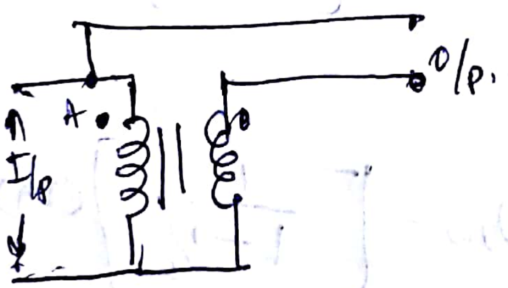
$V_1 + V_2$ (O/p)

Step up Auto tfr

↑ Same

↗ Same

Subtractive polarity Connection



Advantages of Autottr

What other think abt you If you think

Cu loss is less, I^2R ↓, η ↑ (higher) $VA_{AT} > VA_{TW}$, R & X is less (Vtg Regn is Superior), Smooth & continuous variation of voltage

Limitation of Autotrans

(Z (low), Isc ↑ Short cct on secondary).

- Section to primary & secondary opened full vtg appear across Secondary and danger of accidents.
- No electrical separation risky in high vtg levels.
- Economical only when vtg Ratio than 2

Application

Tell them to see

1. As a starter [like Induction, synchron m/c]
2. As a booster.
3. As a furnace transformer [at req^r supply]
4. for Interconnecting systems which are operated roughly at same voltage.
5. Used as variac [device giving Smooth & continuosly]
6. Dimmerstat. [Cinema Hall]
7. In Control system as well as Appliance.

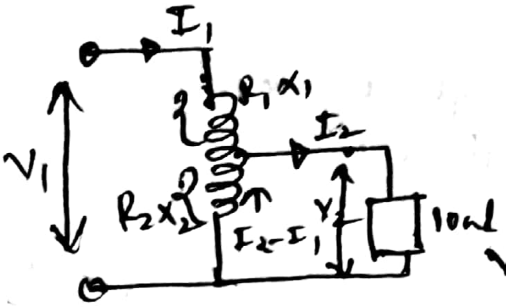
Comparison with Two wdg ttr

Two wdg	Autottr
1) Two	1) one
2) electric isolation	2) no electric isolation
3) Cu more	3) Cu less
4) η less	4) η high
5) size & Cost is high	5) less
6) vtg Regn is poor	6) Superior
7) R & X are more	7) R & X are less
8) Cu losses are more	8) Cu losses are less

~~Equivalent Circuit of Autotfr~~

9) power transfer by induction — 9) By induction as well as conduction
10) variac (cannot) — 10) variac
11) KVA Rating is less (autotfr) — 11) KVA is more than. (2 wdg)

Equivalent Circuit of tfr



$$V_1 = E_1 + I_1(R_1 + jX_1) - (I_2 - I_1)(R_2 + jX_2) \quad \text{— (a)}$$

$$E_2 = V_2 + (I_2 - I_1)(R_2 + jX_2) \quad \text{— (b)}$$

$$E_1 = E_2/k$$

$$V_1 = \frac{V_2 + (I_2 - I_1)(R_2 + jX_2)}{k} + I_1(R_1 + jX_1) + I_1(R_2 + jX_2) - \frac{I_1}{k}(R_2 + j\ldots$$

$$V_1 = \frac{V_2 k + I_1(R_2 + jX_2) - I_1 k(R_2 + jX_2) + I_1(R_1 + jX_1)k^2 + I_1(R_2 + jX_2)k^2 - I_1(R_2 + jX_2)k}{k^2}$$

$$= \frac{V_2}{k} + \frac{I_1}{k^2}(R_2 + jX_2) - \frac{I_1}{k}R_2 - \frac{I_1}{k}jX_2 + I_1R_1 + I_1jX_1 + I_1R_2 + jX_2 I_1 - \frac{I_1}{k}R_2 - \frac{jX_2 I_1}{k}$$

$$= \frac{V_2}{k} + I_1\left\{R_1 + R_2\left[\frac{1}{k^2} - \frac{2}{k} + 1\right] + j\left[X_1 + X_2\left(\frac{1}{k^2} - \frac{2}{k} + 1\right)\right]\right\}$$

