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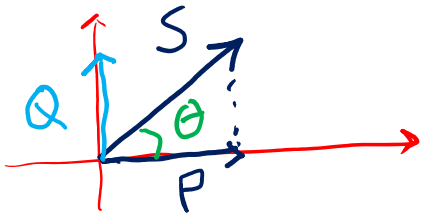
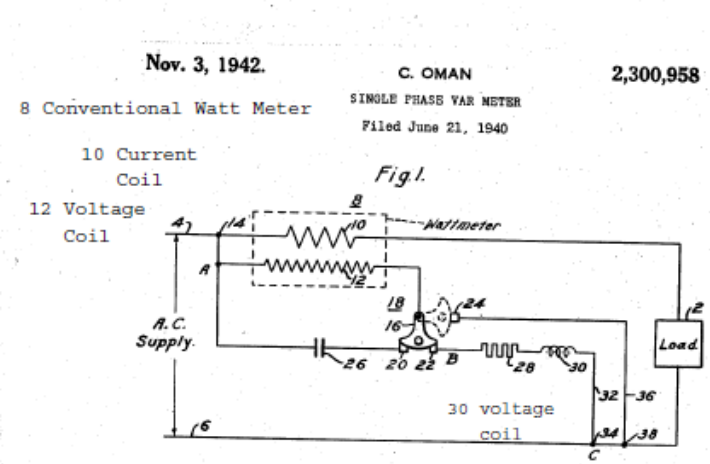
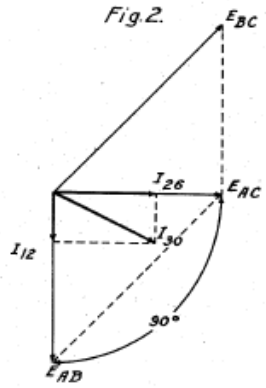
Lab 3 – Real Power & Reactive Power

- Real Power (P) [Watt] [W] $|V||I|\cos\theta$
- Reactive Power (Q) [Var] $|V||I|\sin\theta$
- Complex Power (S) = P + jQ
- Apparent Power (|S|) = SQRT (P^2 + Q^2)



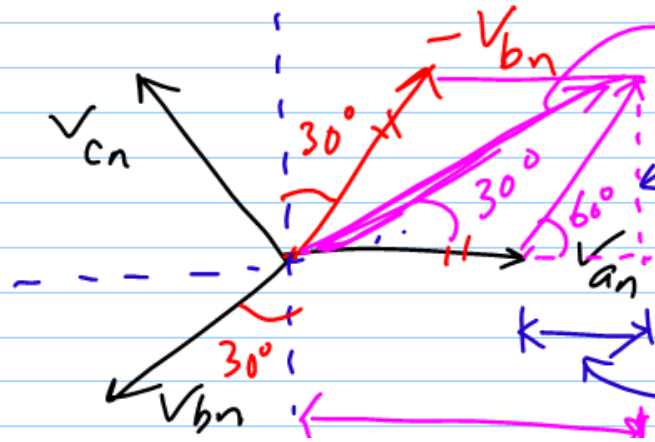




3-phase power systems

Line-to-Line Voltage

$$\bar{V}_{ab} = \bar{V}_{an} + \bar{V}_{nb} = \bar{V}_{an} - \bar{V}_{bn}$$



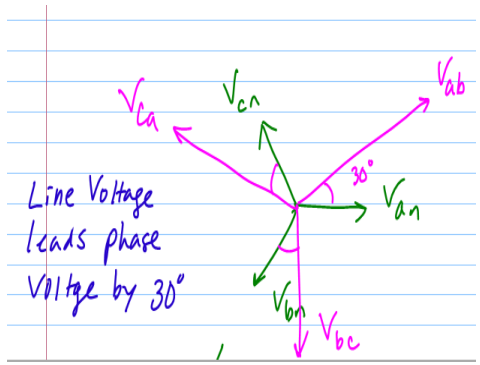
$$|V_{on}| \sin 60^\circ = \frac{\sqrt{3}}{2} |V_{an}|$$

$$|V_{an}| \cos 60^\circ = \frac{|V_{an}|}{2}$$

$$|V_{ab}| = \sqrt{\left(\frac{\sqrt{3}}{2}|V_{an}|\right)^2 + \left(\frac{3}{2}|V_{an}|\right)^2} = \sqrt{\frac{12}{4}|V_{an}|^2} = \sqrt{3}|V_{an}|$$

