Copyright 2002 Kilowatt Classroom, LLC.

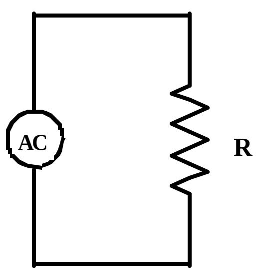
AC Theory
Power is a Resistive Circuit

In a purely resistive circuit (such as electric heaters or incandescent lighting), the circuit voltage and the current will be in-phase.

In this circuit, because the current is in-phase with the voltage, the maximum amount of power in watts will be produced. Single-phase power in watts in an AC circuit is: **P =E x I x Cos Ø**. The phase angle in this case is 0 ^{o}. Since Cos 0 ^{o} = 1, the circuit power is therefore P = E x I x 1. All power is true power in watts.

Remember:

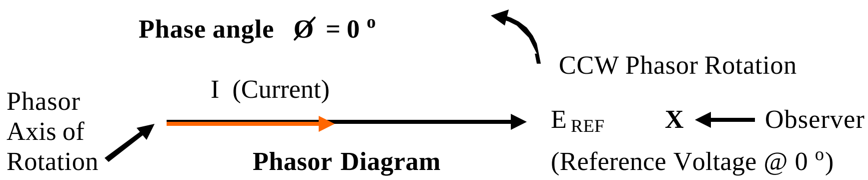
- There are 360 degrees in a sine wave.
- Electrical Phasors rotate counter-clockwise (CCW).
- Phasors (electrical vectors) show two things: (1) magnitude, and (2) direction.



Circuit Diagram

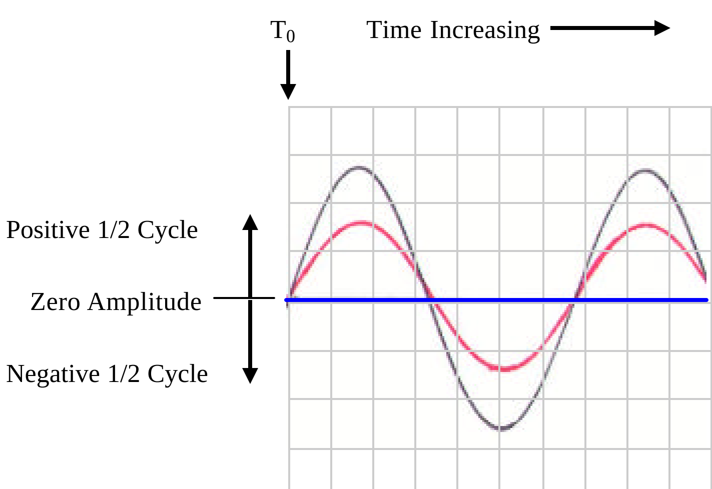
Voltage and Current are in-phase.

Phase angle Ø = 0 ^{o}



Phasor Diagram
Current Red
Voltage Black

If the observer stands a point X above and watches the phasors rotate CCW, the voltage and current phasors will be in-phase with one another.



Sine Wave Relationship
Showing in-phase condition.
Red - Current
Black - Voltage

In the above drawing, the zero crossing for both the current and voltage occurs at the same time.

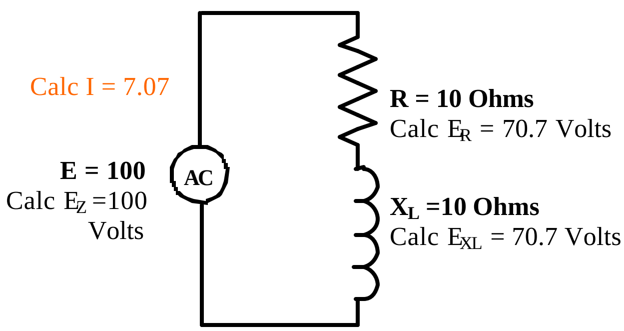
Copyright 2002 Kilowatt Classroom, LLC.

AC Theory
Power in an RL Circuit

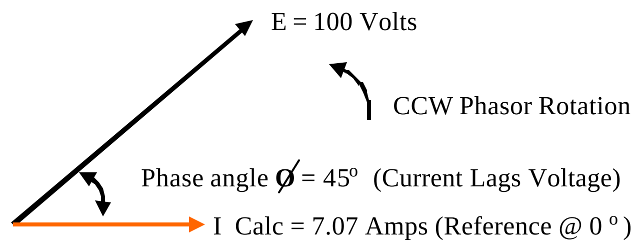
This series circuit combines resistance and reactance. Given: System Voltage = 100, R = 10 Ohms, X_L = 10 Ohms Because this is a series circuit, the current is the same through both circuit elements and current becomes the reference phasor. The circuit is inductive, so the current will lag the voltage.