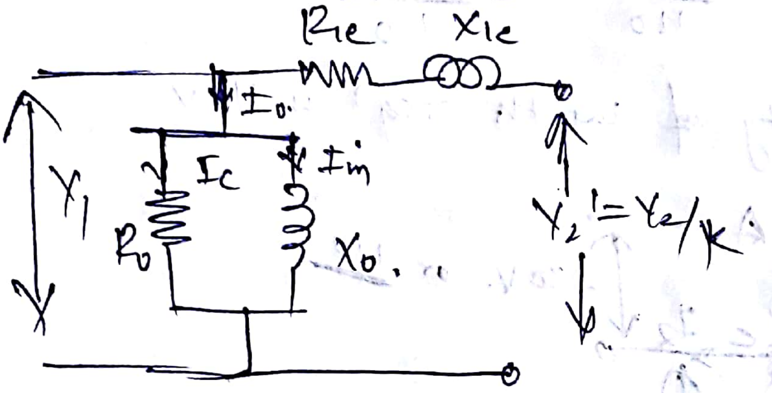
$$V_1 = \frac{V_2}{k} + I_1\left[R_1 + R_2\left(\frac{1}{k}-1\right)^2 + j\left[X_1 + X_2\left(\frac{1}{k}-1\right)^2\right]\right]$$

$$V_1 = V_2' + I_1 R_{1e} + I_1 jX_{1e} \quad — (3)$$

$$R_{1e} = R_1 + R_2\left[\frac{1}{k}-1\right]^2$$

= Equivalent resistance

$X_{1e} = X_1 + X_2\left(\frac{1}{k}-1\right)^2$ = Equi Inductor refd to pry

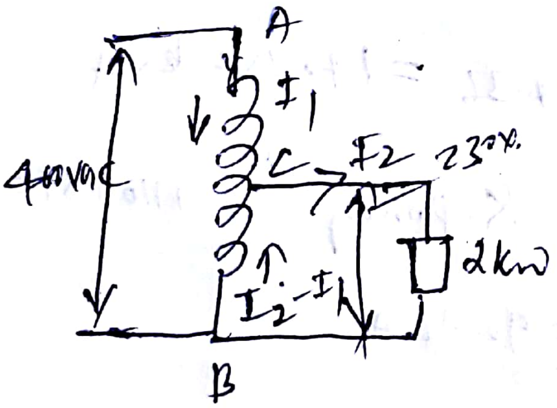


wed

4, 12, (14), 43,

* The fig shows an Autotfr used to supply a load of 2kw at 230V from a 400V ac. Supply. Find Chs in parts AC & BC, neglecting losses and no load Ch. Also find Cu saving due to use of autotfr instead of using two wdg tfr. Assume purely Resistive load.

23 – 96
22 – 97
21 – 98
20 – 84
19 – 80



$o/p = V_2 I_2 = 2\times10^3$

$I_2 = \frac{2\times10^3}{230} = 8.69\ A$

$K = \frac{V_2}{V_1} = \frac{230}{400} = 0.575 = I_1/I_2$

$I_1 = KI_2 = 5A = AC$ //

$BC = I_2 - I_1 = 8.69 - 5 = 3.69A$

Cu saving = $K W_{TW} = 0.575 \times W_{TW} = 57.5\%$

* A 10kVA, 230/110V. tfr is to be used as an autotfr. What will be voltage ratio & o/p rating of autfr.

