DT009/3 , Electrical Energy Systems (Minor)

Three Phase Systems

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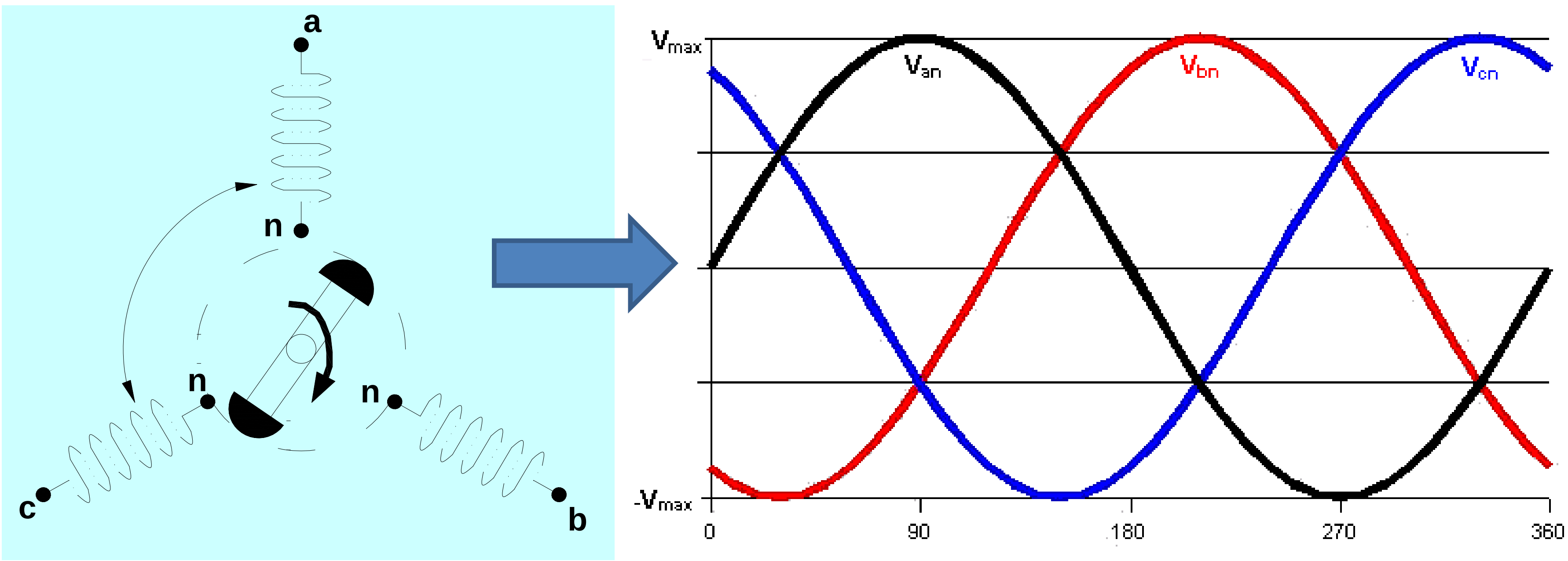
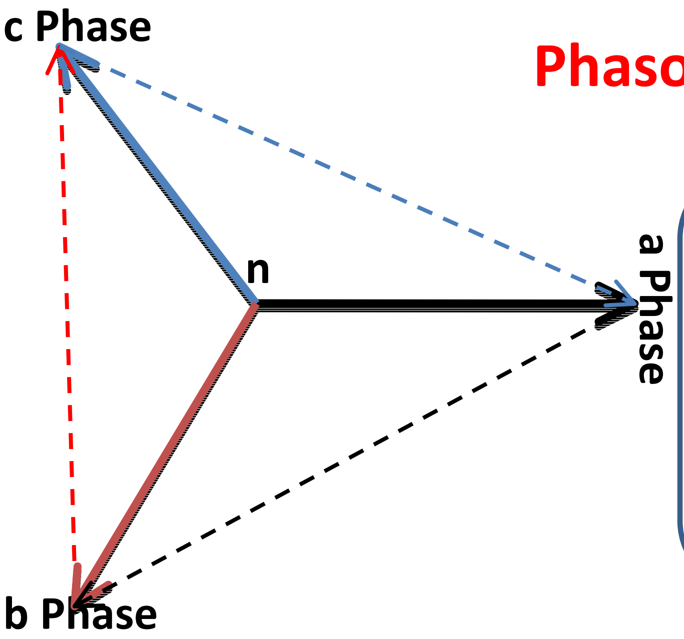


Sinusoidal voltages are induced in three coils placed 120^o out of phase with each other

Phasor Representation



Anticlockwise-abc Sequence

Clockwise-acb Sequence

V_{an}, V_{bn}, V_{cn} --Phase Voltages

V_{ab}, V_{bc}, V_{ca} --Line Voltages

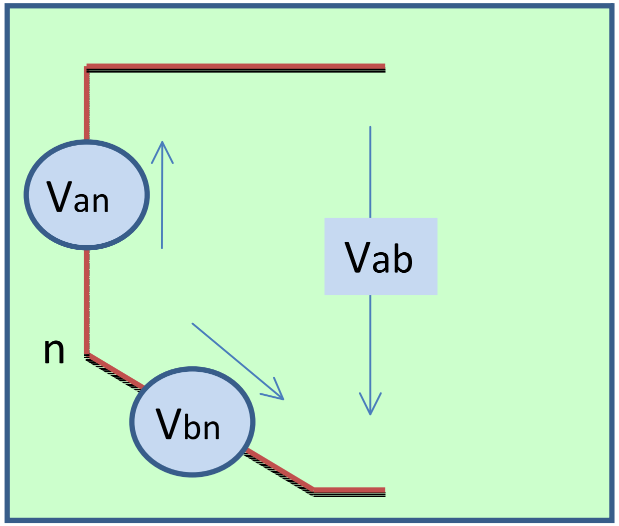
The induced voltages:

$V_{an} = V\ Sin\omega t$

$V_{bn} = V\ Sin\ (\omega t - 120^0)$

$V_{cn} = V\ Sin\ (\omega t - 240^0)$

Writing a KVL equation



Aside: $V_{ab} = V_{an} - V_{bn}$

$= V\angle 0^0 - V\angle -120^0$

$= V - V.e^{+j(-120^0)}$

Eulers rule:

$z = x + jy = |z|(Cos\theta + jSin\theta)$

$= |z|.e^{j\theta}$

$$\Rightarrow V_{ab} = V - V\{Cos(-120^0) + jSin(-120^0)\}$$

$$= V - V\left\{-0.5 - j\frac{\sqrt{3}}{2}\right\}$$

$$= V\left[1 - \left\{-0.5 - j\frac{\sqrt{3}}{2}\right\}\right]$$

$$= V\left[1 + 0.5 + j\frac{\sqrt{3}}{2}\right]$$

$$= V\left[\frac{3}{2} + j\frac{\sqrt{3}}{2}\right] = \sqrt{3}.V\left[\frac{\sqrt{3}}{2} + j\frac{1}{2}\right] = \sqrt{3}V\angle 30^0$$

