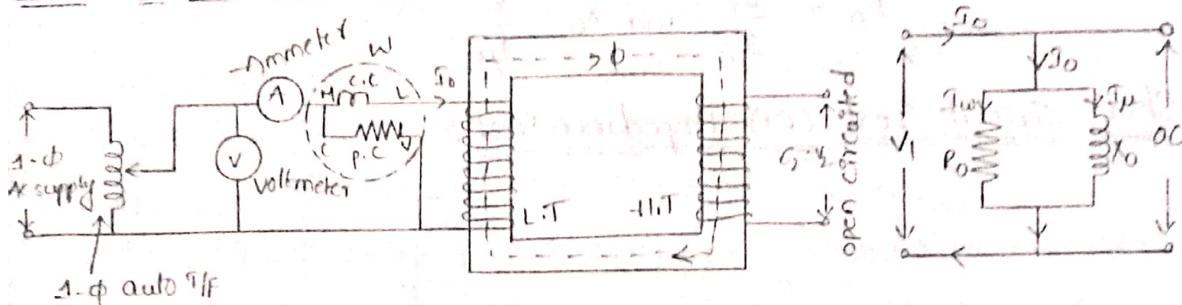


15 (3) 59  
Testing of TIF & poly phase T/P  
open-circuit test (or) No-load test :-



(a) open circuit diagram

b) Equivalent circuit

This test is conducted to find the iron losses and no-load current  $I_0$ , which is helpful in finding the parameters  $P_0$  and  $X_0$  of the transformer. In this test secondary winding is left open-circuited and the normal voltage and frequency is applied to the primary winding as shown in fig. A auto-transformer is used for varying the voltage applied to the low-voltage winding. An Ammeter  $A$ , wattmeter  $W$  and voltmeter  $V$  are connected in low voltage side to measure no-load current  $I_0$ , no load input power  $w_0$  and applied primary voltage  $V_1$ .

With normal voltage applied to the primary, normal flux will setup in the core, hence normal iron losses will occur in the transformer. Since no-load current  $I_0$  is very small, copper losses in the primary are negligibly small and as secondary is kept open the copper losses in the secondary are zero. Hence, the wattmeter reading practically gives the iron losses under no-load condition.

From the data obtained by this test, the various parameters such as  $P_0$ ,  $X_0$ ,  $I_w$ ,  $I_\mu$  can be calculated as follows.

wattmeter reading = Iron loss,  $w_0$  = No-load input power.

voltmeter reading = Applied primary voltage =  $V_1$

Ammeter reading = No-load primary current =  $I_0$

No-load input power,  $w_0 = V_1 I_0 \cos \phi_0$

$\therefore$  watt less component of no-load current,  $I_w = I_0 \cos \phi_0$

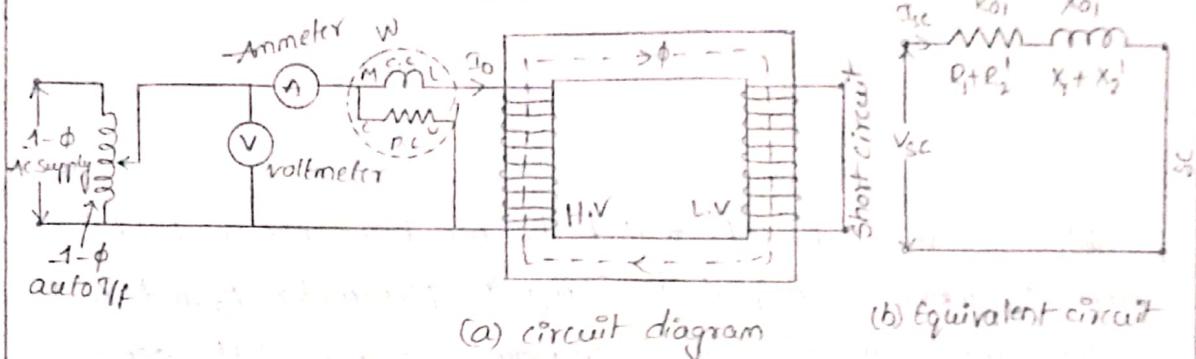
Magnetising component of no-load current,

$$I_\mu = I_0 \sin \phi_0 = \sqrt{I_0^2 - I_w^2}$$

Equivalent circuit parameters,

$$R_0 = \frac{V_1}{I_{sc}} \text{ and } X_0 = \frac{V_1}{I_{sc} \mu}$$

### # Short circuit Test (or) Impedance Test :-



This test is conducted to find the full-load copper losses and equivalent resistance  $R_0$ , (or)  $R_0'$  and equivalent reactance  $X_0$ , (or)  $X_0'$  referred to metering side. In this test Secondary winding is short-circuited by a thick wire or strip and variable low voltage is applied to the primary with the help of a auto-transformer. An Ammeter  $A$ , wattmeter  $W$  and voltmeter  $V$  are connected in the high-voltage side to measure short-circuit current  $I_{sc}$ , input power  $w_{sc}$  and applied primary voltage  $V_{sc}$ .

The applied voltage to the primary is gradually increased till the voltage  $V_{sc}$  at which full-load current  $I_{sc}$  flows through the primary. Since the applied voltage is very small, so the flux is very small and therefore iron losses are negligibly small. Hence, the wattmeter reading practically gives the full-load copper losses. Fig shows the equivalent circuit of a transformer on short circuit as referred to primary.

From the data obtained by this test, the various parameters such as  $R_0$ ,  $X_0$ ,  $\bar{Z}_0$  can be calculated as follows.

Wattmeter reading = full-load copper losses =  $w_{sc}$ .

Voltmeter reading = Applied primary voltage =  $V_{sc}$

Ammeter reading = full-load primary current =  $I_{sc}$

full-load copper losses,  $w_{sc} = I_{sc}^2 R_0$ ,

$\therefore$  Equivalent resistance referred to primary,  $R_0' = \frac{w_{sc}}{I_{sc}^2}$

it may be difficult to arrange suitable loads for loading and it involves considerable waste of energy.

large transformers can be put on full load for determining the temperature rise and accurate efficiency by means of cumper's test. It requires two identical transformers.

The circuit diagram for the test is shown in fig. In this test, the two primaries are connected in parallel across the supply of rated voltage and frequency. The two secondaries are connected together with their polarities in opposition. This is done by first connecting any two terminals, say  $c$  and  $d$  together and connecting a double range voltmeter across the terminals  $a$  and  $b$ . If the voltmeter reads zero, the two secondaries are in opposition and terminals  $a$  and  $b$  can be used for test. If the voltmeter gives a reading twice the voltage rating of the secondary, the terminal connections should be reversed.

