AC POWER

Power triangle and power-factor correction

Review of Power

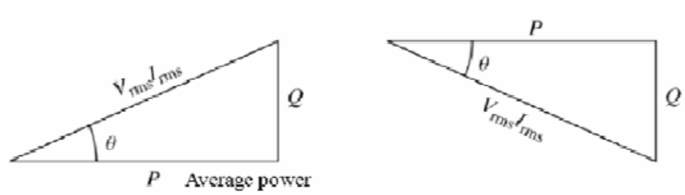
- Power Angle: $\theta=\theta_v-\theta_i$
- Average Power: $P = V_{rms}I_{rms}\cos(\theta)$ [W]
- Apparent Power = $V_{rms}I_{rms}$ [VA]
- Reactive Power: $Q = V_{rms}I_{rms}\sin(\theta)$ [VARs]
  - Peak instantaneous power associated with energy storage elements
  - Related to amount of current demand
    - Large currents require heavy-duty wires, thus increasing cost

Reactive Power I-clicker Question

- Reactive power can be zero when the load is
  a) Purely resistive
  b) Purely inductive
  c) Purely capacitive
  d) Purely resistive or a combination of inductors and capacitors

Power Triangles

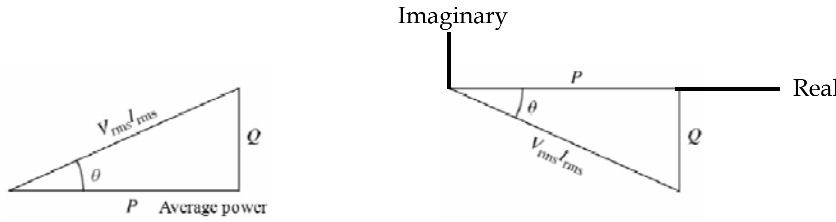
- Relationship between
  - Average power P
  - Reactive power Q
  - Apparent power $V_{rms}I_{rms}$
  - Power angle θ



(a) Inductive load (θ positive) (b) Capacitive load (θ negative)

- Pythagorean Theorem: $P^2 + Q^2 = (V_{rms}I_{rms})^2$

Power Triangles Continued



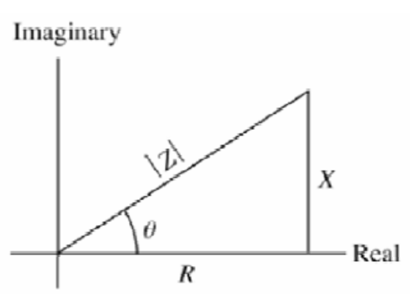
(a) Inductive load (θ positive)

(b) Capacitive load (θ negative)

- Q is positive
- θ is positive

- Q is negative
- θ is negative

Impedance in Complex Plane



$$Z = |Z|\angle\theta = R + jX$$

$$\cos(\theta) = \frac{R}{|Z|}$$

$$\sin(\theta) = \frac{X}{|Z|}$$

Power in Terms of Impedance

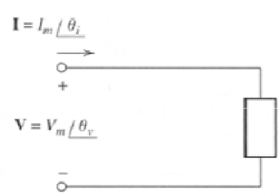
$$P = I_{rms}^2 R \; = \; \frac{V_{Rrms}^2}{R}$$

Voltage is across the resistance and is not the source voltage

$$Q = I_{rms}^2 X \; = \; \frac{V_{Xrms}^2}{X}$$

Voltage is across the reactance

Complex Power



$$\mathbf{S} = \frac{1}{2}\mathbf{V}\mathbf{I}^* = P + jQ$$

I* is the complex conjugate of **I**: $\mathbf{I}^* = I_m \angle -\theta_i$

$P = \mathrm{Re}(\mathbf{S}) = \mathrm{Re}\left(\frac{1}{2}\mathbf{V}\mathbf{I}^*\right)$ **Re means the real part**

$Q = \mathrm{Im}(\mathbf{S}) = \mathrm{Im}\left(\frac{1}{2}\mathbf{V}\mathbf{I}^*\right)$ Im means the imaginary part

apparent power $= |\mathbf{S}| = \left|\frac{1}{2}\mathbf{V}\mathbf{I}^*\right|$ **Previously, we defined apparent power =** $V_{rms}I_{rms}$

Power-Factor Correction

- Average power is related to apparent power by the PF, which depends on the phase difference between the voltage and current.

- Average Power: $P = V_{rms}I_{rms}\cos(\theta)$ ← PF!!
  where $\theta=\theta_v-\theta_i$

Average power is the power delivered to and dissipated by the load!

Power-Factor Correction

- Large currents can flow in energy-storage devices without average power being delivered
  - Higher currents lead to higher rating lines and transformers than a purely resistive or 100 % power factor load would require

- Power companies charge industries based on their power factor

Power-Factor Correction I-Clicker Question

- Typically, loads in industry are somewhat inductive. How might companies increase their power factor, so they have lower energy rates?
  a) Add capacitors in series
  b) Add capacitors in parallel
  c) Add inductors in series
  d) Add inductors in parallel

Summary

- Average power
  - Is NOT absorbed by inductances and capacitors.
  - IS absorbed by resistances and dissipated as heat.
- Desire power-factors of 1
  - Large reactive powers lead to higher currents and higher costs
    - They reduce the power-factor
  - Can introduce capacitors in parallel to improve power-factor
- The real and imaginary components of power can be thought of in terms of Power Triangles
  - $P^2 + Q^2 = (V_{rms}I_{rms})^2$