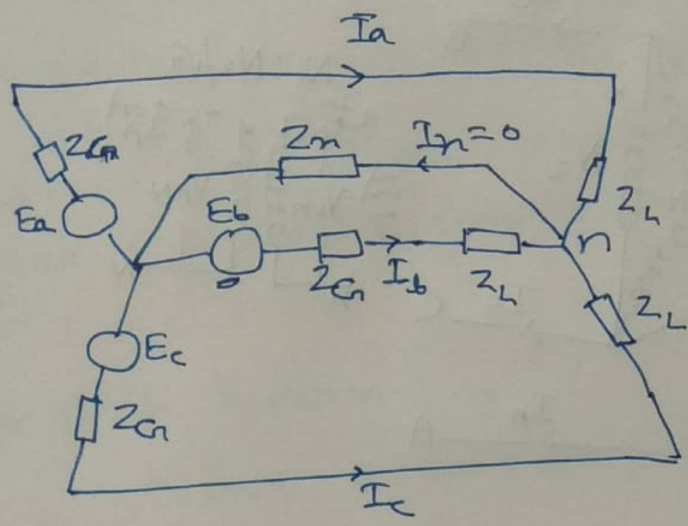
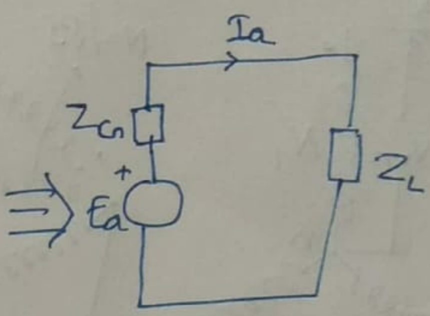
Module 1 :→ Representation of Power System Components

→ A Balanced three phase network can be represented by single phase representation. (Because for a balanced three phase network all the quantities like V_a, V_b, V_c will have same R.M.S. value but they will be having phase difference of 120° apart by solving equations for a single phase we can calculate all the three phase quantities