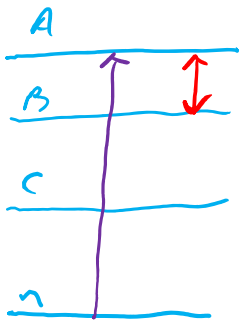
$$\Rightarrow \bar{V}_{ab} = \sqrt{3}\,\bar{V}_{an}\angle 30^\circ \qquad \Rightarrow \bar{V}_{ca} = \sqrt{3}\,\bar{V}_{cn}\angle 30^\circ$$

$$\Rightarrow \bar{V}_{bc} = \sqrt{3}\,\bar{V}_{bn}\angle 30^\circ$$



3-phase power: P and Q

$V_{AB} = V_L$ ("Line voltage")



$V_{An} \rightarrow V_p$ "phase voltage"

"line-to-neutral" voltage

$$\Rightarrow P_{3\phi} = 3 V_p I_p \cos\theta_p$$

V_L: Line-to-Line Voltage magnitude (or 1ϕ equiv)

$V_p = \frac{V_L}{\sqrt{3}}$ and $I_p = I_L$ (Y-Load case)

I_L: current over a line

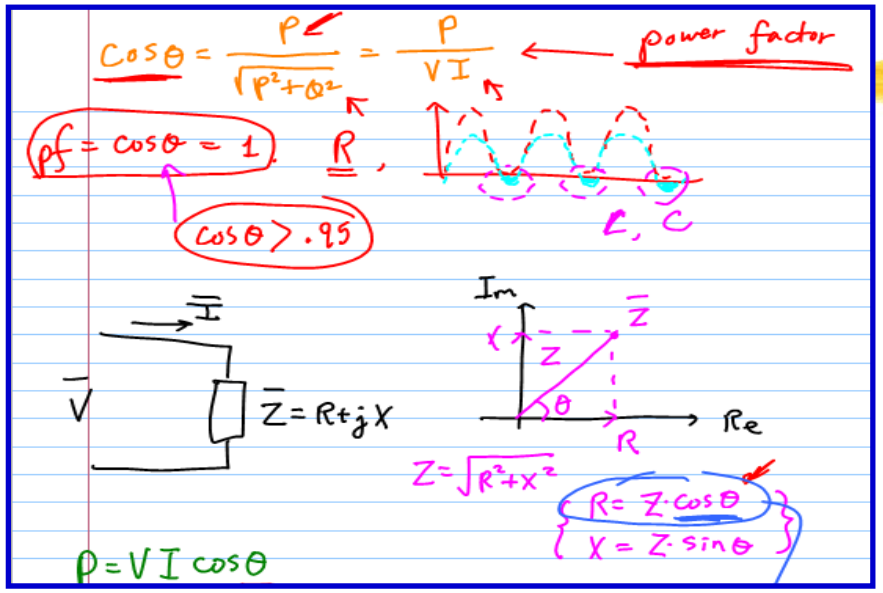
$I_L = I_p \sqrt{3}$ (Δ Load case)

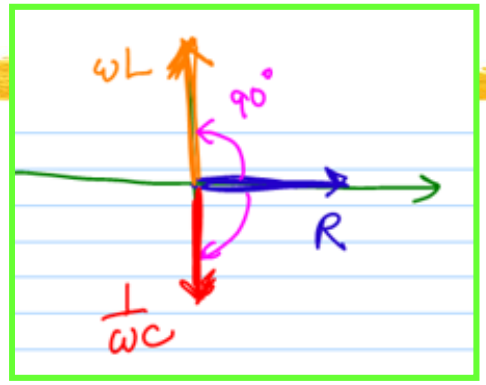
$$\Rightarrow P_{3\phi} = 3 V_p I_p \cos\theta_p$$