$$\Rightarrow V_{ab} = \sqrt{3}.V\angle 30^0$$

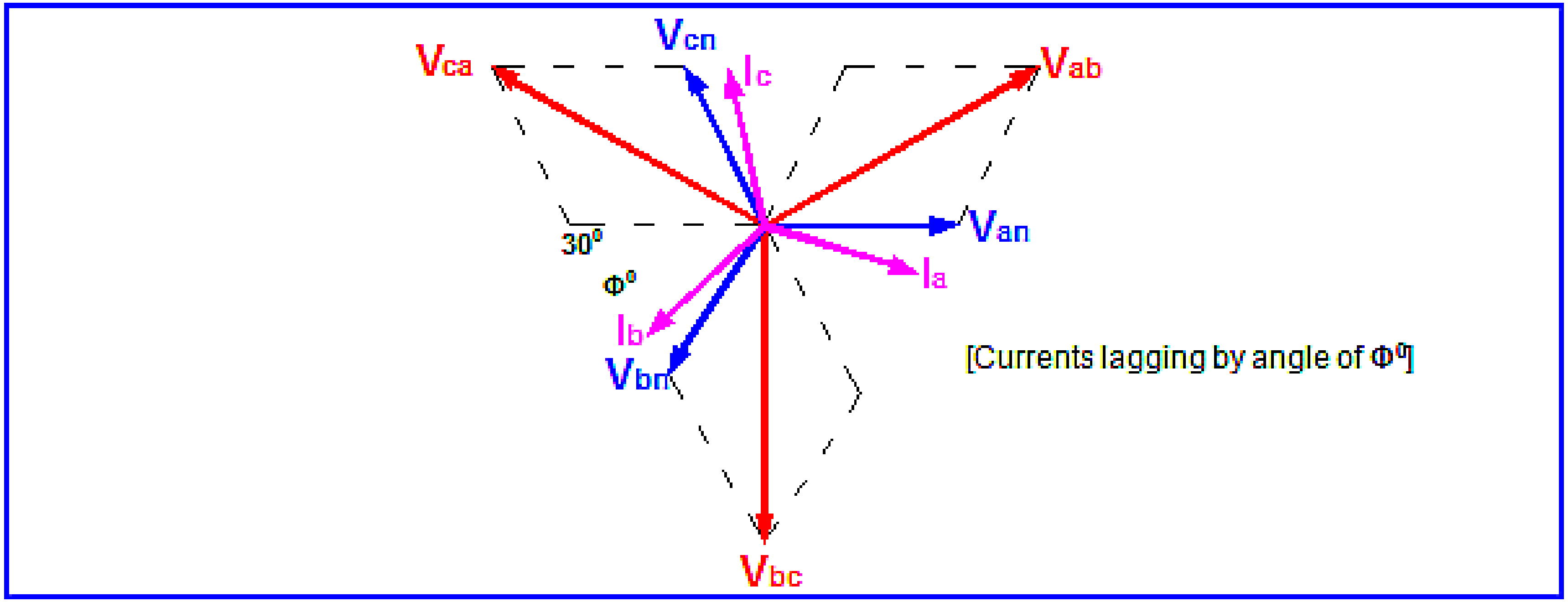
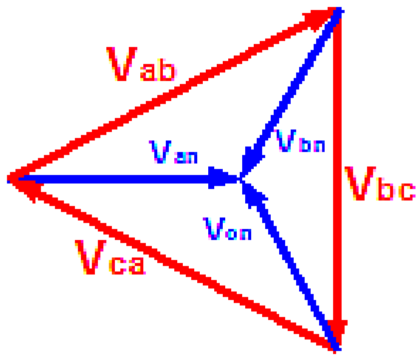


Figure 4: Phasor diagram of a star connected generator



Note: Since balanced line-to-line voltages form a closed triangle, their phasor sum is zero. Also in a balanced system, $\overline{V}_{an} + \overline{V}_{bn} + \overline{V}_{cn} = 0$

Example 1: **A balanced star-connected load is supplied from a symmetrical 3 wire, three-phase 400 V supply. The magnitude of the current in each phase is 30 A and lags 30° behind the respective phase voltage. The phase sequence is ABC and the reference phasor is V_{AN}.**

a) **Calculate the phase voltage magnitude and the active power.**
b) **Draw a phasor diagram showing the phase currents and the line-to-line voltages.**
c) **What are the active and reactive components of the "A" phase current?**

Solution:

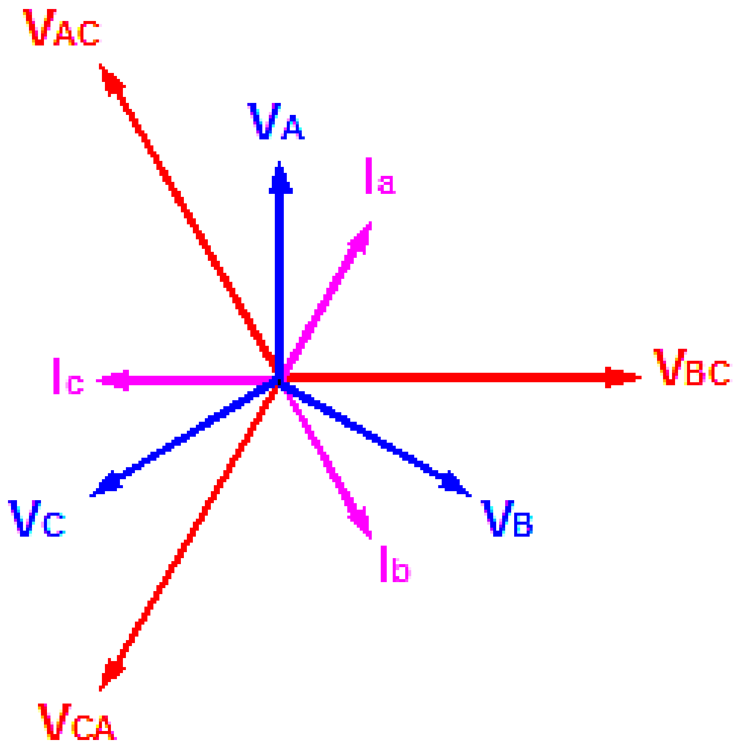
a) $$|V_{ph}| = \frac{|V_{Line}|}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 230.9 \qquad [V]$$

$$P = V.I.Cos\varphi \quad = \quad V.I.Cos30^0$$

$$= \quad (230.9).(30).Cos30^0$$
$$= \quad 6000 \quad [W/ph]$$

$$= \quad (6000).(3) \quad = \quad 18000 \quad [W]$$

b)



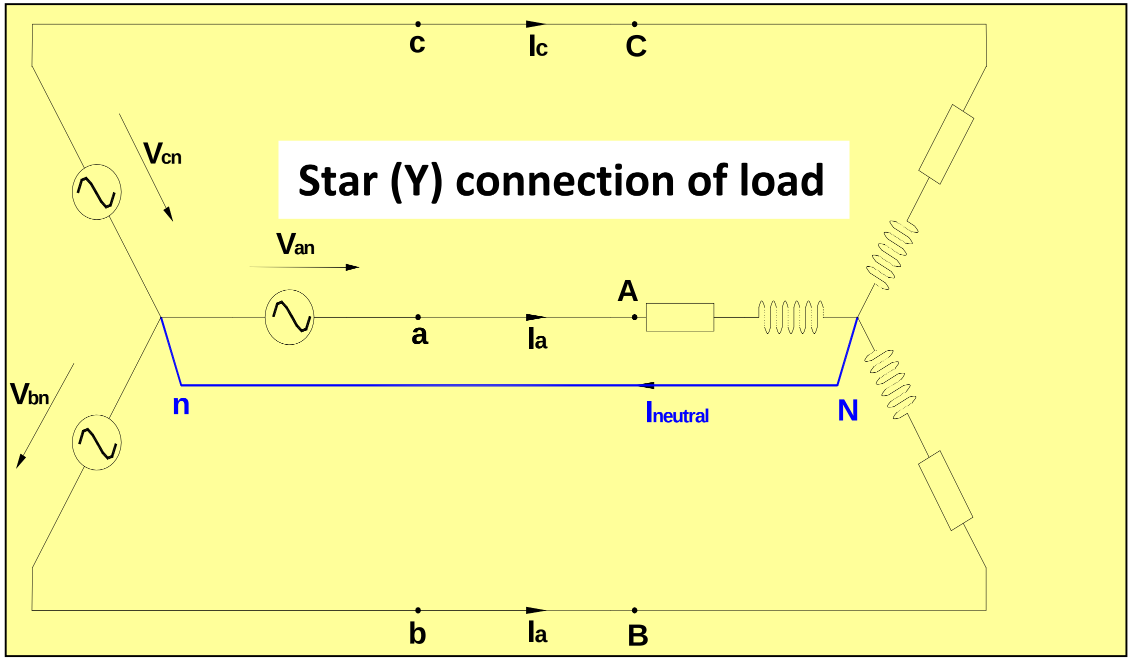
Phasor Diagram illustrating the phase currents and line-to-line voltages

