Parallel operation of Single phase transformers:-

For supplying a load in excess of the rating of an existing transformer, a second transformer may be connected in parallel with it.

Conditions for parallel operation are -

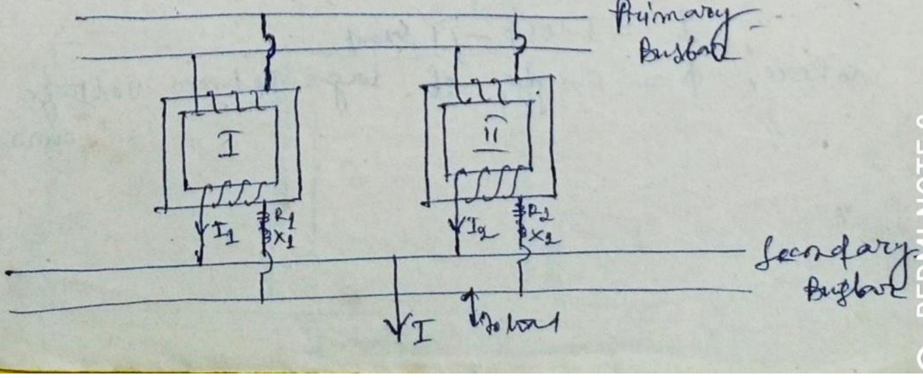
(i) Primary windings of the transformers should be suitable for the supply system voltage and frequency.

(ii) The transformers should be properly connected with regard to polarity.

(iii) The voltage ratings of both primaries and secondaries should be identical.

(iv) The percentage impedances should be equal in magnitude & and have the same $\frac{X}{R}$ - ratio in order to avoid circulating currents and operation at different power - factors.

(v) With transformers having different KVA - ratings, the equivalent impedances should be inversely proportional to the individual KVA - rating if circulating currents are to be avoided.



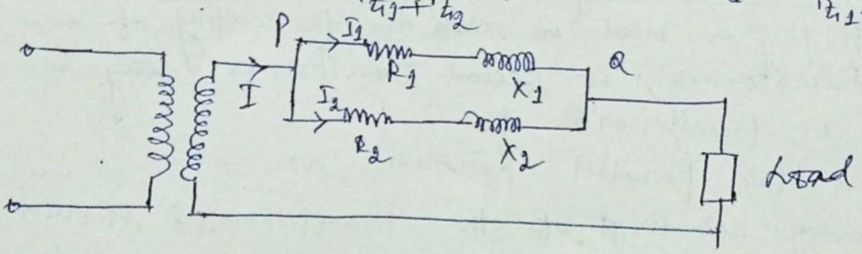
If the transformation ratios are same, the voltages across the secondary terminals will be the same. When these are connected to form a secondary bus, the voltage will not vary with the changing load.

If $\frac{R_1}{X_1} = \frac{R_2}{X_2}$, then I_1 and I_2 will be in phase.

R_1, X_1 and R_2, X_2 — are equivalent resistances, reactances of transformers I and II — respectively.

$$\frac{I_1}{I_2} = \frac{Z_2}{Z_1} \quad \text{and} \quad I_1 + I_2 = I$$

$$\therefore \quad I_1 = \frac{Z_2}{Z_1+Z_2} \cdot I \quad \text{and} \quad I_2 = \frac{Z_1}{Z_1+Z_2} \cdot I$$



$Z_1 = R_1 + jX_1$ and $Z_2 = R_2 + jX_2$.

Currents, $I_1 = x_1 + jy_1$ and $I_2 = x_2 + jy_2$.

Since, voltage drop across PQ are same,

$$(R_1 + jX_1) I_1 = (R_2 + jX_2) I_2$$

and $I_1 + I_2 = I$.

$$\therefore \quad I_1 = \frac{(R_2 + jX_2)\, I}{(R_1 + R_2) + j(X_1 + X_2)}$$

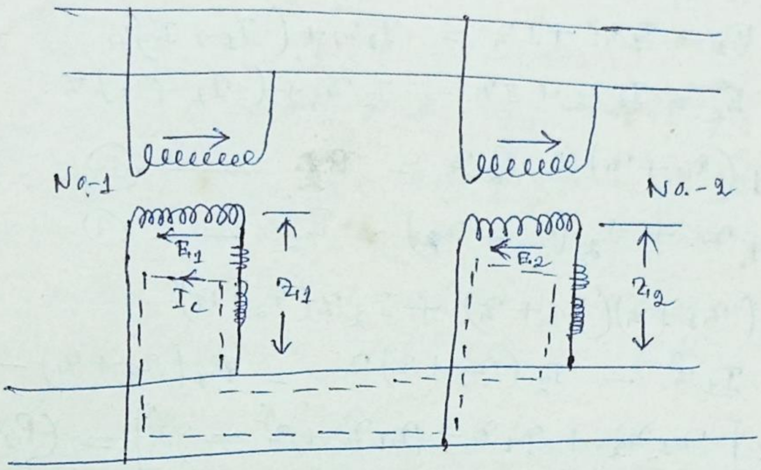
$$I_2 = \frac{(R_1 + jX_1)\, I}{(R_1 + R_2) + j(X_1 + X_2)}$$

Taking ~~V_2 as~~ secondary terminal voltage V_2 as reference vector, $V_2 = V_2 + j0$,

$$I = I\cos\phi - jI\sin\phi.$$

where, ϕ = angle of lag between voltage and current.