Soln:- two wdg tfr = 230/110 V

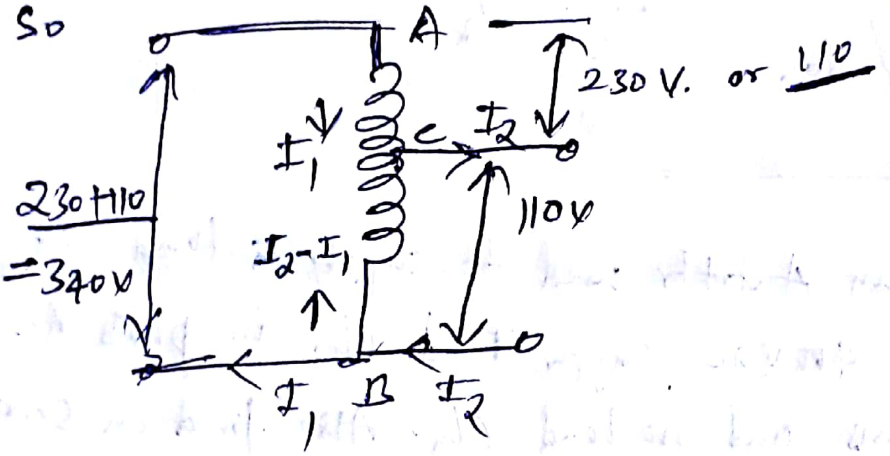
KVA = 10 kVA.

$\therefore$ Crn in 230V wdg = $\frac{VA\ Rating}{230} = \frac{10\times10^3}{230} = 43.478$ A

Crn in 110V wdg = $\frac{VA\ Rating}{110} = \frac{10\times10^3}{110} = 90.90$ A.

let us assume o/p vtg of auto tfr reqr is 110V.

So



$K = \frac{V_2}{V_1} = \frac{110}{340} = 0.323 = \frac{I_1}{I_2} \Rightarrow I_2 = \frac{43.47}{0.323}$

$I_2 = 134.36$ A

o/p rating $= V_2 I_2 = 110 \times 134.36 = 14.782$ kVA

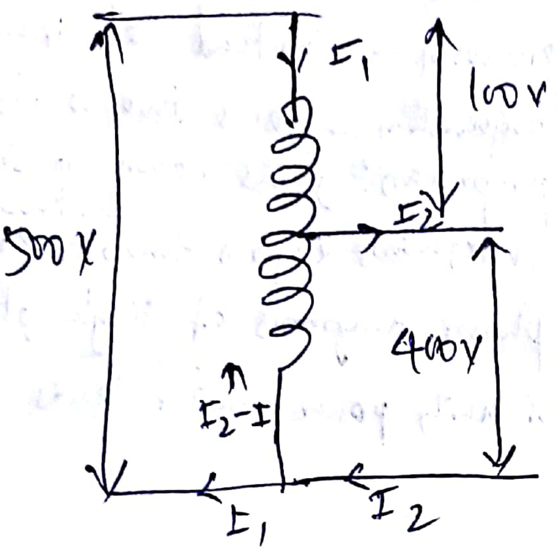
Note:- Take secondary as 230 & primary 230+110=340

$K = \frac{V_2}{V_1} = \frac{230}{340} = 0.676$, $I_1 = 90.90$ A.

$\frac{I_1}{K} = I_2 \Rightarrow 133.04 \Rightarrow V_2 I_2 = 30.600$ kVA

* A 400/100V, 10 kVA, 2 wdg tfr is to be employed as an autotransformer to supply a 400V circuit from 500V source. When tested as a 2 wdg tfr at rated load of 0.85 pf lagging, its η is 97%. Determine its kVA & η as autotransformer (0.8).

11, 12, 17, 18, 22, 23, 24, 30, 33



Two wdg

$$\%\eta = \frac{KVA \times \cos\phi}{x + P_i + P_{cu}}$$

rated $\eta = 1$

$$0.97 = \frac{10\times10^3 \times 0.85}{10\times10^3\times0.85 + P_i + P_{cu}}$$

$$(8500 \times 0.97 + 0.97(P_i + P_{cu})) = 10\times10^3\times0.85$$

$$P_i + P_{cu\,(FL)} = 262.886\,W.$$

$$\eta_{AT} = \frac{VA\cos\phi}{VA\cos\phi + P_i + P_{cu\,(FL)}} \times 100.$$

4, 11, 16, 46

9, 29, 30, 32, 33, 34, 43, 49, 50.