Phasors are not drawn to scale

c) $I_a = 30\angle 30^0 \quad = \quad 25.98 - j15$

Active Reactive

Three Phase Connections



KVL for loop "a-A-N-n-a"

$$\Rightarrow V_{an} - I_a . Z\angle\phi = 0$$

$$\Rightarrow V_{an} = I_a Z\angle\phi$$

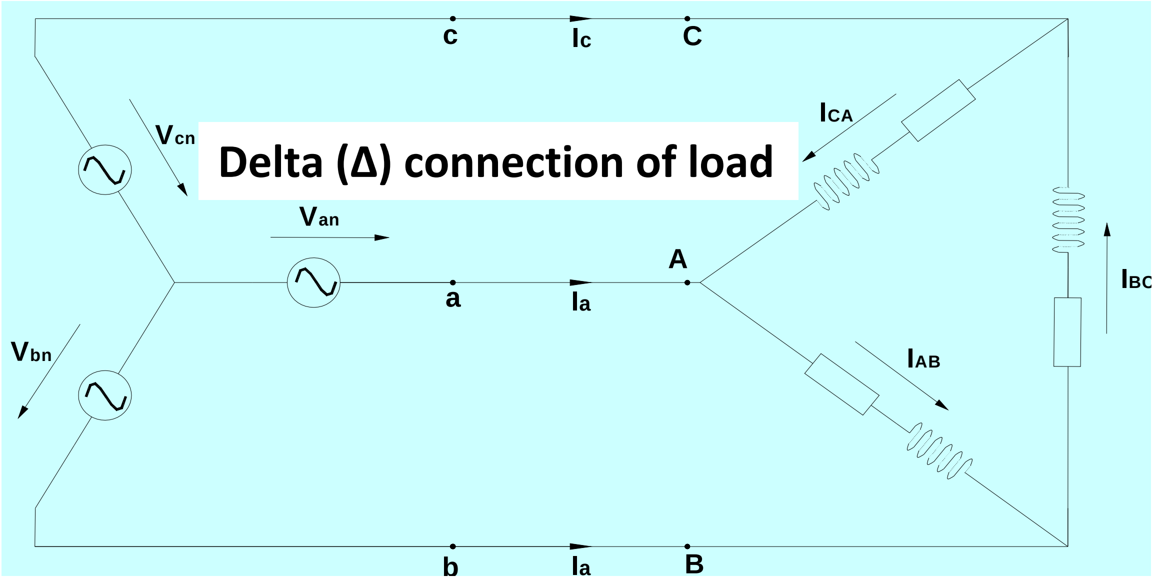
$$\Rightarrow I_a = \frac{V_{an}}{Z\angle+\phi} = \frac{V\angle 0}{Z\angle\phi} = \frac{V}{Z}\angle-\phi$$

$$I_b = \frac{V\angle-120}{Z\angle\phi} = \frac{V}{Z}\angle-120-\phi$$

$$I_c = \frac{V\angle+120}{Z\angle\phi} = \frac{V}{Z}\angle+120-\phi$$

- Line Currents are same as phase currents
- Electrically displaced by 120°, with magnitude V/Z
- Ineutral=Ia+Ib+Ic=0 for a balanced system
- Line voltages lead phase voltages by 30°
- Line voltages = √3*Phase voltages

Three Phase Connections Cntd...



Applying KVL to the loop "a-A-B-b-a" $\Rightarrow$ Phase current I_{AB} can be determined.

$$\Rightarrow V_{an} - I_{AB}.Z\angle\phi - V_{bn} = 0$$

$$\Rightarrow V_{an} - V_{bn} = I_{AB}.Z\angle\phi \quad \therefore \quad V_{ab} = I_{AB}.Z\angle\phi$$

$$\Rightarrow \frac{V_{ab}}{Z\angle\phi} = I_{AB} \Rightarrow \frac{\sqrt{3}.V\sqrt{30}}{Z\angle\phi} = \frac{\sqrt{3}.V\angle 30-\phi}{Z} = I_{AB}$$

The phase currents in the delta connected load core balanced and displaced from one another by 120 $\Rightarrow$ *Balanced*

Three Phase Connections Cntd...

Determining the line currents: - KCL

$$I_a = I_{AB} - I_{CA}$$

$$\frac{\sqrt{3}V\angle 30-\phi}{Z} - \frac{\sqrt{3}V\angle 150-\phi}{Z}$$

$$\frac{\sqrt{3}}{Z}.V\{Cos(30-\phi)+jSin(30-\phi)-Cos(150-\phi)-jSin(150-\phi)\}$$

Recall:

$$CosA - CosB = -2Sin[\frac{A+B}{2}]Sin[\frac{A-B}{2}]$$

$$SinA - SinB = +2Cos[\frac{A+B}{2}]Sin[\frac{A-B}{2}]$$

$$\Rightarrow \vec{I}_a = \frac{\sqrt{3}}{Z}V\left\{\left(-2Sin\left[\frac{30-\phi+150-\phi}{2}\right]\right)\left(Sin\left[\frac{30-\phi-150+\phi}{2}\right]\right) + \left(2jCos\left[\frac{30--\phi+150-\phi}{2}\right]\right)\left(Sin\left[\frac{30-\phi-150+\phi}{2}\right]\right)\right\}$$

$$= \frac{\sqrt{3}}{Z}.V\{-2Sin(90-\phi)Sin(-60)+2jCos(90-\phi)Sin(-60)\}$$

Three Phase Connections Cntd...

$$= \frac{\sqrt{3}}{Z} V \left\{ -2Sin(90-\phi).-\frac{\sqrt{3}}{2} + 2jCos(90-\phi) - \frac{\sqrt{3}}{2} \right\}$$

$$= \frac{\sqrt{3}}{Z} V \left\{ \sqrt{3}\, Sin(90-\phi) - \sqrt{3}\, jCos(90-\phi) \right\}$$

$$= \frac{\sqrt{3}V}{Z} \left\{ \sqrt{3}Sin(90-\phi) - \sqrt{3}\, jCos(90-\phi) \right\}$$

$$= \frac{3V}{Z} \left\{ Cos\phi - jSin\phi \right\}$$

$$\Rightarrow \vec{I}_a = \frac{3V}{Z} \angle -\phi$$

Note: $Sin(\frac{\pi}{2}-\phi)=Cos\phi$

$Cos(\frac{\pi}{2}-\phi)=Sin\phi$

Recall: $\vec{I}_{AB} = \sqrt{3}.\frac{V}{Z}\angle 30-\phi$

$\Rightarrow I_a = \sqrt{3}\, I_{AB} \angle -30 \;\Rightarrow$ i.e. line current lags phase currents 30^0.

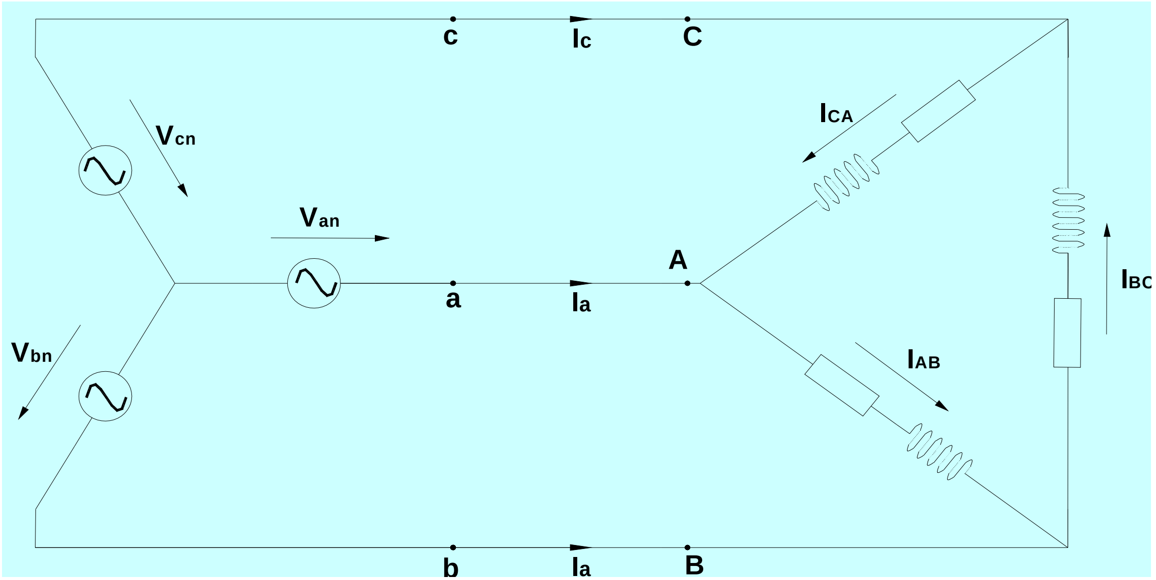
i.e. $|\, I_a \,| = |\, \sqrt{3}\, |\, I_{AB}\, |$