When the two secondaries are in opposition, no current flows through the secondary windings. Hence the transformers act as if their secondaries are open circuited and wattmeter,  $w_1$ , measures the iron losses of the two transformers and ammeter,  $A_1$  will indicate the total no-load current.

To circulate full load current in the transformer windings by injecting some voltage in the secondary circuit through a regulating transformer. The injected voltage is adjusted till the Ammeter  $A_2$  indicates F.L. sec. current. The sec. current will cause a current to circulate in the two primaries having a path, as shown dotted a path in fig. and will not affect the reading of wattmeter,  $w_1$ . Thus the wattmeter,  $w_2$  gives the F.L. cu losses of the two transformers.

The core and full load cu. losses in one transformer will be  $(\frac{w_1 + w_2}{2})$ , the efficiency of the transformer can therefore be calculated.

For measurement of temperature rise of the two transformers, these are kept under F.L. conditions for several hours with a small expenditure of energy equal to that required by the losses only.

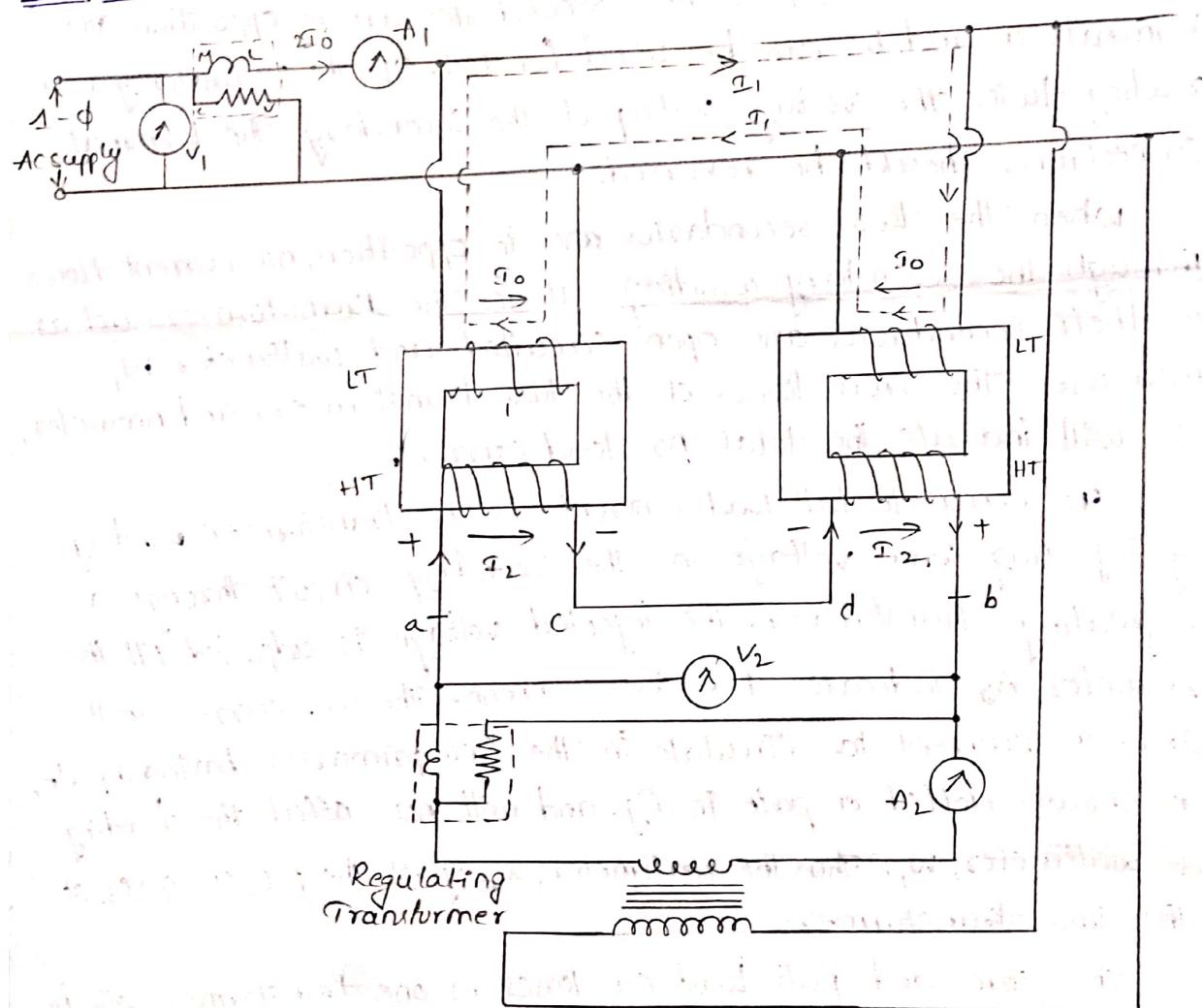
Equivalent impedance referred to primary,  $Z_{01} = \frac{V_{sc}}{I_{sc}}$

Equivalent resistance referred to primary,  $X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$

Short circuit power factor,  $\cos\phi_{sc} = \frac{W_{sc}}{V_{sc} I_{sc}}$

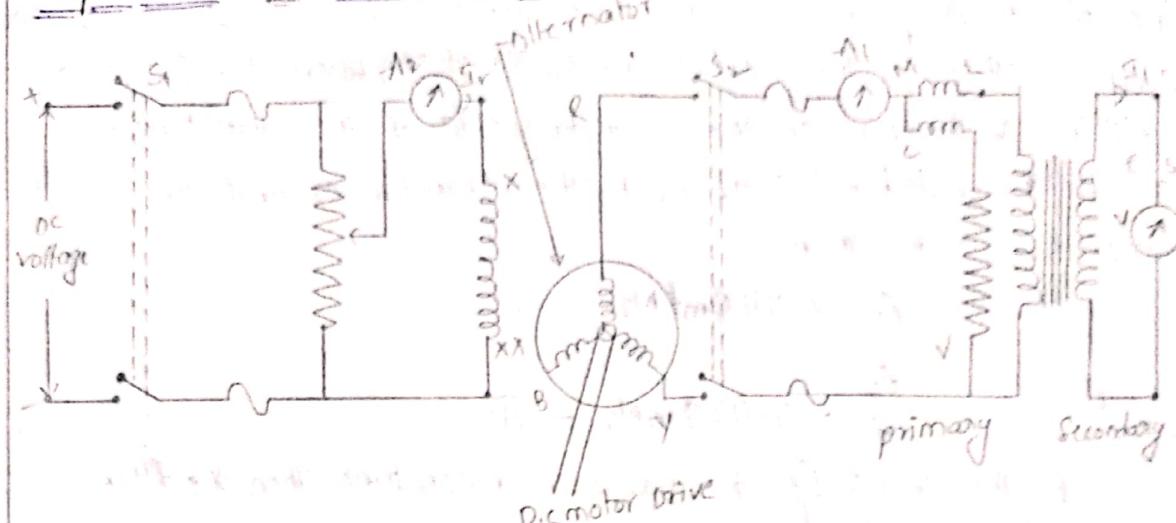
Short-circuit test will give full-load copper losses at a full-load current of  $I_{sc}$ . If the current value is other than full-load current ( $I_{sc}$ ), the copper losses for that current is  $\left(\frac{I_{PL}}{I_{sc}}\right)^2 \times W_{sc}$ .