Steps to solving this circuit:

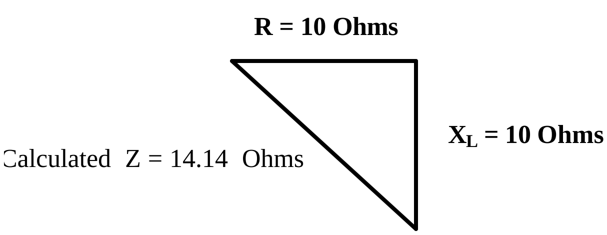
- Find system impedance - Use Trig or Pythagorean Theorem to find Z.
- Calculate system current - Divide given system voltage (100) by Z.
- Calculate voltage drops - Multiply calculated current times R, X_L, and Z.
- Calculate values for power triangle - Multiply current (I) times E_R, E_{XL}, and E_Z. (Or you can use $P = I^2 R$.)
- Calculate phase angle - There are several ways to do this, shown is Trig calculation using Watts and Vars.
- Calculate system power factor - This is the Cosine of the phase angle expressed as a percent.



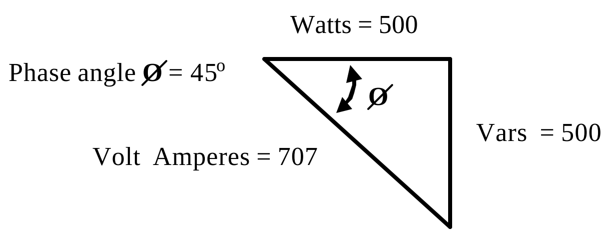
Circuit Diagram
Given data shown bold.



Phasor Diagram
Current Red
Voltage Black



Impedance Triangle
Given data shown bold.



Power Triangle

Calculations

Impedance:

$$Z^2 = R^2 + X^2 \quad \text{or} \quad Z = \sqrt{R^2 + X^2}$$

$$Z = \sqrt{10^2 + 10^2} = \sqrt{100 + 100} = \sqrt{200} = 14.14 \text{ Ohms}$$

Current: I = E / Z

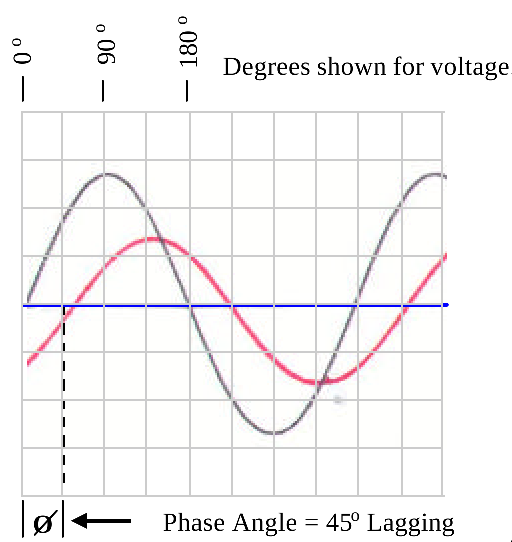
I = E / Z = 100 volts / 14.14 ohms = 7.07 Amps

Voltage E_R = I x R = 7.07 x 10 = 70.7 Volts
E_{XL} = I x X_L = 7.07 x 10 = 70.7 Volts
E_Z = I x Z = 7.07 x 14.14 = 100 Volts

Power: Watts = E_R x I = 70.7 x 7.07 = 500 Watts
Vars = E_{XL} x I = 70.7 x 7.07 = 500 Vars
Volt Amperes = E_Z x I = 100 x 7.07 = 707 VA

Phase Angle: Tan Ø = Opp / Adj = Vars / Watts = 500 / 500 = 45°

Power Factor = Cos Ø x 100 = Cos 45° x 100 = .707 x 100 = 70.7 %



Sine Wave Relationship
Red - Current
Black - Voltage

AC Theory
Power in an RLC Circuit

Copyright 2002 Kilowatt Classroom, LLC.