Similarly

$$\vec{I}_b = \sqrt{3}\,\vec{I}_{BC}\angle -30$$

$$\vec{I}_c = \sqrt{3}\,\vec{I}_{CA}\angle -30$$

Three Phase Connections Cntd...



- Both line currents and phase currents in a delta connector balanced load are balanced
- The phasor sum of the balanced delta phase currents equals zero ($I_{AB}+I_{BC}+I_{CA}=0$)
- The phasor sum of the line currents is always zero for a delta load even if the load is unbalanced because there is no neutral wire ($I_a+I_b+I_c=0$)
- The line current lags the phase current by 30^0 for a balanced Delta load
- Line Voltages and Phase voltages are same in a delta connection

Example 2: In a three-phase four wire system, the line voltage is 400V and non-inductive loads of 10 kW [L_1], 8 kW [L_2] and 5 kW [L_3] are connected between the three lines and the neutral conductor.

Calculate:

a) the current In each line, and
b) the current in the neutral conductor

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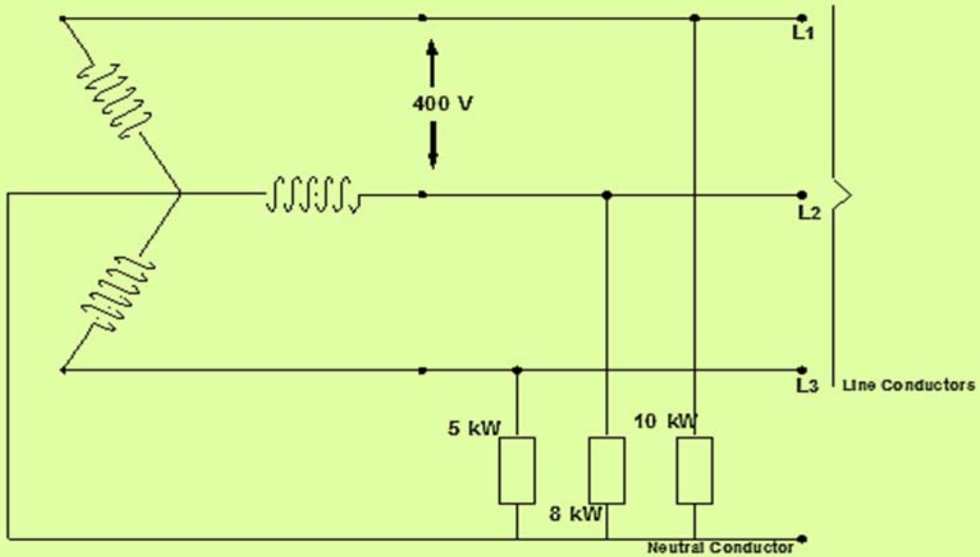
Solution:



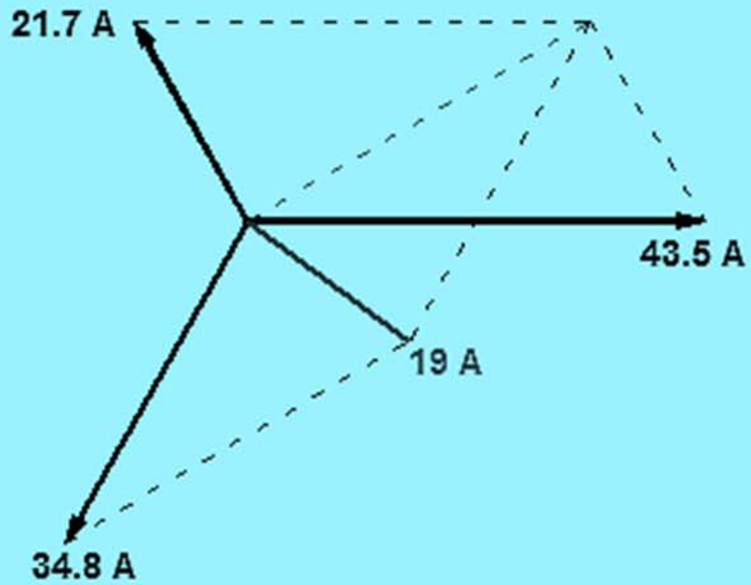
$$V_{ph} = \frac{V_{Line}}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 230\,V$$

$$I_{ph} = I_{Line}$$

$$\Rightarrow \left|I_{L_1}\right| = \frac{10000}{230} = 43.5\,A$$

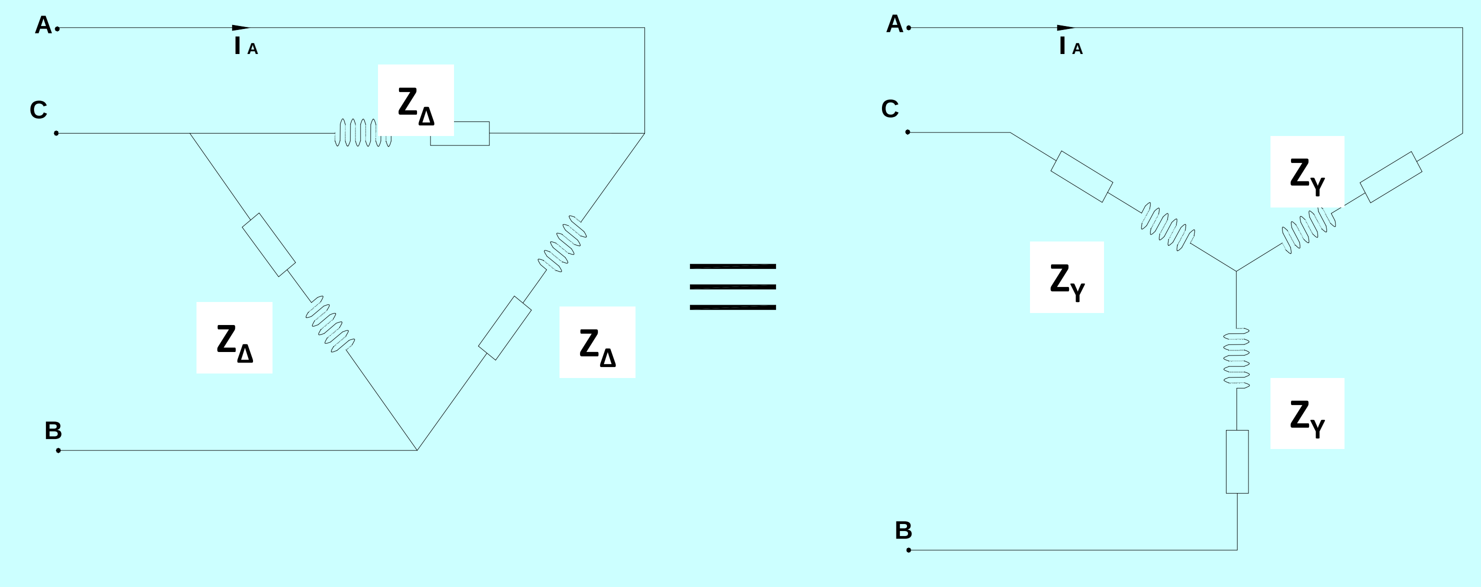
$$\left|I_{L_2}\right| = \frac{8000}{230} = 34.8\,A$$

$$\left|I_{L_3}\right| = \frac{5000}{230} = 21.7\,A$$



The Neutral Current, $I_N = 43.5\angle 0^0 + 34.8\angle -120^0 + 21.7\angle -240^0$