Sumpner's Test (Back to Back OR Load TEST)



The efficiency of a transformer can be determined by conducting OC and SC tests. However a full load test is necessary to determine the temperature rise. A small transformer can be put on full load by means of a suitable load impedance. But for large transformers,

## Separation of losses in a transformer



The iron losses in a transformer consists of hysteresis and eddy current losses. When the flux density ( $B_{max}$ ) employed in the core is constant then the hysteresis loss is proportional to frequency.

$$\text{Then, hysteresis loss} \propto f \quad \text{--- (1)}$$

$$\text{and eddy current loss} \propto f^2 \quad \text{--- (2)}$$

$$\text{i.e. eddy current loss} = Bf^2$$

then the no-load loss can be expressed as:

$$w_c = Af + Bf^2 \quad (\text{where } A \text{ and } B \text{ are constants})$$

$$\text{i.e., } \frac{w_c}{f} = A + B.f. \quad \text{--- (3)}$$

If  $\frac{w_c}{f}$  is plotted on the y-axis and  $f$  is plotted on the x-axis, the graph is a straight line as shown in fig. The intercept on the y-axis gives the constant  $A$  and  $B$ , the hysteresis and the eddy current losses can be determined at any desired frequency using the expression (1) & (2). The relationship between  $w_c$  and  $f$  gives by equation (3), can be determined experimentally using the circuit arrangement shown in fig.

The arrangement shows a variable frequency alternator connected to the HF under test to supply the primary voltage. The alternator is driven by D.C shunt motor whose speed can be varied over a wide range. The switches  $S_1$  and  $S_2$  are opened and the alternator is started with the help of the D.C.

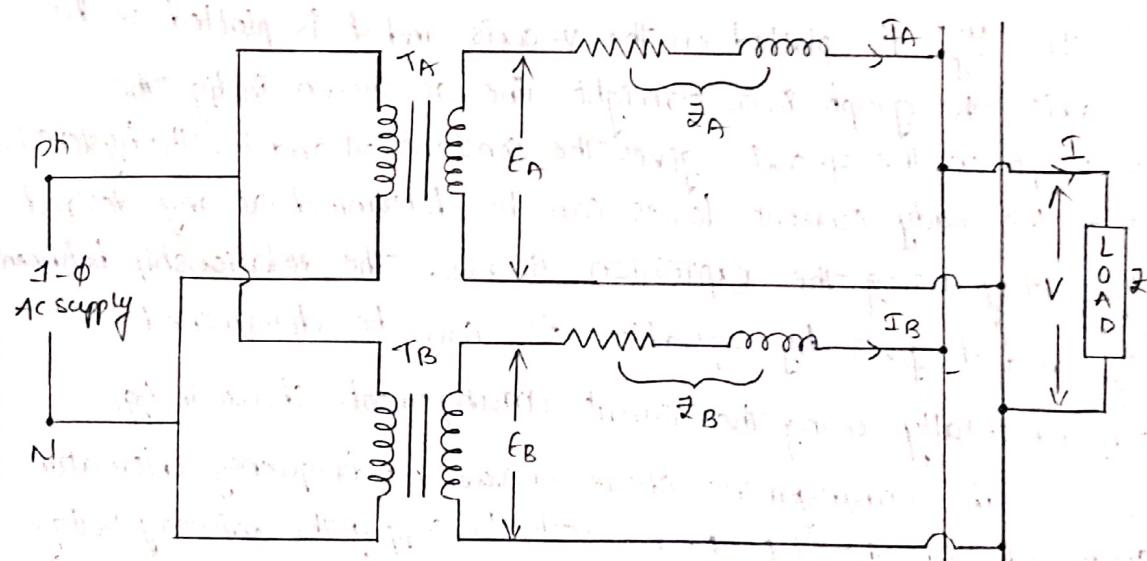
motor and the speed is adjusted to a value corresponding to the rated frequency of the transformer. The D.C. excitation current through the field coil X, XX of the alternator is varied until the voltmeter on the secondary side of the transformer reads the rated value. If  $E_2$  is the transformer emf on Secondary side then

$$E_2 = 4.44 \Phi m f N_2$$

i.e.,  $\frac{E_2}{f} = 4.44 \Phi m N_2 - (1)$

If the ratio  $\frac{E_2}{f}$  is maintained constant, then the flux density in the transformer remains constant. This is achieved by varying the frequency of the alternator e.m.f such that  $\frac{E_2}{f}$  remains constant. If necessary  $f$  can be adjusted to vary  $E_2$  to keep  $\frac{E_2}{f}$  constant. The readings of the wattmeter (W) are noted down for different frequencies above and below the rated value. Then the graph  $\frac{W}{f}$  vs  $f$  is drawn to determine the constants A and B and the hysteresis and eddy current losses are determined using the expression given by equations ①. and ②.