$$I_1 = \frac{VA\ Rating}{100V} = \frac{10\times10^3}{100} = 100\,A.$$

Now kVA Rating of auto tf

$$= \frac{V_1 I_1}{100} = \frac{500\times100}{100} = 50\,kVA.$$

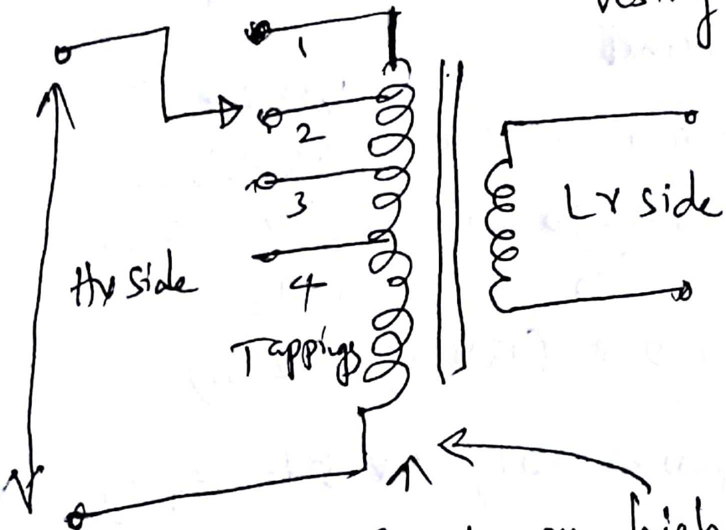
$$\therefore \eta_{AT} = \frac{50\times10^3\times0.85}{50\times10^3\times0.85 + 262.886}\times100 = 99.34$$

Indian Standard Binary

Tap Changing Transformer

How much

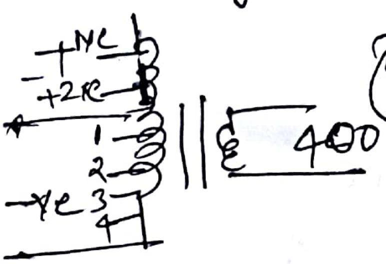
Power system networks.



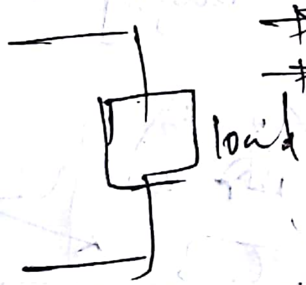
Using The Transformation Ratio the voltage can be varied

The tappings are provided on windings as lead to provide different vtg. (1)

The tappings can be on high voltage, low voltage or both. (2)



(3)



→ Constant voltage at consumer
→ Control active power & Reactive power (4)

locating of tappings at phase end, neutral point

Why tappings are on HV side

plan each word

1) Fine voltage Regulation possible with high voltage wdg as it carries large no of turns
2) ~~Cannot~~ interruption high current (difficulties) (bcoz tappings)
3) easier & simpler to provide tappings (HV). (LV near core)
4) At light load, on LV side voltage increases, it is reqr to decrease the vtg by adjusting tapping in HV side (large no of turns). ϕ & B_m ↓ core loss ↓ η ↑.
5) If tappings are provided on LV side then the exact vtg Regulation may not be provided.