Delta star conversion (Δ-Y) for balanced loads



For the $\Delta - load$: $$I_A = \sqrt{3}\, I_{AB}\angle -30^0 = \frac{\sqrt{3}.E_{AB}\angle -30^0}{Z\Delta}.$$

For the $Y - load$: $$I_A = \frac{E_{AN}}{Z_y} = \frac{E_{AB}\angle -30^0}{\sqrt{3}Z_y}$$

Comparing two equations IA will be same if $$Z_y = \frac{Z\Delta}{3}$$

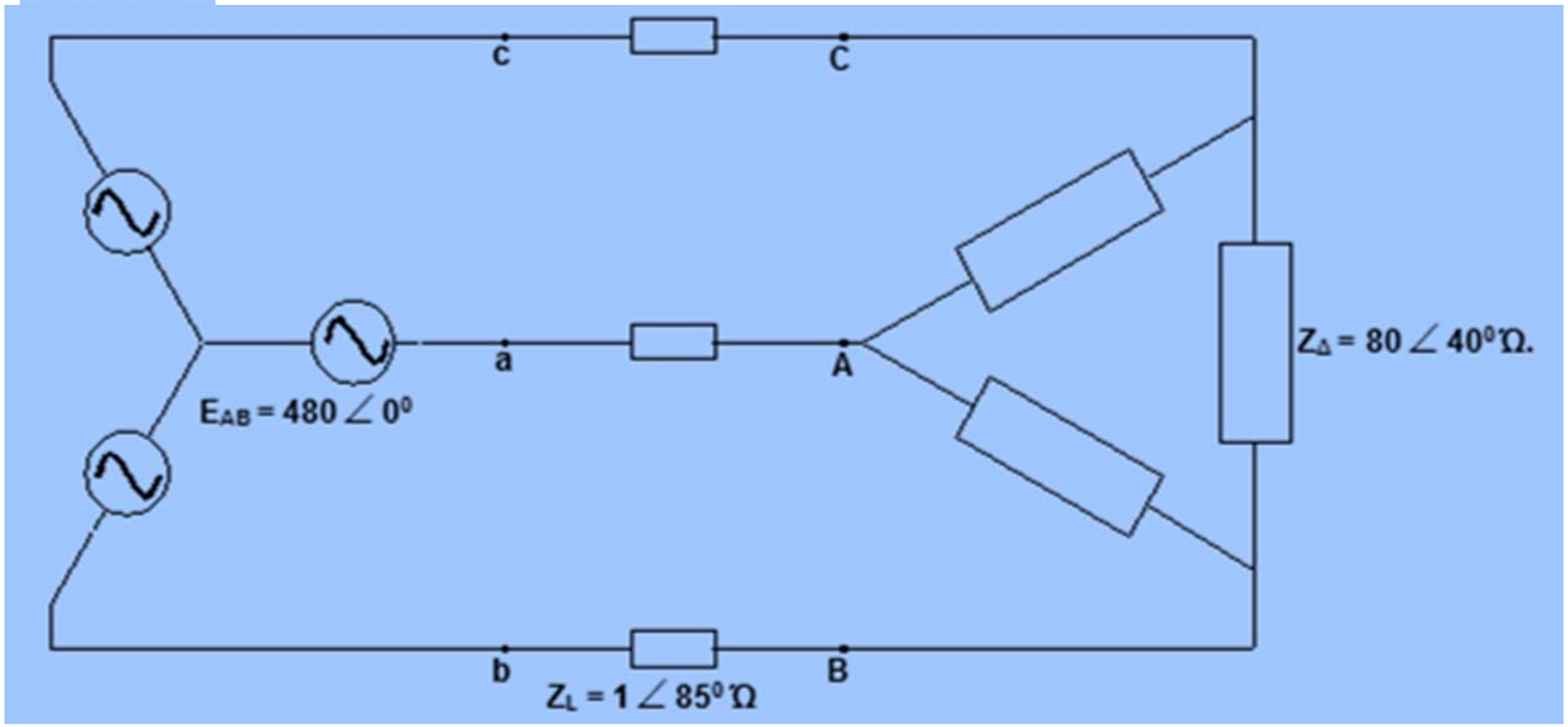
Similarly $$Z_\Delta = 3Z_y$$

Example 3: A balanced star connected positive sequence voltage source with $E_{AB} = 480 \angle 0^0$ is applied to a balanced delta connected load with $Z_\Delta = 30 \angle 40^0\,\Omega$. The line impedance between the source and the load is $Z_L = 1 \angle 85^0\,\Omega$ per phase.

Calculate:

a) The line currents
b) The voltage at the load terminals

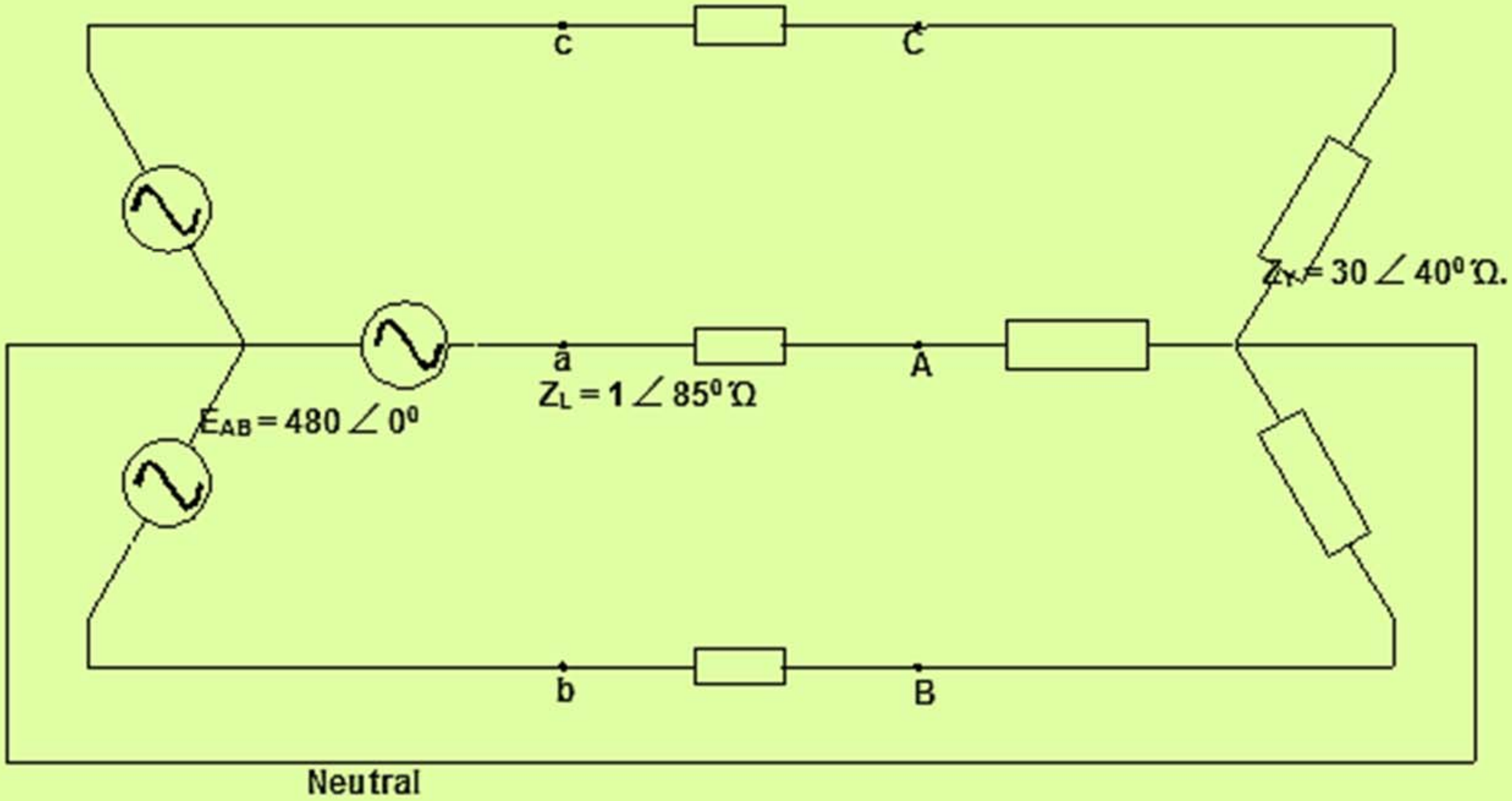
Solution:



Converting the Delta Impedance to the Star equivalent:

$$Z_{\Delta} \rightarrow Z_{Y} \therefore Z_{Y} = \frac{Z_{\Delta}}{3} = \frac{30}{3}\angle 40^{0} \quad 10\angle 40^{0}$$

Therefore, this transposes to:



$$I_A = \frac{E_{AN}}{Z_{Line} = Z_Y} = \frac{\frac{480}{\sqrt{3}}\angle -30^0}{1\angle 85^0 + 10\angle 40^0}$$

Recall, in a star-connected system, V_{Line} leads V_{Phase} by 30^0

$$\therefore \quad I_A = 25.83\angle -73.78^0 \ [A]$$

$$I_B = 25.83\angle -193.78^0 \ [A]$$

$$I_C = 25.83\angle 46.22^0 \ [A]$$

Note: The magnitude of each current is the same and their respective phase displacement is 120^0.

The Delta load currents are:

$$I_{AB} = \frac{I_a}{\sqrt{3}}\angle 30^0 = \frac{25.83}{\sqrt{3}}\angle(-73.78+30)^0 = 14.91\angle -43.78^0 \qquad [A]$$

Recall, in a delta-connected system, I_{Line} lags I_{Phase} by 30^0

$$I_{AB} = 14.91\angle -163.78^0 \qquad [A]$$

$$I_{AB} = 14.91\angle +76.22^0 \qquad [A]$$

The voltages at eh load terminals:

$$E_{AB} = Z_\Delta . I_{AB} = (30\angle 40^0).(14.91\angle -43.78^0) = 447.3\angle -3.78^0$$

$$E_{BC} = 447.3\angle -123.78^0$$

$$E_{CA} = 447.3\angle 116.22^0$$

Instantaneous Power

For a single phase circuit instantaneous power can be given as a product of instantaneous voltage and current values

$$p_{(t)} = v_{(t)} . i_{(t)} = V_m I_m . Sin\omega t . Sin(\omega t - \phi)$$

$$V_m I_m . Sin\omega t . \{Sin\omega t . Cos\phi - Cos\omega t Sin\phi\}$$

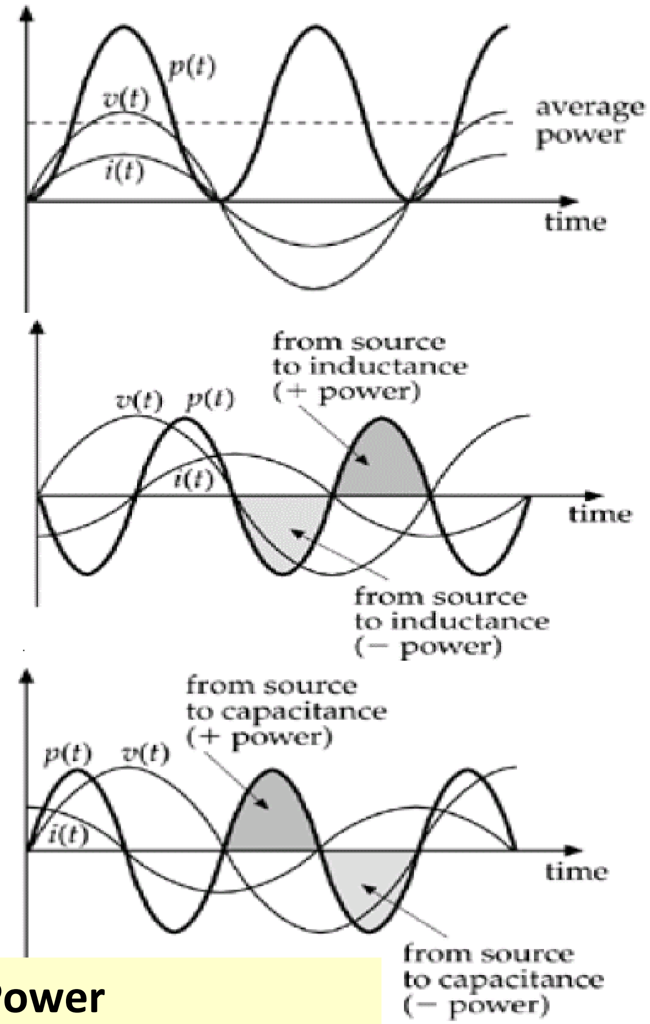
$$= V_m I_m \; \underbrace{Sin^2\omega t . Cos\phi}_{= \frac{1}{2}\{1 - Cos 2\omega t\}} - \underbrace{Sin\omega t . Cos\omega t}_{\frac{1}{2} Sin 2\omega t} . Sin\phi$$

$$\Rightarrow \quad V_m I_m \left[\frac{1}{2}\{1 - Cos 2\omega t\} Cos\phi - \frac{1}{2}\{Sin 2\omega t\} Sin\phi \right]$$

$$= \frac{V_m I_m}{2} \{(1 - Cos 2_{wt}) Cos\phi - (Sin 2_{wt}) Sin\phi\}$$

$$= \frac{\sqrt{2} V . \sqrt{2} I}{2} \{(1 - Cos 2\omega t) Cos\phi - (Sin 2\omega t) Sin\phi$$

$$\Rightarrow p_{(t)} = V I [(1 - Cos 2_{wt}) Cos\phi - (Sin 2_{wt}) Sin\phi$$



Active Power

- *Average power to the load*
- *Pulsates at twice the supply frequency*

Reactive Power

- *Power exchanges between load and source, average is zero*
- *Pulsates at twice the supply frequency*

Instantaneous Power Contd...

Similarly If equations are solved for a three phase balanced circuit scenario:

$$p_{3-\phi(t)} = V_m Sin\omega t.I_m Sin(\omega t-\phi)+V_m Sin(\omega t-120).I_m Sin(\omega t-\phi-120)$$
$$+V_m Sin(\omega t+120)I_m Sin(\omega t-\phi+120)$$

$$=\frac{V_m.I_m}{2}\left\{Cos\phi - Cos(2\omega t-\phi)+Cos\phi - Cos(2\omega t-\phi-240)+Cos\phi - Cos(2\omega t-\phi-120^0\right\}$$

Since $[Cos(2wt-\phi)+Cos(2\omega t-\phi-240)+Cos(2\omega t-\phi-120^0)=0$

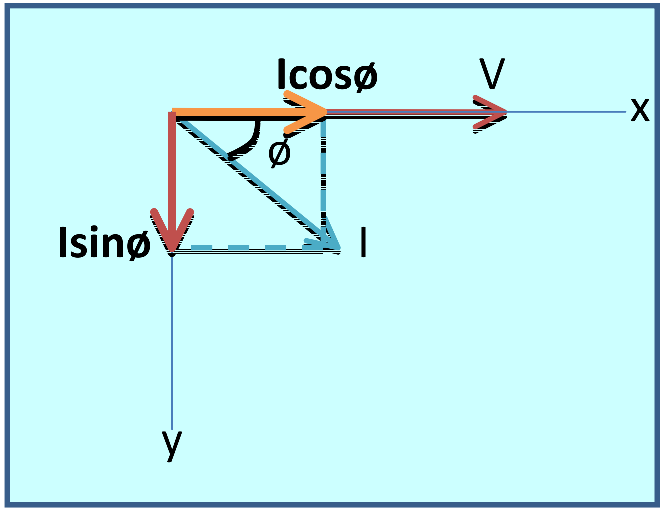
$$\Rightarrow p(t)=\frac{V_m.I_m}{2}.3Cos\phi$$

$$\Rightarrow \sqrt{3}.V_{Line}.I_{Line}Cos\phi$$

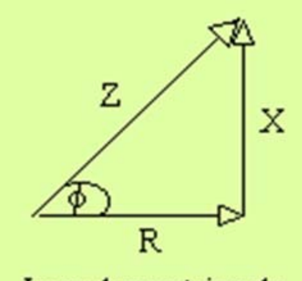
- **The total power = 3 x times the active power in each phase *for balanced loads*.**
- **For both Star and Delta connections, the power is described by:** $\sqrt{3}.V_{Line}.I_{Line}Cos\phi$
- **The three phase power does not pulsate as in the single phase case**