\* parallel operation with equal and unequal voltage ratios:-



## Equal voltage Ratio:-

$$I = I_A + I_B$$

$$I_A \rightarrow V = E_A - I_A Z_A \quad \text{--- (1)}$$

$$I_B \rightarrow V = E_B - I_B Z_B \quad \text{--- (2)}$$

Equaling Equations (1) & (2)

$$E_A - I_A Z_A = E_B - I_B Z_B$$

$$\boxed{E_A = E_B}$$

$$I_A Z_A = I_B Z_B = I Z_{AB}$$

$Z_{AB}$  is equal impedance, combine  $Z_A$  and  $Z_B$ .

$$Z_{AB} = \frac{Z_A Z_B}{Z_A + Z_B}$$

$$I_A Z_A = I Z_{AB}$$

$$I_A = \frac{I Z_{AB}}{Z_A}$$

$$I_A = \frac{I}{Z_A} \times \frac{Z_A \times Z_B}{Z_A + Z_B}$$

$$I_A = \frac{I Z_B}{Z_A + Z_B} \quad \text{--- (3)}$$

Similarly,

$$I_B = \frac{I Z_A}{Z_A + Z_B}$$

Multiplying equation (3) with 'V' on Both sides.

$$V I_A = \frac{V I Z_B}{Z_A + Z_B}$$

$S = VI \rightarrow$  output load kVA of Transformer.

$$S_A = \frac{S Z_B}{Z_A + Z_B}$$

## Unequal voltage Ratio:-

$$I_A = \frac{E_A Z_B + (E_A - E_B) Z}{Z(Z_A + Z_B) + Z_A Z_B}$$

$$\mathcal{D}_B = \frac{\epsilon_B \mathfrak{Z}_A - (\epsilon_A - \epsilon_B) \mathfrak{Z}}{2(\mathfrak{Z}_A + \mathfrak{Z}_B) + \mathfrak{Z}_A \mathfrak{Z}_B}$$

$$\mathfrak{T} = \mathcal{D}_A + \mathcal{D}_B$$

$$= \frac{\epsilon_A \mathfrak{Z}_B + (\epsilon_A - \epsilon_B) \mathfrak{Z}}{2(\mathfrak{Z}_A + \mathfrak{Z}_B) + \mathfrak{Z}_A \mathfrak{Z}_B} + \frac{\epsilon_B \mathfrak{Z}_A - (\epsilon_A - \epsilon_B) \mathfrak{Z}}{2(\mathfrak{Z}_A + \mathfrak{Z}_B) + \mathfrak{Z}_A \mathfrak{Z}_B}$$

$$= \frac{\epsilon_A \mathfrak{Z}_B + \epsilon_B \mathfrak{Z}_A}{2(\mathfrak{Z}_A + \mathfrak{Z}_B) + \mathfrak{Z}_A \mathfrak{Z}_B} \quad \text{--- (4)}$$

Equation (4) is divided with  $\mathfrak{Z}_A \mathfrak{Z}_B$

$$\mathfrak{T} = \frac{\frac{\epsilon_A \mathfrak{Z}_B}{\mathfrak{Z}_A \mathfrak{Z}_B} + \frac{\epsilon_B \mathfrak{Z}_A}{\mathfrak{Z}_A \mathfrak{Z}_B}}{\frac{2(\mathfrak{Z}_A + \mathfrak{Z}_B)}{\mathfrak{Z}_A \mathfrak{Z}_B} + \frac{\mathfrak{Z}_A \mathfrak{Z}_B}{\mathfrak{Z}_A \mathfrak{Z}_B}}$$

$$\mathfrak{T} = \frac{\epsilon_A / \mathfrak{Z}_A + \epsilon_B / \mathfrak{Z}_B}{1 + \frac{\mathfrak{Z}_A}{\mathfrak{Z}_A \mathfrak{Z}_B} + \frac{\mathfrak{Z}_B}{\mathfrak{Z}_A \mathfrak{Z}_B}}$$

$$\mathfrak{T} = \frac{\epsilon_A / \mathfrak{Z}_A + \epsilon_B / \mathfrak{Z}_B}{1 + \mathfrak{Z} / \mathfrak{Z}_B + \mathfrak{Z} / \mathfrak{Z}_A}$$

$$V = \mathfrak{T} \mathfrak{Z}$$

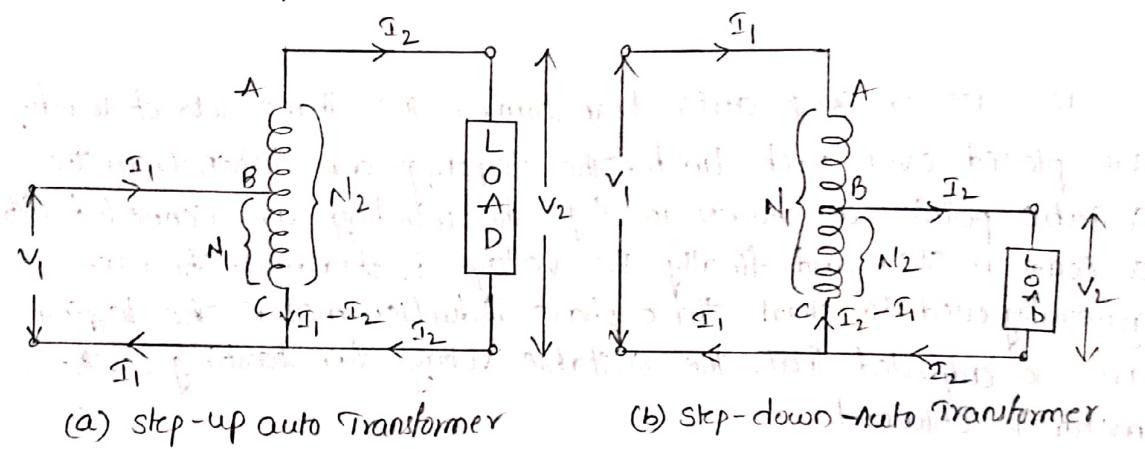
$$= \left( \frac{\epsilon_A / \mathfrak{Z}_A + \epsilon_B / \mathfrak{Z}_B}{1 + \mathfrak{Z} / \mathfrak{Z}_B + \mathfrak{Z} / \mathfrak{Z}_A} \right) \cdot \mathfrak{Z}$$

$$= \frac{\epsilon_A / \mathfrak{Z}_A + \epsilon_B / \mathfrak{Z}_B}{\frac{1}{\mathfrak{Z}} + \frac{1}{\mathfrak{Z}_B} + \frac{1}{\mathfrak{Z}_A}}$$

$$V = \boxed{\frac{\epsilon_A / \mathfrak{Z}_A + \epsilon_B / \mathfrak{Z}_B}{\frac{1}{\mathfrak{Z}} + \frac{1}{\mathfrak{Z}_B} + \frac{1}{\mathfrak{Z}_A}}}$$

## \* Auto-Transformers:

-A transformer with only one winding is known as Auto-transformer. An auto-transformer works on the principle of self induction i.e. whenever the current changes in a coil, the change of flux linking with the same coil induces a voltage in the same coil. This induced e.m.f is used for the practical purpose.



Construction:- An auto-transformer has only one winding, a part of the winding is common to both primary and secondary as shown in fig. The single winding is wound on a laminated silicon steel core. The two winding core connected electrically as well as magnetically. Therefore, power is transferred from primary to the Secondary conductively as well as inductively. It has one continuous winding with tappings for different voltages. The Secondary voltage depends upon the number of turns on primary and secondary i.e.,  $V_2 = V_1 \times \frac{N_2}{N_1}$ .

