Chapter 17

Power in AC Circuits

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Active Power

- Instantaneous power to a load is $p = v \cdot i$
- In an ac circuit
  - *p* may be positive sometimes and negative other times
- Average value of the power, *P*
  - Real power

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Active Power

- Average value of instantaneous power, real power, active power, and average power mean the same thing

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Reactive Power

- During times when p is negative, power is being returned from load
- This can happen for inductive or capacitive loads

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Reactive Power

- Power that flows into these loads and back out is called the reactive power
- Average value of reactive power is zero

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Power to a Resistive Load

$$p = vi = (V_m \sin \omega t)(I_m \sin \omega t)$$

$$p = V_m I_m \sin^2 \omega t$$

$$p = \frac{V_m I_m}{2}(1 - \cos 2\omega t)$$

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Power to a Resistive Load

- *p* is always positive (except when zero)
- Power flows only from source to load
  - Power is absorbed by the load
- Power to a pure resistance consists of active power only

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Average Power

- Average value of power is halfway between zero and peak value of $V_m I_m$
- $P = V_m I_m / 2$
- If *V* and *I* are in RMS values
  - Then $P = VI$

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Average Power

- Also, $P = I^2R$ and $P = V^2/R$
- Active power relationships for resistive circuits are the same for ac as for dc

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Power to an Inductive Load

- Voltage and current of an inductor are 90° out of phase
  - Average power to an inductance over a full cycle is zero
- There are no power losses associated with a pure inductance

Power to an Inductive Load

- Power that flows into and out of a pure inductance is reactive power only

Power to an Inductive Load

- $p_L = VI \sin 2\omega t$ (V and I rms values)
- Product VI is the reactive power, Q_L
- $Q_L = VI = I^2X_L = V^2/X_L$
- Units are VARs

Power to an Inductive Load

- VAR means Volt-Amperes-Reactive
- Inductive reactive power is represented as positive

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Power to a Capacitive Load

- Voltage and current are 90° out of phase
  - Average power over one complete cycle is equal to zero
- There are no power losses associated with a pure capacitance

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Power to a Capacitive Load

- Power that flows into and out of a pure capacitance is reactive power only
- This power cycle is 180° out of phase with the inductive cycle

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Power to a Capacitive Load

- $p_C = -VI \sin 2\omega t$
- $Q_C = VI$
- $Q_C = I^2X_C = V^2/X_C$
- Capacitive reactive power is represented as negative
- Units are VARs

Power in More Complex Circuits

- It does not matter how a circuit or system is connected
  - Sum of the power is found by summing individual powers
- Total real power *P* is found by summing each of the individual real powers

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Power in More Complex Circuits

- Total Reactive power *Q* is found by summing individual *Q*'s
  - Inductive powers are positive
  - Capacitive powers are negative

Apparent Power

- Power to a load is *VI*
- If load has both resistance and reactance
  - Product is neither the real power nor the reactive power, but a combination of both

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Apparent Power

- This is called the apparent power, *S*
- $S = VI = I^2Z = V^2/Z$
- Units are volt-amperes (VA)

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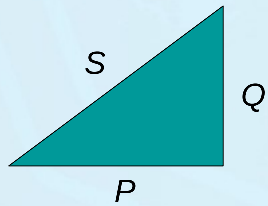
Relationship Between *P*,*Q*, and *S*

- *P*, *Q*, and *S* are related by the "power triangle"



$$S = \sqrt{P^2 + Q^2}$$

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Active and Reactive Power Equations

- $P = VI \cos \theta = S \cos \theta$
- $Q = VI \sin \theta = S \sin \theta$
- *V* and *I* are RMS values
- θ is the phase angle between V and I
- *Q* is positive for inductive circuits and negative for capacitive circuits

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Power Factor

- Ratio of real power to apparent power is called the power factor, F_p
- $F_p = P/S = \cos \theta$
- Angle θ is angle between voltage and current

Power Factor

- For pure resistance $\theta = 0°$
- For inductance, $\theta = 90°$
- For capacitance, $\theta = -90°$
- For a circuit containing a mixture, θ is somewhere between 0° and ±90°

Power Factor

- Unity power factor
  - For a purely resistive circuit, the power factor will be one
- For load containing resistance and inductance
  - Power factor will be less than one and lagging
  - Current lags the voltage

Power Factor

- For a circuit containing resistance and capacitance
  - F_p is less than one and is leading

Why Equipment Is Rated in VA

- A highly reactive load
  - May seem to require a small amount of power while requiring a large current
- Equipment is rated in VA to prevent overloading the circuit

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Why Equipment Is Rated in VA

- Size of electrical apparatus required by a load
  - Governed by its VA requirements

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Power Factor Correction

- A load with a small power factor can draw a large current
- Can be alleviated by
  - Cancelling some or all reactive components of power by adding reactance of opposite type to the circuit
    - This is power factor correction

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Power Factor Correction

- Industrial customers may pay a penalty for low power factors due to large currents required for highly reactive loads

AC Power Measurement

- To measure power in an ac circuit you need a wattmeter
- Meter consists of
  - Current-sensing circuit
  - Voltage-sensing circuit
  - Multiplier circuit
  - Averaging circuit

AC Power Measurement

- This will measure load voltage and current and find the product and the angle between these

Effective Resistance

- At high frequencies
  - Resistance of a circuit may change
- $R_{eff} = P/I^2$
  - Anything that affects *P* will affect resistance

Effective Resistance

- Changing magnetic fields may set up eddy currents in conductors
  - These cause power losses that affect effective resistance

Effective Resistance

- Ferromagnetic materials
  - Power losses due to hysteresis effects
- Magnetically induced voltages created by a changing magnetic field cause a non-uniform current called a skin effect
  - Causes an increase in resistance
  - Energy escapes due to radiation resistance