3ϕ, 11kV/415V, delta/star, $E_t = 15V$

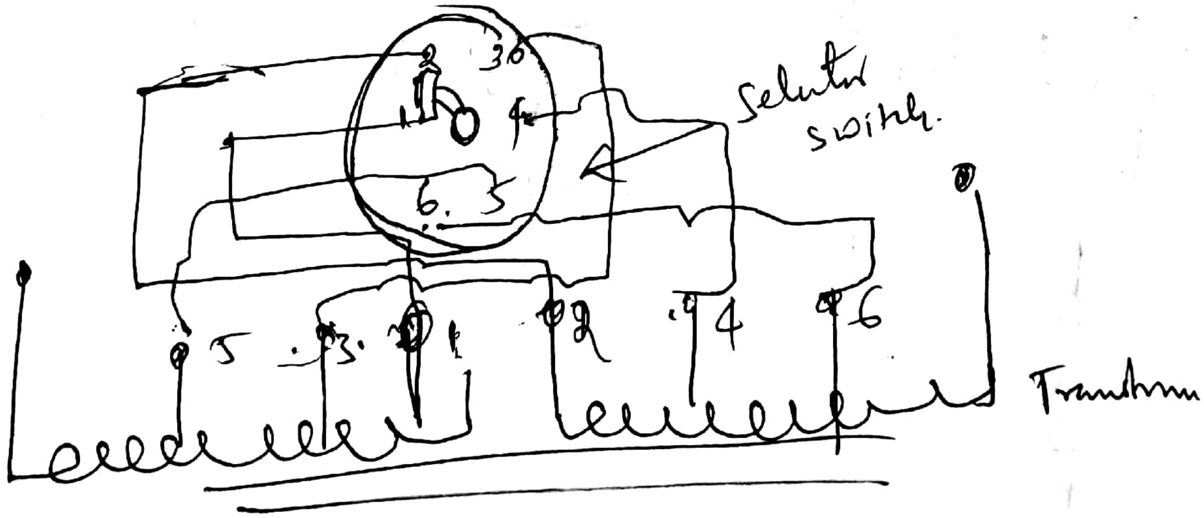
$\frac{415}{\sqrt{3}} = 240V$, no of turns $= \frac{240}{15} = 16$,

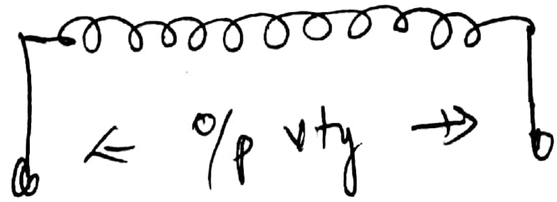
1, 12, 24, (26), 30, 31, 33, 43, (45), 46, 52, 53, (1/16)

minimum no of tapping is one. (15V or 6.25%)