$$= 3 \frac{V_L}{\sqrt{3}} I_L \cos\theta_p = \sqrt{3}\, V_L I_L \cos\theta_p$$

& $Q_{3\phi} = 3 V_p I_p \sin\theta_p = \sqrt{3}\, V_L I_L \sin\theta_p$

P and Q & R and X





$$Z = R + jX = R + j(X_L - X_C)$$

$$X_L = \omega L, \quad X_C = \frac{1}{\omega C}$$

$$\bar{V} = \bar{I}\bar{Z} \qquad \bar{I} = \frac{\bar{V}}{\bar{Z}} = \frac{V\angle 0^\circ}{Z\angle\theta} = \frac{V}{Z}\angle -\theta$$

$$P = VI\cos\theta = I^2 \cdot Z\cdot\cos\theta = I^2 R$$

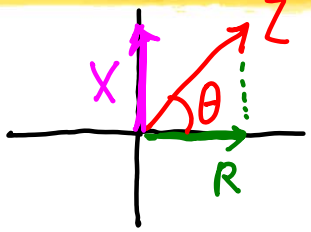
$$Q = VI\sin\theta = I^2 \cdot Z\cdot\sin\theta = I^2 X$$

$$\cos\theta = \frac{R}{Z} \leftarrow \text{power factor}$$

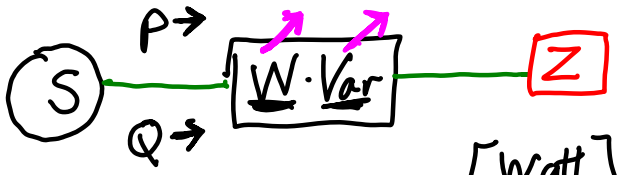
P and Q with Z

$P = VI\cos\theta$ $Q = VI\sin\theta$

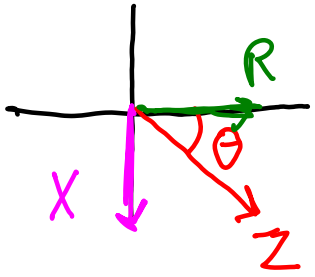
[Watt] [Var]



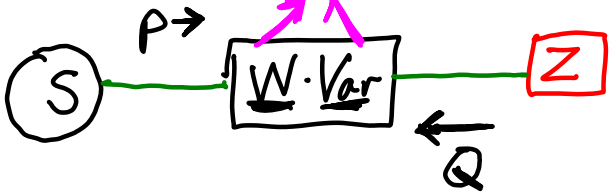
$R = 5$ $X = 5$ $\theta = 45°$ $P > 0$ $Q > 0$

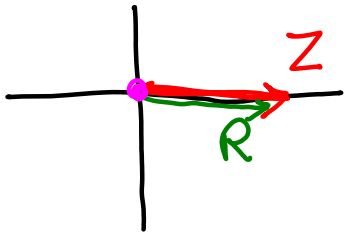


[Watt] [Var]

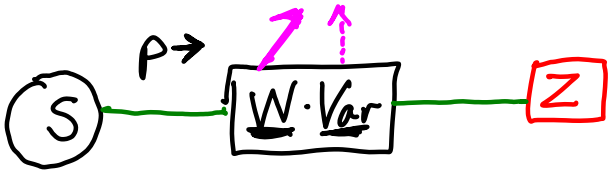


$R = 5$ $X = -5$ $\theta = -45°$ $P > 0$ $Q < 0$



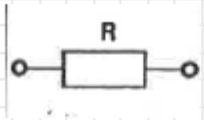


$R = 5$ $X = 0$ $\theta = 0$ $P > 0$ $Q = 0$



Example

LAB 3 -- EXAMPLE CALCULATION



$$P_{3\phi} = 3 V_p I_p \cos\theta_p$$

$$= 3 \frac{V_L}{\sqrt{3}} I_L \cos\theta_p = \sqrt{3}\, V_L I_L \cos\theta_p$$

$$Q_{3\phi} = 3 V_p I_p \sin\theta_p = \sqrt{3}\, V_L I_L \sin\theta_p$$

$VP := 120$

$VL := VP \cdot \sqrt{3} = 207.846097$

$R := 300$

$Z := R \qquad |Z| = 300$

$\theta := \arg(Z) = 0$

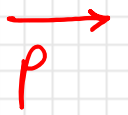
$IL := \frac{VP}{Z} = 0.4$ We measure this in the lab