Inequality of turns ratio :-



If the turns-ratios are not equal, the secondary induced e.m.f.s are not equal. The inequality will produce a circulating current which will flow even on no-load condition. On-load, this circulating current will be super-imposed on the load currents.

Let, $E_1 > E_2$.

$\therefore$ Difference in voltage acting on the local circuit,

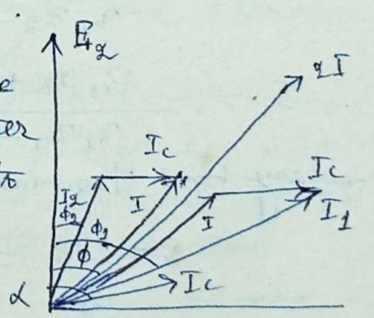
$$E_c = E_1 - E_2.$$

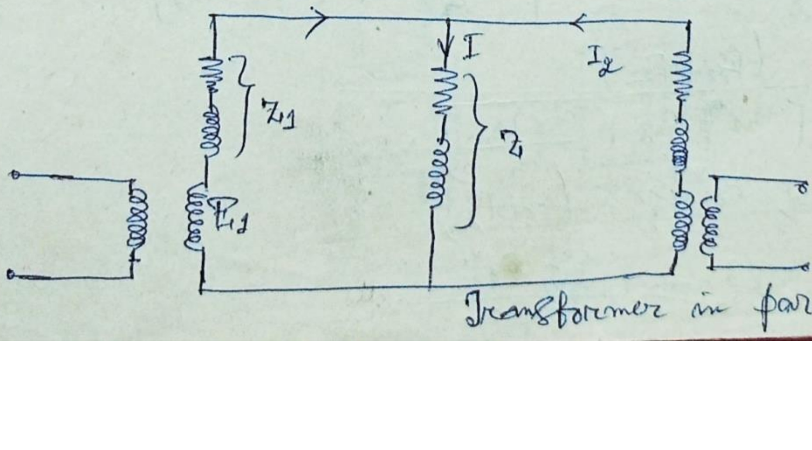
$$\therefore \quad I_c = \frac{E_1 - E_2}{Z_1 + Z_2}.$$

This current will lag E_2 by an angle α, where,

$$\alpha = \tan^{-1}\left(\frac{X_1 + X_2}{R_1 + R_2}\right).$$

It is seen that, the effect of circulating current is to reduce the power factor having the greater no-load induced e.m.f. and to increase the power factor of the other.





Transformer in parallel

Z_1, Z_2 — are transformer impedances
Z — is the load impedance.

$$E_1 = I_1 Z_1 + I Z = I_1 Z_1 + (I_1 + I_2) Z$$
$$E_2 = I_2 Z_2 + I Z = I_2 Z_2 + (I_1 + I_2) Z.$$

$$\therefore \quad I_1 (Z_1 + Z) + I_2 Z = E_1 \quad \text{—— (1)}$$
$$I_1 Z + I_2 (Z_2 + Z) = E_2 \quad \text{—— (2)}$$

$$\therefore \quad I_1 (Z_1 + Z)(Z_2 + Z) + I_2 Z (Z_2 + Z)$$
$$- I_1 Z^2 - I_2 (Z_2 + Z) Z = E_1 (Z_2 + Z) - E_2 Z$$

$$\Rightarrow \quad I_1 \left[Z_1 Z_2 + Z_2 Z + Z_1 Z + \cancel{Z^2} - \cancel{Z^2} \right] = (E_1 - E_2) Z + E_1 Z_2$$

$$\Rightarrow \quad I_1 = \frac{E_1 Z_2 + (E_1 - E_2) Z}{Z_1 Z_2 + (Z_1 + Z_2) Z}$$

$$I_1 (Z_1 + Z) Z + I_2 Z^2 - I_1 Z (Z_1 + Z) - I_2 (Z_2 + Z)(Z_1 + Z)$$
$$= E_1 Z - E_2 (Z_1 + Z)$$

$$\Rightarrow \quad I_2 \left[\cancel{Z^2} - Z_1 Z_2 - Z_1 Z - Z_2 Z - \cancel{Z^2} \right] = (E_1 - E_2) Z - E_2 Z_1$$

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

$$= \frac{E_2 Z_1 - (E_1 - E_2) Z}{Z_1 Z_2 + (Z_1 + Z_2) Z}.$$

$$\therefore \quad I = \frac{E_1 Z_2 + E_2 Z_1}{Z_1 Z_2 + (Z_1 + Z_2) Z}.$$

Secondary load terminal voltage,

$$V = I Z = \frac{(E_1 Z_2 + E_2 Z_1)}{\left[\frac{Z_1 Z_2}{Z} + (Z_1 + Z_2) \right]}$$

$$I_c = \frac{(E_1 - E_2)}{\left(Z_1 + Z_2 + \frac{Z_1 Z_2}{Z} \right)}.$$

At no-load, Z is infinity,

$$\therefore \quad I_c = \frac{E_1 - E_2}{Z_1 + Z_2}.$$