Power Factor

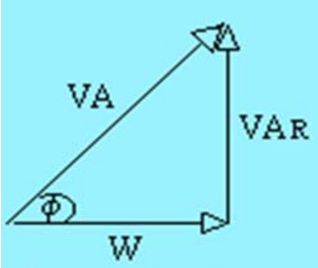
If some angle ϕ exists between the current and voltage then the current can be split into two components along Voltage axis.



- **Useful power delivered by the in-phase component of current, P=V.I cosφ Watts**
- **Power exchanged between source and load is delivered by the quadrature component of the current, Q= V.I sinφ VAr**
- **The product of current and voltage is apparent power , S=V.I**
- **Ratio of useful power (real power) to apparent power is called power factor (p.f.), p.f.=P/S=cosφ**
- **Increased VAr has following disadvantages:**
  - ✓ **Burdens the supply with higher current**
  - ✓ **Increases the transmission loss**
  - ✓ **Reduces efficiency**
  - ✓ **Transformers, cables, protection devices have to be overrated to accommodate higher current**



Impedance triangle



Power triangle

$$\cos\phi = \frac{R}{Z} = \frac{W}{VA}$$

Example 4: **A three-phase, 400V, star-connected motor has an output of 50kW, with an efficiency of 90% and a power factor of 0.85.**

Calculate

a) The line current.

b) If the motor windings were connected in mesh, what would be the current flowing through the windings of the motor

Solution

a) $$\text{Efficiency} = \frac{Output\ Power\ [W]}{Input\ Power\ [W]}$$

$$\eta = \frac{Output\ Power\ [W]}{\sqrt{3}.V_{Line}.I_{Line}.Cos\Phi[W]}$$

$$0.90 = \frac{20 \times 10^3}{\sqrt{3}.400.I_{Line}.0.85}$$

$$\Rightarrow I_{Line} = 37.74[A]$$

b) For a Mesh/Delta connected winding,

$$I_{ph} = \frac{I_{Line}}{\sqrt{3}} \therefore I_{Mtr-Winding} = \frac{37.74}{\sqrt{3}} = 21.79\,[A]$$

Example 5:

a) **Find the complex power (S = power + j Vars) when V = (200 – j150) and I = (-2.8 – j6.3.)**

b) **Find the current if S = (1200 – j600) and (V = -120 + j300).**

Solution:

a) $S = V.I^{*} \quad = \quad (200 - j150).(-2.8 + j6.3)$ [VA]

$\quad = \quad (385 + j1680)$ [VA]

$\quad = \quad (P + jQ)$

Therefore: $P = 385$ [W]

$Q = 1680$ [VAr]

b) Find the current if $S = 1200 - j600$

$V = -120 + j300$

$S = V.I^{*}$

$$\Rightarrow I^{*} = \frac{S}{V} = \frac{(1200 - j600)}{(-120 + j300)}$$

$$\Rightarrow I^{*} = -3.1 - j2.758$$

$$\Rightarrow I = -3.1 + j2.758 \quad \text{[A]}$$

Example 7: Two 3ph generators supply a 3Ø load although separate 3Ø lines. The load absorbs 30kw @0.8pf lag. The line impedances:

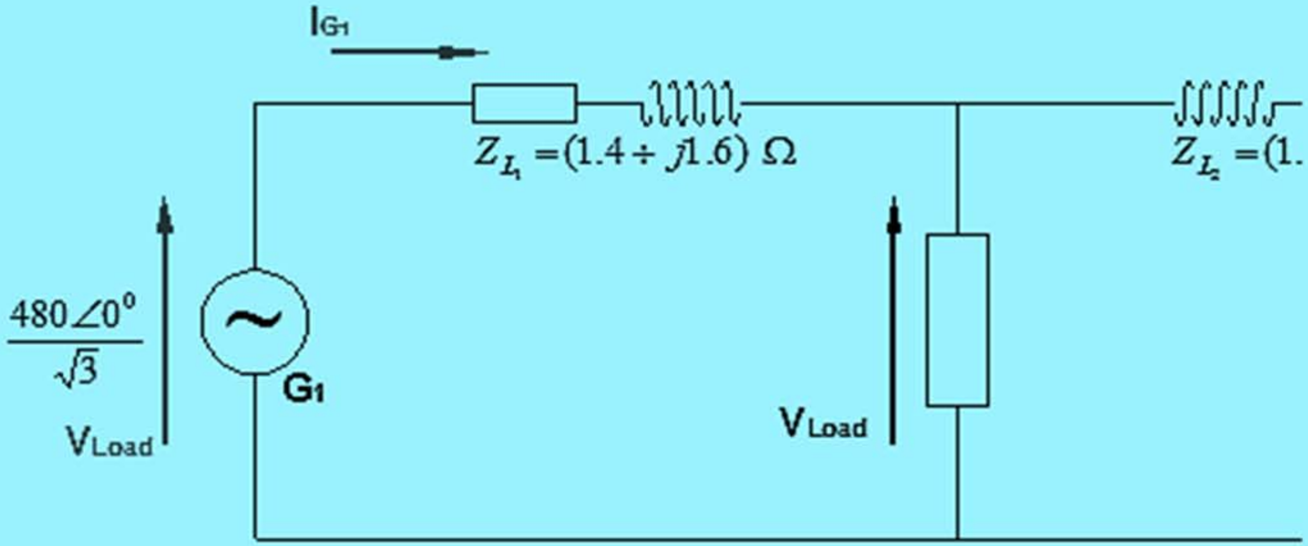
- $Z_{L-G_1} = (1.4 + j1.6)\Omega / ph$
- $Z_{L-G_2} = (1.8 + j1)\Omega / ph$

If generator G_1 supplies 15kw @0.8pF lag with a terminal voltage of 480V (|V|=460, {Line], determine

a) The voltage at the load terminals
b) The voltage at terminals G_2
c) The real and reactive power supplied by G_2

Solution:

a) Assume balanced operation and utilise an equivalent per phase approach



$$\vec{I}_{G_1} = \frac{P\phi_1}{\sqrt{3}.V_L.Cos\phi} = \frac{15\times10^3}{\sqrt{3}.460.08}\angle 0 - Cos^{-1}0.8 = 23.53\angle -36.87^0 \quad [A]$$

$$\vec{V}_{Load} = \vec{V}_{G_1} - \vec{Z}_{Load}\vec{I}_{G_1} = \frac{460}{\sqrt{3}}\angle 0^0 - \left[(1.4 + j1.6).(23.53\angle -36.87^0)\right] \ [V]$$

$$= 265.6\angle 0^0 - 50.08\angle 11.94^0 = 216.7 - j10.35 \quad [V]$$

$$\Rightarrow \vec{V}_{Load} = 216.9\angle -2.73^0 \qquad [V_{L-N}]$$

$$= 375.7 \qquad [V_{L-L}]$$

b) $\vec{I}_{Load} = \dfrac{30x10^3}{\sqrt{3}.375.7.0.8}\angle -2.73-(Cos-0.8) = 57.63\angle -39.6 \quad [A]$