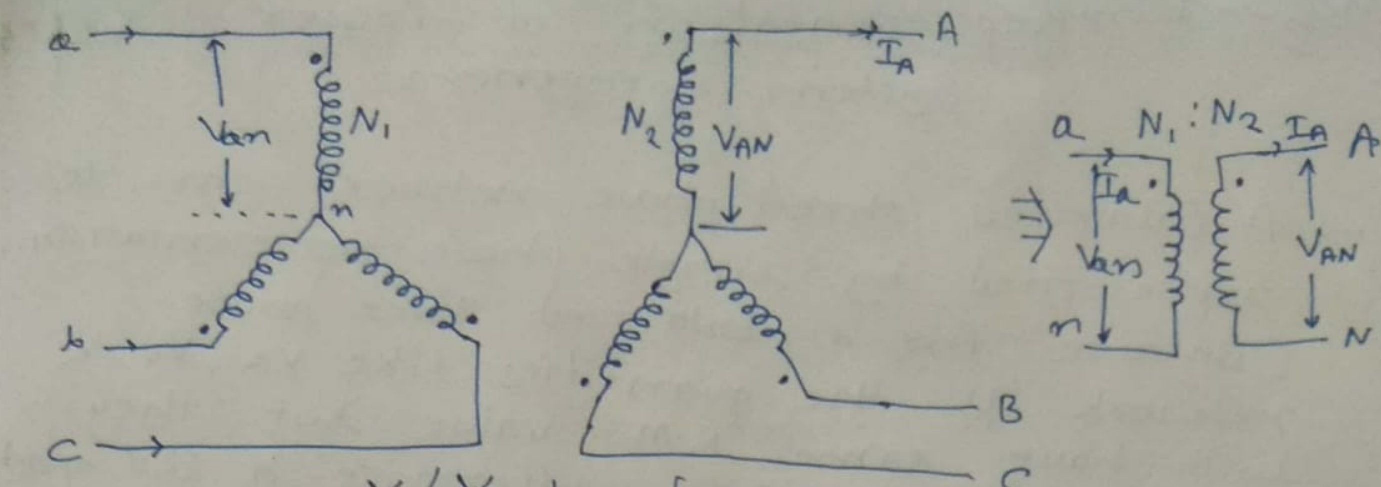




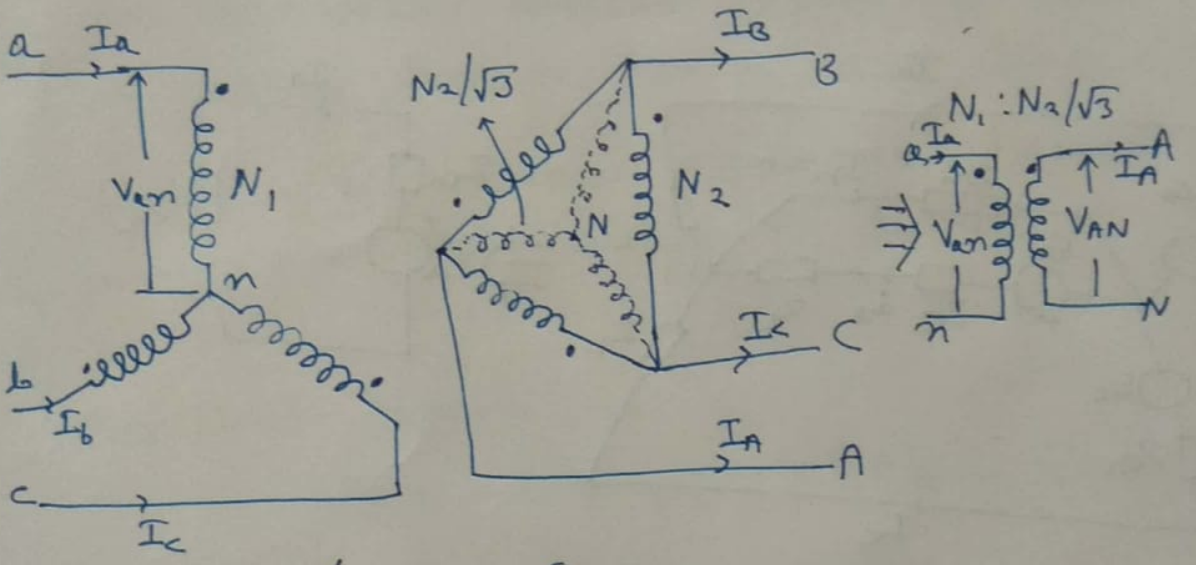
$|E_a|_{rms} = |E_b|_{rms} = |E_c|_{rms}$

$I_n = 0$ for balanced network

→ If the network is unbalanced then single phase representation cannot be used to represent three phase network.



Y/Y transformer



Y/Δ transformer

One-Line Diagram :→

→ One-line diagram of a power system show the main connections and arrangements of components.

→ Any particular component may or may not be shown depending on the information required in a system study, e.g. circuit breakers need not be shown in a load flow study but are a must for a protection study.

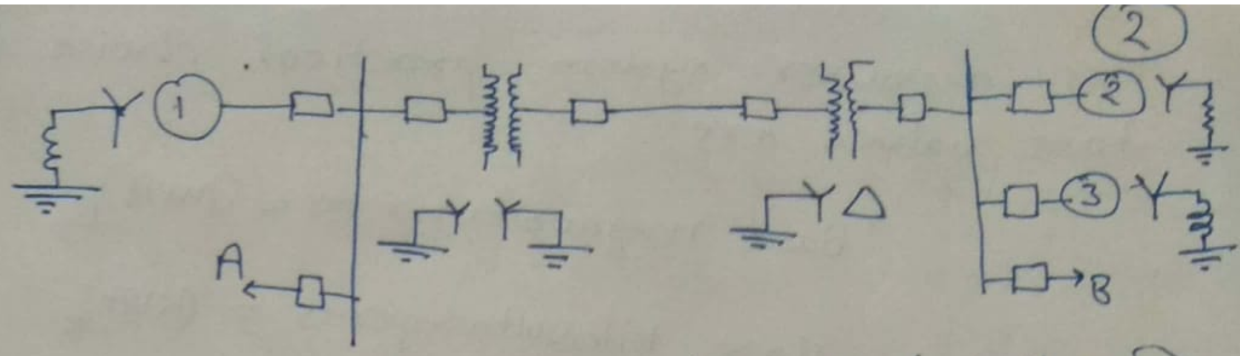


Fig. 4.5 from MPSA (Nagrath & Kothari)
One-line Diagram of a simple power system

The impedance diagram on single phase basis for use under balanced operating conditions can be easily drawn from one line diagram.

Exercise 1 :- Draw impedance diagram for the power network shown in Fig. 4.5

Per Unit System : →

Base voltamperes $= (VA)_B$

Base voltage $= V_B$

Base current $I_B = \frac{(VA)_B}{V_B}$ A

Base impedance $Z_B = \frac{V_B}{I_B} = \frac{V_B^2}{(VA)_B}$ Ω

$$Z_{(pu)} = \frac{Z}{Z_B} = \frac{Z(\Omega) \times (VA)_B}{V_B^2}$$

For a power system, practical choice of base values are:

$$\text{Base megavoltamperes} = (MVA)_B$$

$$\text{Base kilovoltamperes} = (KVA)_B$$

$$\text{Base kilovolts} = (KV)_B$$

$$Z_{pu} = \frac{Z_{ohm} \times (MVA)_B}{(kV)_B^2}$$

$$Z_{pu} = \frac{Z_{ohm} \times (KVA)_B}{(KV)_B^2 \times 1000}$$

In a three phase system:-

$$\text{Three-phase base megavoltamperes} = (MVA)_B$$

$$\text{Line-to-Line base kilovolts} = (KV)_B$$

For star connection

$$\text{Base current } I_B = \frac{1000 \times (MVA)_B}{\sqrt{3}\,(KV)_B} \text{ A}$$

$$\text{Base impedance } Z_B = \frac{1000 \times (KV)_B}{\sqrt{3}\, I_B}\ \Omega$$