There are two types of auto-transformers namely Step-up auto-transformer and step-down auto-transformer. An auto-transformer appears to be similar to a resistive potential divider, but its operation is quite different. A resistive potential divider cannot step-up the voltage, whereas an auto-transformer can step-up the voltage.

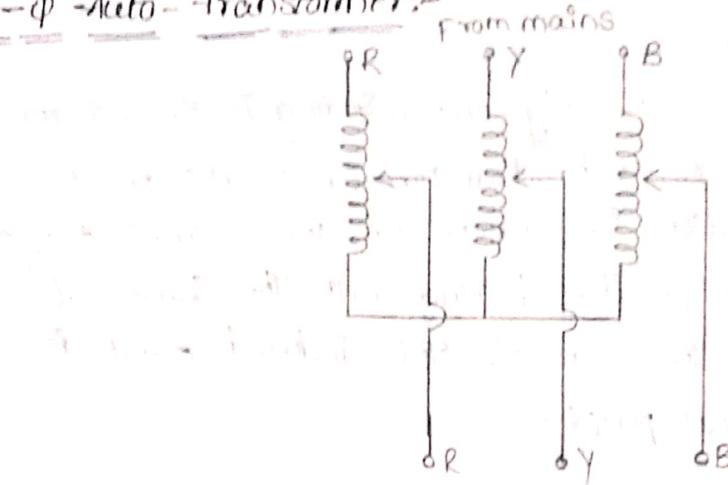
The power transferred inductively.

$$= \text{Input} \times (1 - K)$$

The power transferred conductively

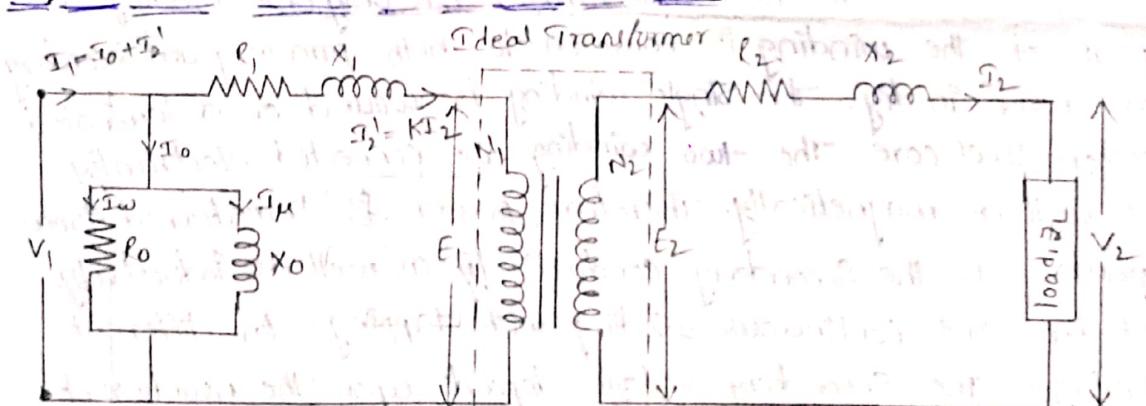
$$= \text{Input} \times K \quad (K = \text{Transformation ratio})$$

### 3- $\phi$ Auto-transformer:-



In case of 3- $\phi$  auto-transformer - the three sets of winding are placed over each limb. The tappings are taken from the suitable points as shown in fig. The windings are connected with a common star and finally the voltage is obtained. These are generally used to start three phase induction motors. The tappings are so adjusted that the suitable voltage for starting of the motor is obtained.

### Equivalent circuit of a Transformer:-



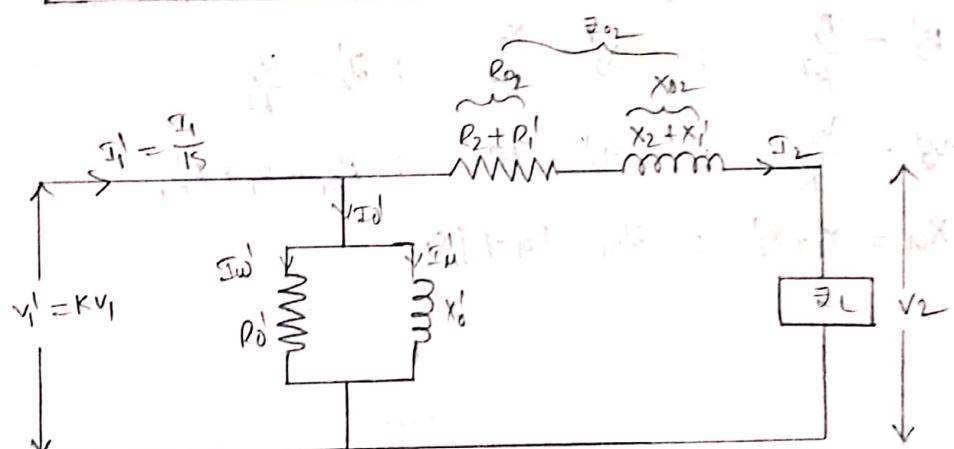
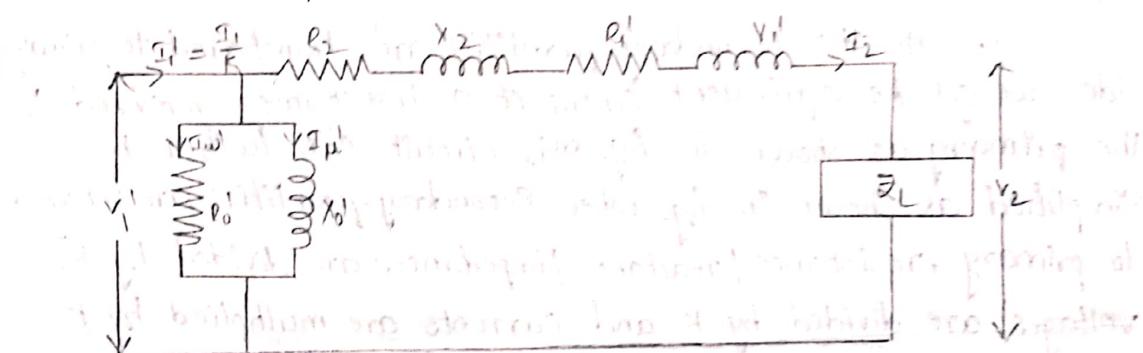
The equivalent circuit is useful to know the performance and behaviour of a transformer. Using the equivalent circuit, the analysis of the transformer can be done by the direct application of electric circuit theory. Fig. shows the equivalent circuit of a transformer on load. The primary winding has a resistance of  $R_1$  and leakage reactance of  $X_1$ . The secondary winding has a resistance of  $R_2$  and leakage reactance of  $X_2$ . The parallel circuit consisting of  $R_0$  and  $X_0$  is the no-load equivalent circuit of a transformer. The resistance  $R_0$  represents the effect of core loss. The current  $I_{0w}$  passing through  $R_0$  and