if 5% is desired it is not possible with LV side tapping

Off Circuit Tap Changing

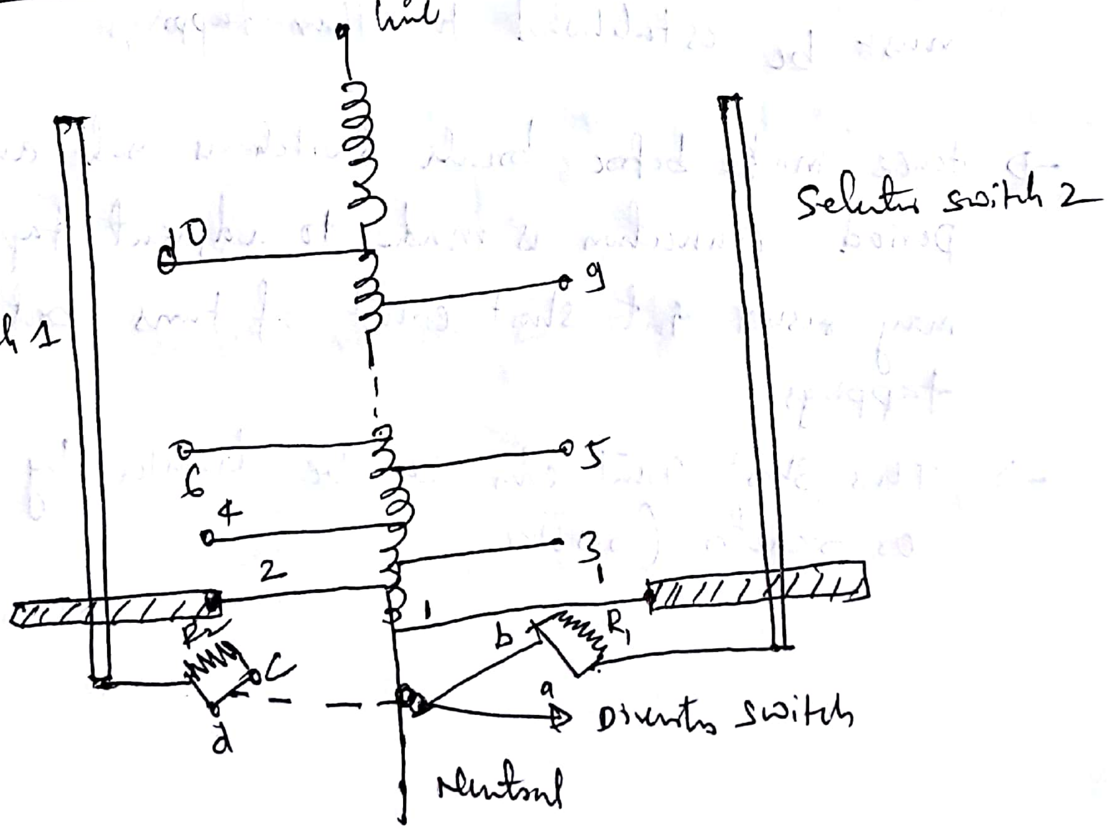




Off load tap Changer

- Tappings are changed when tfr is disconnected from supply
- As per requirement tappings are taken out
- manually operated selector switches are provided (vertical tapping switches & face plate switches).
- ±5% change in steps
- Insulating base on which six brass or Cu terminals are mounted.
- Taps of wdg are connected to terminals of ~~switch~~ tap changer
- Contactor mounted on shaft
- ex Selector switch (tap 1 & 2) (total used)
- Contactor moved one point left (1 & 6) (Cutting (2 & 6)
- (6 & 5) [Cutting (1 to 5) & (2 to 4)]

<u>On load tap Changing</u>



→ load condⁿ have to maintain vtg on secondary side with
→ of an arrangement.
→ If this works without ~~off~~ load off it is called OLTC
→ without interruption in supply, tap changing gear
Should change turns Ratio.
→ neutral end of HV (Tapping are commonly)
→ Tap changer is in form of selector switch.
(motor, operated mechanism, remote control or manual)
→ vital factor is continuity of circuit.
→ As selector switch should not break Cty, Additional Separate oil filled Compartment is used to mount. diverter switch. which breaks the load Cty by Interrupted arc which Carry from Carbon.
→ main consideration when one tapping is opened, contact must be established to other tappings
→ Hence make before break Switch is used and in transition period connection is made to adjacent taps which may result into short circuit of turns betⁿ adjacent tappings.
→ This Short Circuit Cty Can be limited by using resistor or reactor (resistor

Page

* Selector switch 1 & 2 are provided on taps 1 & 2 respectively
* Diverter switch is connecting tap 1 to neutral terminals of wdg.

True
T.E., (4), 16, 19, 23, (24), 33, 41, 46, 50, 52, ...

If we want to change tap from position 1 & 2 then following is sequence of operation

i) Resistance R_1 is short circuited as a & b are closed. The load c/n flow through contact 'a' from tap This is running position at tap 1.

ii) help of external operating mechanism, diverter switch is moved to open the contact 'a'. load c/n flows through R_1 Resistor & contact b1.

iii) The contact 'c' close to open R_1 when moving contact of diverter switch continues movement to left. The R_1 & R_2 are now connected across tap 1 & 2 so that load c/n flows through these resistances to mid point of b & c.

iv) with further movement of DS to left makes contact b open Now load c/n flow from tap 2 through R_2 & c.

v) The load c/n flows from tap 2 through d which is Running position of tap 2.

* The primary & secondary vtges of autotfr are 230V & 75V respectively. Calculate the c/n in different parts of winding when load c/n is 200A. Calculate Cu saving.

65, 134.7, 32.8%

(2) 111

2, 6, 30, 33, 41, 43, 47, 48, 49, 51, 54, 55