$|IL| = 0.4$

$P := 3 \cdot |VP| \cdot |IL| \cdot \cos(\theta) = 144$

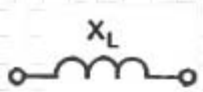
$P := \sqrt{3} \cdot |VL| \cdot |IL| \cdot \cos(\theta) = 144$ W

$Q := \sqrt{3} \cdot |VL| \cdot |IL| \cdot \sin(\theta) = 0$ Var



$Q = 0$

Example



$$P_{3\phi} = 3 V_p I_p \cos\theta_p$$

$$= 3 \frac{V_L}{\sqrt{3}} I_L \cos\theta_p = \sqrt{3}\, V_L I_L \cos\theta_p$$

$$Q_{3\phi} = 3 V_p I_p \sin\theta_p = \sqrt{3}\, V_L I_L \sin\theta_p$$

$VP := 120$

$VL := VP \cdot \sqrt{3} = 207.846097$

$R := 0 \qquad XL := 300$

$Z := R + i \cdot XL \qquad |Z| = 300$

$\theta := \arg(Z) = 1.570796$

$\theta deg := \theta \cdot \frac{180}{\pi} = 90$

$IL := \frac{VP}{Z} = -0.4 \cdot i$ We measure this in the lab

$|IL| = 0.4$

$P := \sqrt{3} \cdot |VL| \cdot |IL| \cdot \cos(\theta) = -5.027736 \cdot 10^{-13}$ W

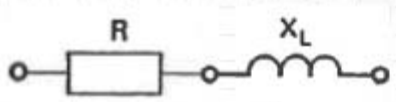
0

$P = 0$

$Q := \sqrt{3} \cdot |VL| \cdot |IL| \cdot \sin(\theta) = 144$ Var

$Q \rightarrow$

Example



$$P_{3\phi} = 3 V_p I_p \cos\theta_p$$

$$= 3 \frac{V_L}{\sqrt{3}} I_L \cos\theta_p = \sqrt{3}\, V_L I_L \cos\theta_p$$

$$Q_{3\phi} = 3 V_p I_p \sin\theta_p = \sqrt{3}\, V_L I_L \sin\theta_p$$

$VP := 120$

$VL := VP \cdot \sqrt{3} = 207.846097$

$R := 300$

$XL := 300$

$Z := R + i \cdot XL$

$|Z| = 424.264069$

$\theta := \arg(Z) = 0.785398$

$\theta deg := \theta \cdot \frac{180}{\pi} = 45$

$IL := \frac{VP}{Z} = 0.2 - 0.2 \cdot i$ We measure this in the lab

$|IL| = 0.282843$

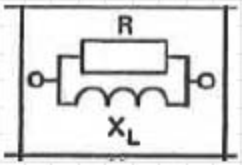
$P := \sqrt{3} \cdot |VL| \cdot |IL| \cdot \cos(\theta) = 72$ W

$Q := \sqrt{3} \cdot |VL| \cdot |IL| \cdot \sin(\theta) = 72$ Var

P →

Q →

Example



$$P_{3\phi} = 3 V_p I_p \cos\theta_p$$

$$= 3 \frac{V_L}{\sqrt{3}} I_L \cos\theta_p = \sqrt{3}\, V_L I_L \cos\theta_p$$

$$Q_{3\phi} = 3 V_p I_p \sin\theta_p = \sqrt{3}\, V_L I_L \sin\theta_p$$

$VP := 120$

$VL := VP \cdot \sqrt{3} = 207.846097$

$R := 300 \quad XL := 300 \quad X := i \cdot XL$

$Z := \frac{R \cdot X}{R + X} = 150 + 150 \cdot i \qquad |Z| = 212.132034$

$\theta := \arg(Z) = 0.785398 \qquad \theta deg := \theta \cdot \frac{180}{\pi} = 45$

$IL := \frac{VP}{Z} = 0.4 - 0.4 \cdot i$

We measure this in the lab

$|IL| = 0.565685$

$P := 3 \cdot |VP| \cdot |IL| \cdot \cos(\theta) = 144$

$P := \sqrt{3} \cdot |VL| \cdot |IL| \cdot \cos(\theta) = 144$ W

$Q := \sqrt{3} \cdot |VL| \cdot |IL| \cdot \sin(\theta) = 144$ Var

P →

Q →