## 2: Referred to Secondary:-

If all the primary quantities are transferred to Secondary side, we get the equivalent circuit of a transformer referred to Secondary as shown in fig. when primary quantities are referred to Secondary, resistance/reactance/impedance are multiplied by  $k^2$ , voltages are multiplied by  $k$  and currents are divided by  $k$ .

$$R'_1 = k^2 R_1 ; X'_1 = k^2 X_1 ; Z'_1 = k^2 Z_1 ; V'_1 = k V_1$$

$$I'_1 = \frac{I_1}{k} ; P_{02} = P_2 + P'_1 ; X_{02} = X_2 + X'_1 ; Z_{02} = R_{02} + j X_{02}$$

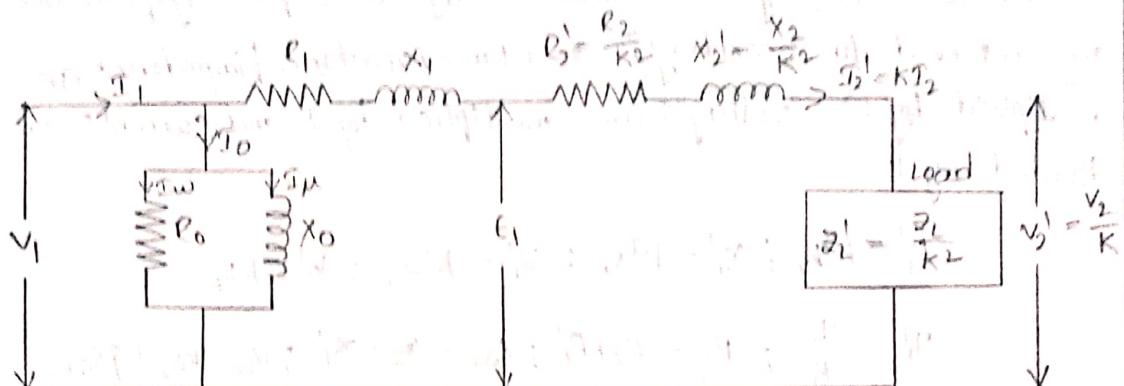


## \* Three-phase Transformers:-

Like 1- $\phi$ -transformers, the 3- $\phi$  transformers are also of the core-type or shell-type. Generally the core-type construction is used. In 3- $\phi$  core-type transformers, the cores have three limbs, one limb for each phase winding, the width of each limb is same as shown in fig. The 3- $\phi$  shell-type transformers may have three or five limbs, the winding is done only on the internal limbs as shown in fig.

and supplying the core losses, the reactance  $X_0$  is a loss-free coil through which magnetising current  $I_\mu$  is passing. The vector sum of  $I_0$  and  $I_\mu$  is the no-load primary current  $I_0$ .

#### Equivalent circuit referred to primary:

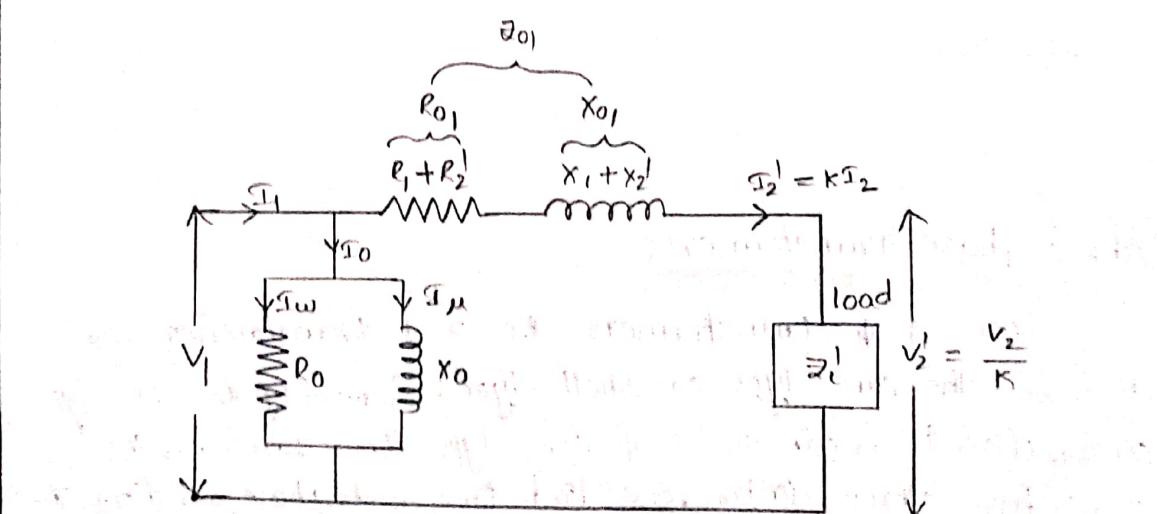


If all the secondary quantities are transferred to primary side, we get the equivalent circuit of a transformer referred to the primary as shown in fig. This circuit can further be simplified as shown in fig. when secondary quantities are referred to primary, resistance/reactance/impedances are divided by  $K^2$ , voltages are divided by  $K$  and currents are multiplied by  $K$ .