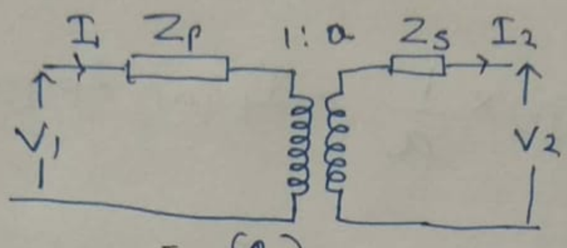
$$Z_B = \frac{1000 \times (KV)_B}{\sqrt{3} \times \frac{1000 \times (MVA)_B}{\sqrt{3}\,(KV)_B}}$$

$$Z_B = \frac{(KV)_B^2}{(MVA)_B}\ \Omega$$

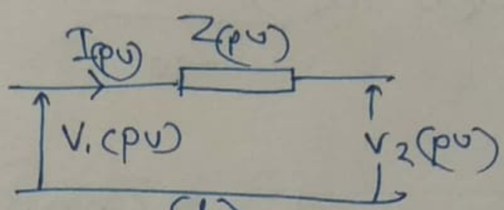
Changing Base :→

$$Z_{(pu)new} = Z_{(pu)old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(KV)^2_{B,old}}{(KV)^2_{B,new}}$$

Per-unit representation of a Transformer :-



(a)



(b)

$$\frac{V_{1B}}{V_{2B}} = \frac{1}{a}$$

$$\frac{I_{1B}}{I_{2B}} = a \quad [(VA)_B \text{ is common}]$$

$$Z_{1B} = \frac{V_{1B}}{I_{1B}}, \quad Z_{2B} = \frac{V_{2B}}{I_{2B}}$$

$$V_2 = (V_1 - I_1 Z_p)a - I_2 Z_s \quad \text{(from abov fig. a)}$$

$$V_{2(pu)} V_{2B} = [V_{1(pu)} V_{1B} - I_{1(pu)} I_{1B} Z_{p(pu)} Z_{1B}]a - I_{2(pu)} I_{2B} Z_{s(pu)} Z_{2B} \quad \text{— (I)}$$

Dividing (I) by V_{2B}

$$V_{2}(pu) = \left[V_1(pu) \frac{V_{1B}}{V_{2B}} - I_1(pu)\, Z_p(pu) \frac{I_{1B} Z_{1B}}{V_{2B}} \right] a$$

$$- \frac{I_2(pu)\, I_{2B}\, Z_s(pu)\, Z_{2B}}{V_{2B}}$$

$$V_2(pu) = \left[V_1(pu) \times \frac{1}{a} - I_1(pu)\, Z_p(pu) \frac{I_{1B} Z_{1B}}{a V_{1B}} \right] a$$

$$- I_2(pu)\, Z_s(pu) \frac{Z_{2B}}{Z_{2B}}$$

$$V_{2}(pu) = V_1 pu - I_1(pu) Z_p(pu) - I_2(pu) Z_s(pu) \quad -\text{(II)}$$

now $\frac{I_{1B}}{I_{2B}} = a = \frac{I_1}{I_2}$

$$\frac{I_1}{I_{1B}} = \frac{I_2}{I_{2B}}$$

$$I_1(pu) = I_2(pu) = I(pu) \quad -\text{(III)}$$

now from (III) & (II)

$$V_2(pu) = V_1(pu) - I_{pu} Z_{pu}$$

where $Z_{pu} = Z_p(pu) + Z_s(pu)$

On primary side: (4)

$$Z_1 = Z_p + Z_s/a^2$$

$$Z_{1(pu)} = \frac{Z_1}{Z_{1B}} = \frac{Z_p}{Z_{1B}} + \frac{Z_s}{Z_{1B}} \times \frac{1}{a^2}$$

$$a^2 Z_{1B} = Z_{2B}$$

$$Z_{1(pu)} = Z_{p(pu)} + Z_{s(pu)} = Z_{(pu)} \quad \text{— (IV)}$$

On secondary side:

$$Z_2 = Z_s + a^2 Z_p$$

$$Z_{2(pu)} = \frac{Z_2}{Z_{2B}} = \frac{Z_s}{Z_{2B}} + a^2 \frac{Z_p}{Z_{2B}}$$

$$\Rightarrow \quad Z_{2(pu)} = Z_{s(pu)} + Z_{p(pu)} = Z_{(pu)} \quad \text{— (V)}$$

from eq^n (IV) & (V) we can say that per unit impedance of a transformer is same whether computed from primary or secondary side so long as the voltage bases on the two sides are in the ratio of transformation (equivalent per phase ratio of a 3-ϕ X-mer which is same as the ratio of line-to-line voltage rating).

Per Unit Impedance Diagram of a power system :→

→ Choose an appropriate common MVA or KVA base

→ Consider the system to be divided into a number of sections by the transformer. Choose an appropriate KV base in one of the sections. Calculate

→ KV bases of other sections in the ratio of transformation.