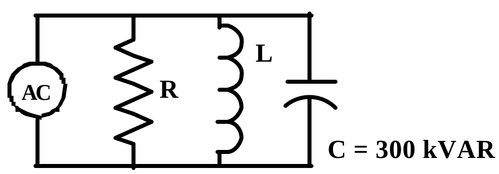
This parallel circuit combines resistance, inductance, and capacitance. Because capacitive reactance Xc and inductive reactance X_L are opposite one another, the two reactances can be vectorally (algebraically) added to obtain a single reactance with the magnitude of the resultant vector being equal to the difference between the quantities and the vector direction being that of the larger quantity. Because it is a parallel circuit, the voltage is the same across each circuit element and is chosen as the reference phasor.

A practical application of this principle is power factor correction. Primarily because of induction motor load, electrical systems are generally inductive and have a lagging power factor. Power factor correction capacitors can be added to the system to supply leading vars and offset some of the lagging system vars.

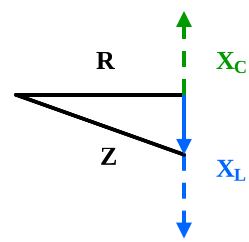
To simplify the application of power factor correction capacitors to electrical systems, manufacturers rate these capacitors in kilovars (kVAR) rather than in microfarads. The correlation between microfarads and kVARs is given by the formula: **$kVAR = 2\pi FCE^2 / 10^9$** Where: $2\pi = 6.28$, F = Frequency in hertz, C = Capacitance in microfarads, and E^2 = Voltage^2.

The Circuit Diagram shown below represents a typical distribution system. The resistance element represents resistive loads such as incandescent lighting , electric heat, and the resistive component of inductive loads such as motors and transformers. The inductance symbol represents the inductive component of motors, transformers, and other magnetic circuits, and the capacitance represents a bank of power factor correction capacitors of 300 kVAR.

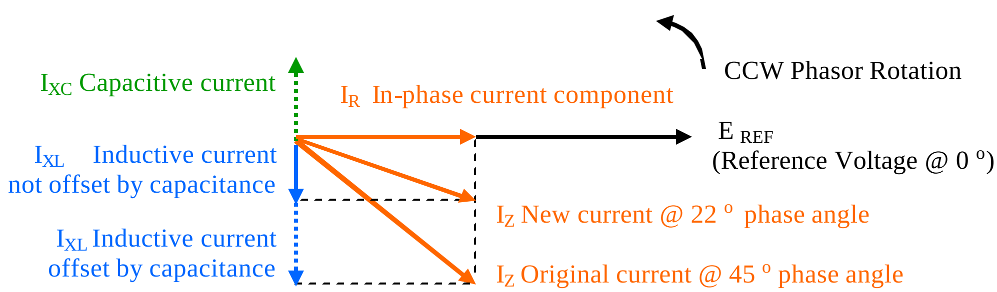
The Original System Power Triangle, below left, shows a system with a 500 kW (true power) load, 500 kVAR of reactive (wattless) power, and a kVA (apparent power) of 707. The system phase angle $\phi = 45^o$, resulting in a system power factor of 70% (Cos 45^o = .707). The Phasor Diagram and the Resultant Power Triangle, bottom right, illustrate the system improvement by the addition of a 300 kvar power factor correction capacitor.



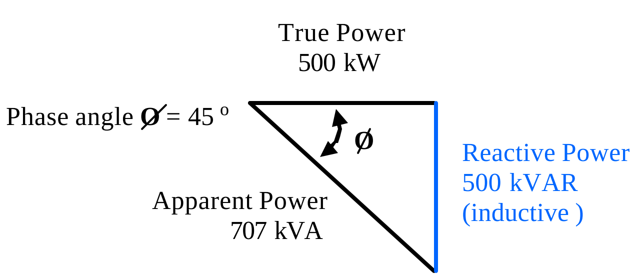
Circuit Diagram



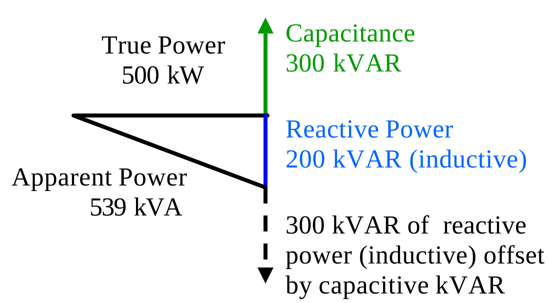
Impedance Triangle



Phasor Diagram



Original Power Triangle
Before addition of power factor correction capacitors.



Resultant Power Triangle
After addition of power factor correction capacitors.