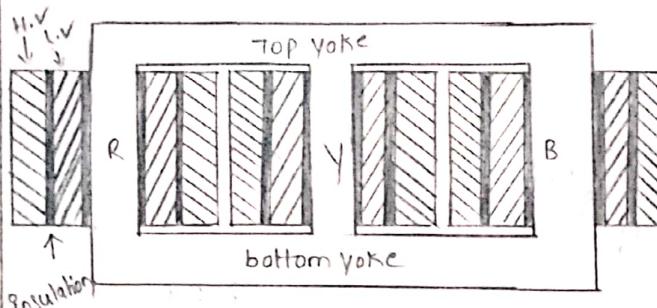
$$R_2' = \frac{R_2}{K^2} ; \quad X_2' = \frac{X_2}{K^2} ; \quad Z_2' = \frac{Z_2}{K^2}$$

$$V_2' = \frac{V_2}{K} ; \quad I_2' = K I_2 ; \quad R_{01} = R_1 + R_2'$$

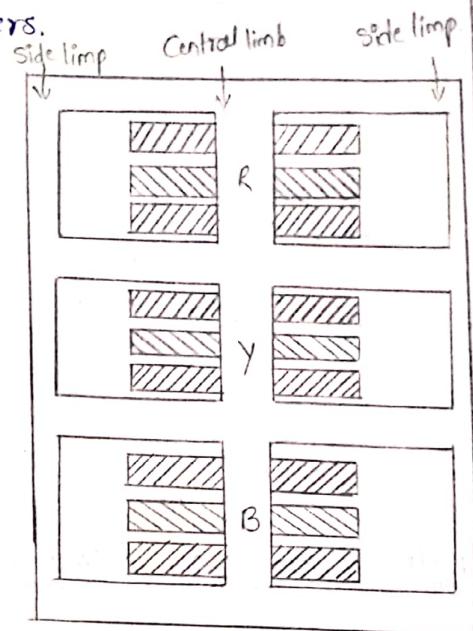
$$X_{01} = X_1 + X_2' ; \quad Z_{01} = R_{01} + j X_{01}.$$



7  
The principle of operation, construction of 3- $\phi$ -transformers is same as that of 1- $\phi$  transformers.



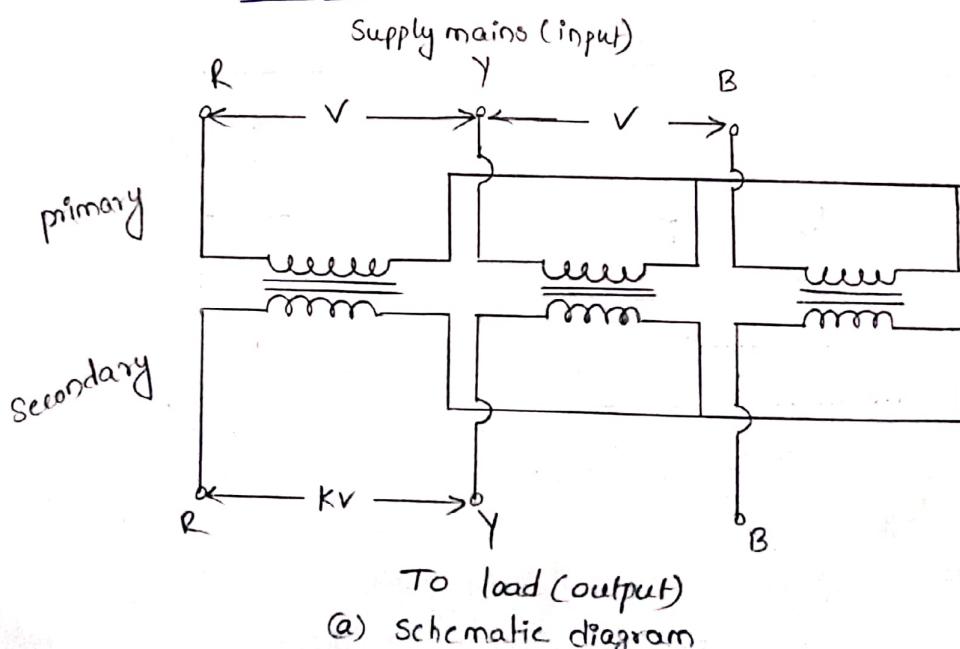
(a) 3- $\phi$  core type T/F

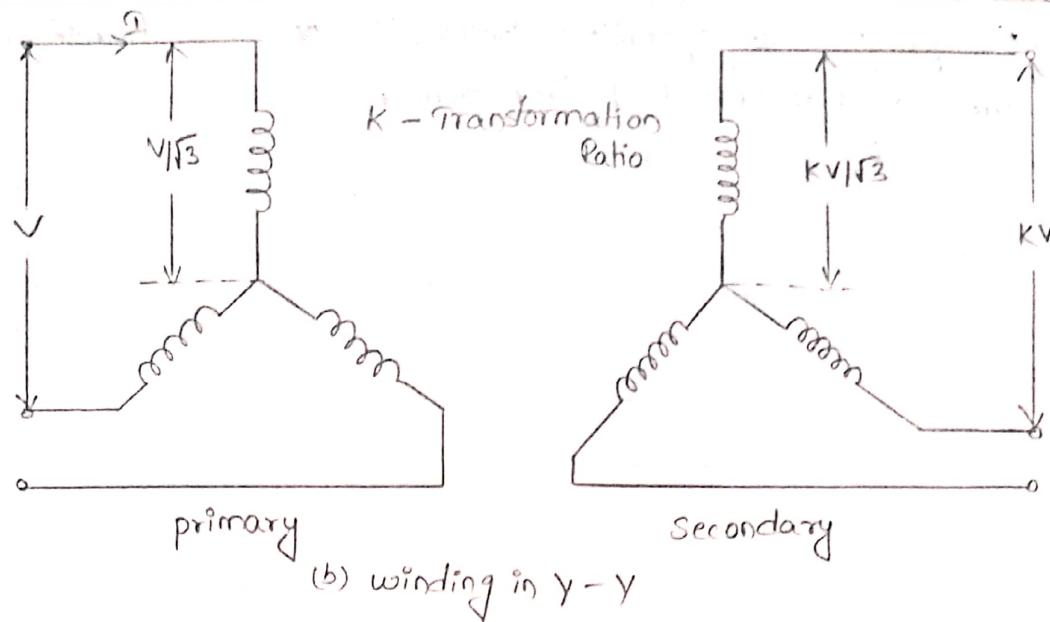


In 3- $\phi$  T/F, each limb carries the primary and secondary windings. On each limb the L.V winding is placed over the core and the H.V winding is placed over the L.V winding. A suitable insulation is provided b/w the core and L.V winding and also b/w two windings. So there are three sets of primary and three sets of secondary windings. The windings may be cylindrical or sandwich type of coils. The coils can be connected either in star (Y-star) or delta. The possible connections are Star (Y-Y), Delta-Delta ( $\Delta-\Delta$ ), Star-Delta ( $Y-\Delta$ ), Delta-Star ( $\Delta-Y$ ) as per the requirement.