$$\Rightarrow \vec{I}_{G_2} = \vec{I}_{Load} - \vec{I}_{G_1} = (57.63\angle -59.6) - (23.57\angle -36.87) \quad [A]$$

$$= 34.14\angle -41.49 \quad [A]$$

$$\Rightarrow \vec{V}_{G_2} = \vec{V}_{Load} + \vec{Z}_{Load}.\vec{I}_{G_2}$$

$$= (216.9\angle -2.73) + ((0.8 + j1.0)34.14\angle -41.49^0) \quad [V]$$

$$= 259.7\angle -0.63^0 \quad [V_{L-N}]$$

$$\Rightarrow \left|\vec{V}_{G_2}\right| = \sqrt{3}(259.7) = 449.8 \quad [V.]$$

c) Complex Power

$$S_{G2} = 3.\vec{V}_{G_2}.\vec{I}_{G_2}^{\,*}$$

$$= 3(259.7\angle -0.63^0)(34.14\angle 44.49^0)$$

$$= 26.6x10^3\angle 40.86 \quad = (20.12 + j17.4)\times 10^3$$

$$\Rightarrow P_{G2} = 20.120 \quad [kW]$$

$$Q_{G2} = 17.4 \quad [kVAr]$$

Advantages of three phase systems

- A 3-phase system is a dual voltage system. This means that light domestic loads can be from a voltage lower (i.e. V_{ph}) than a commercial or industrial load (V_{line})
- Reduced capital and operating costs of transmissions and distribution - as well as better voltage regulations.
- Total instantaneous power delivered to a system is a constant, not a time dependent variable
- For a given frame surge a 3-phase machine will give an output 50% higher than that of a single-phase m/c of the case frame
- Three Phase supply generates rotational magnetic field to help induction machines to self start unlike a single phase supply case

Example 8: An inductive load draws a current of 10A at a power factor of 0.7 when connected to a 100V, 500Hz supply.

Calculate:

(a) The apparent power, active power and reactive power drawn by the load, and

(b) The shunt capacitance that must be connected to the load so that the overall power factor across the load terminals will be unity.

Solution

a) Apparent Power, S $= |V|.|I| = 10\times100 = 1000$ [VA]

Active Power, P $= |V|.|I|.Cos\phi = 10\times100\times0.7 = 700$ [W]

Reactive Power, Q $= |V|.|I|\,Sin\phi = 10\times100\times Sin\phi = 1000\times Sin\phi$

$$\phi = Cos\phi^{-1} = 45.57^{0}$$

$$\therefore Q = 10\times100\times Sin[45.57^{0}) = 714.1 \quad \text{[VAr]}$$

b) $S_c = V.I^{*}$

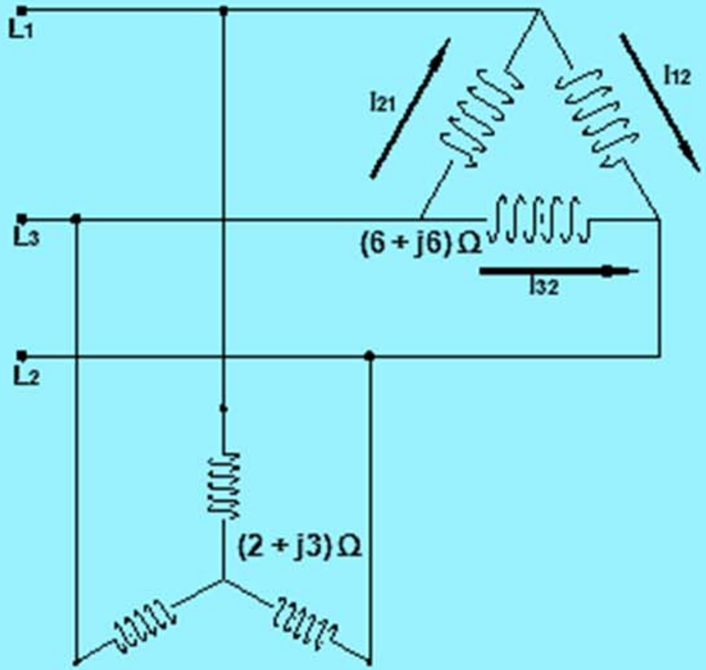
$$= V.\left\{\frac{V}{\frac{1}{j\omega C}}\right\}^{*} = V^2.(-j2.\pi.f.C) \quad \text{[VA]}$$

$$\Rightarrow \quad 714.1 = 100^2.(-j2.\pi.50.C)$$

$$\Rightarrow \quad C = \frac{714.1}{(100^2).(2.\pi.50.)} = 227.3 \quad [\mu F]$$

Example 9: A balanced star-connected load of $(2 + j3)\Omega$ per phase and a balanced delta-connected load of $(6 + j6\Omega$ per phase are connected in parallel to a three-phase, 400V, 50 Hz supply. Calculate the phase current in each load, the total current in each supply line, the total power supplied and the overall power factor.

Solution



Delta Connected Load:

Essentially V_{Line}

$$I_{12} = \frac{V_{ph}\angle 30^0}{Z\angle \Phi^0} = \frac{400\angle 30^0}{(6+j6)} = \frac{400\angle 30^0}{8.485\angle 45^0} = \frac{400\angle -15^0}{8.485} = 47.16\angle -15^0 \quad [A]$$

$$I_{23} = \frac{V_{ph}\angle -90^0}{8.485\angle 45^0} = \frac{400\angle -135^0}{8.485} = 47.16\angle -135^0 \quad [A]$$

$$I_{31} = 47.16\angle(-210-45)^0 = 47.16\angle -255^0 \quad [A]$$

Converting these currents into Line Currents:

$$I_1 = \sqrt{3} \times \left[47.16\angle(-15-30)^0\right] = 81.68\angle -45^0\ [A]$$
$$I_1 = \sqrt{3} \times \left[47.16\angle(-135-30)^0\right] = 81.68\angle -165^0\ [A]$$
$$I_1 = \sqrt{3} \times \left[47.16\angle(-255-30)^0\right] = 81.68\angle -285^0\ [A]$$

Star Connected Load:

$$I_1 = \frac{V_{ph}\angle 0^0}{Z\angle\Phi^0} = \frac{230\angle 0^0}{(2+j3)} = \frac{230\angle 0^0}{3.61\angle 56.31^0} = \frac{230\angle -56.31^0}{8.485} = 63.88\angle -56.31^0 \quad [A]$$

$$I_2 = 63.88\angle(-120-56.31)^0 = 63.88\angle(-176.31)^0\ [A]$$
$$I_3 = 63.88\angle(-240-56.31)^0 = 63.88\angle(-296.31)^0\ [A]$$

Total Line Currents:

$$I_{1\text{-Total}} = 81.68\angle -45^0 + 63.88\angle -56.31^0 = 144.86\angle -49.96^0 \quad [A]$$
$$I_{2\text{-Total}} = 81.68\angle -165^0 + 63.88\angle -176.31^0 = 144.86\angle -169.96^0 \quad [A]$$
$$I_{3\text{-Total}} = 81.68\angle -285^0 + 63.88\angle -296.31^0 = 144.86\angle -289.96^0 \quad [A]$$

Power: $S = V.I^*$
$= [P + jQ]$

$$S_1 = (230.9)(144.86\angle -49.16) = (21.52 + j25.61)\times 10^3$$
$$S_2 = (230.9\angle -120^0)(144.86\angle -169.16) = (21.52 + j25.61)\times 10^3$$
$$S_1 = (230.9\angle -240^0)(144.86\angle -289.16) = (21.52 + j25.61)\times 10^3$$

Therefore:

$S =$	$[P$	$+$	$jQ]$
$L_1 =$	$[21.518$	$+$	$j25.61] \times 10^3$
$L_2 =$	$[21.518$	$+$	$j25.61] \times 10^3$
$L_3 =$	$[21.518$	$+$	$j25.61] \times 10^3$
	64.55 kW		j76.83 kVAr

$S_{Total} = 100.25\angle -49.96^0$

Power Factor: $Cos\Phi = Cos -49.96^0 = 0.64$ [Lag]