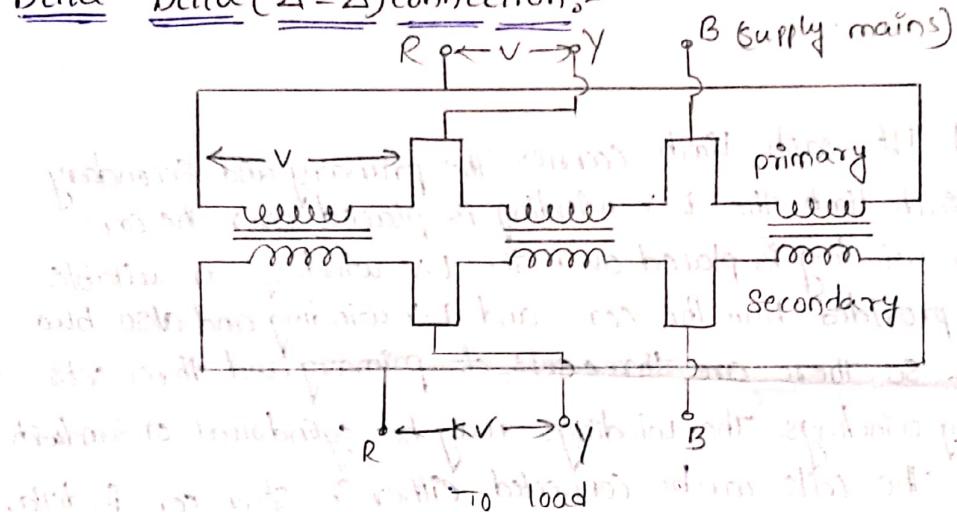
#### 3- $\phi$ T/F connections:-

##### Star - star (Y-Y) connection:-



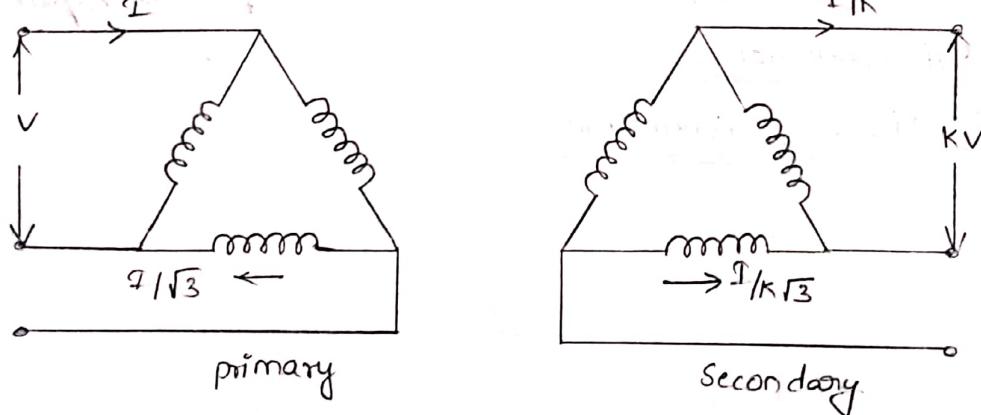


\*  $\Delta - \Delta$  ( $\Delta - \Delta$ ) connection:-



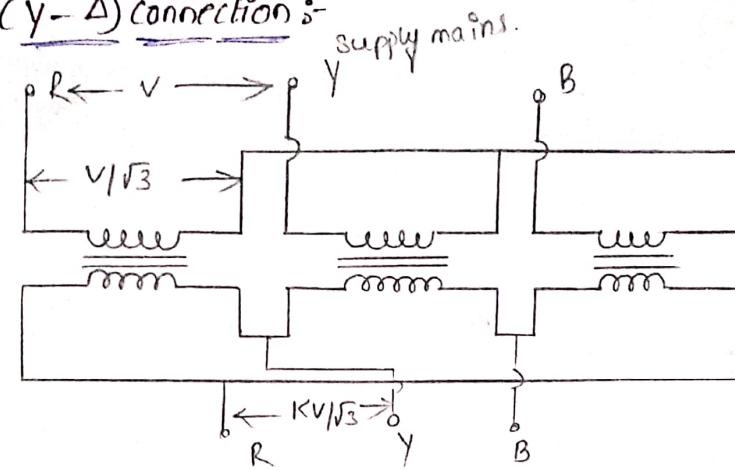
(a) Schematic diagram.

Primary voltage  $V$  & secondary voltage  $KV$  are same.

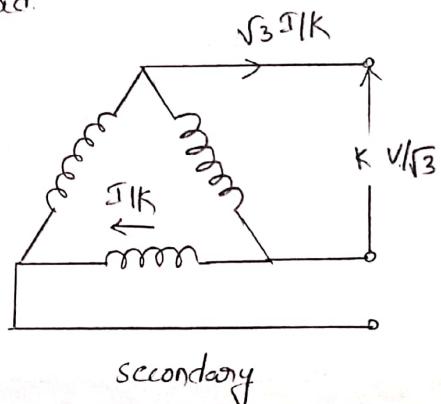
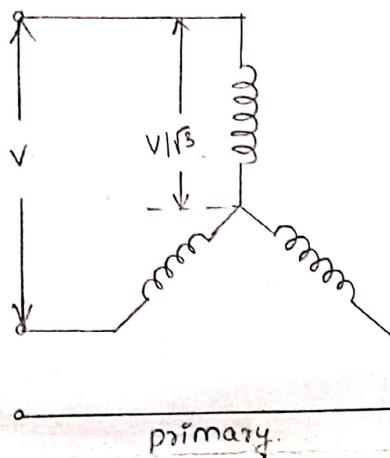


(b) windings in " $\Delta - \Delta$ "

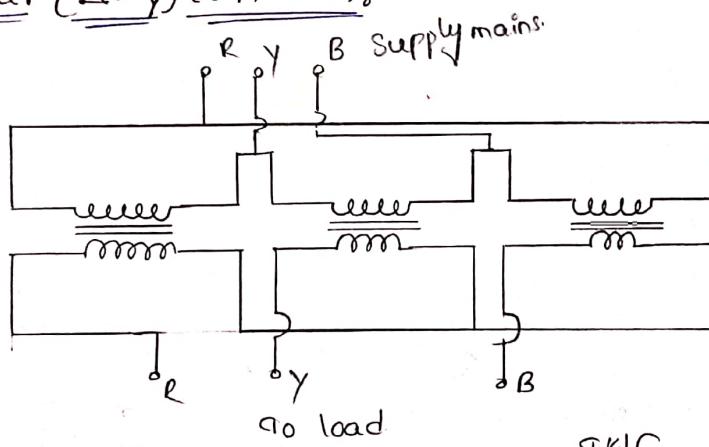
\* Star-Delta ( $\gamma - \Delta$ ) connection :-



To load.



\* Delta-Star ( $\Delta-\gamma$ ) connection :-



To load

