Voltage/Current Phase Angle

"ELI the ICE man"

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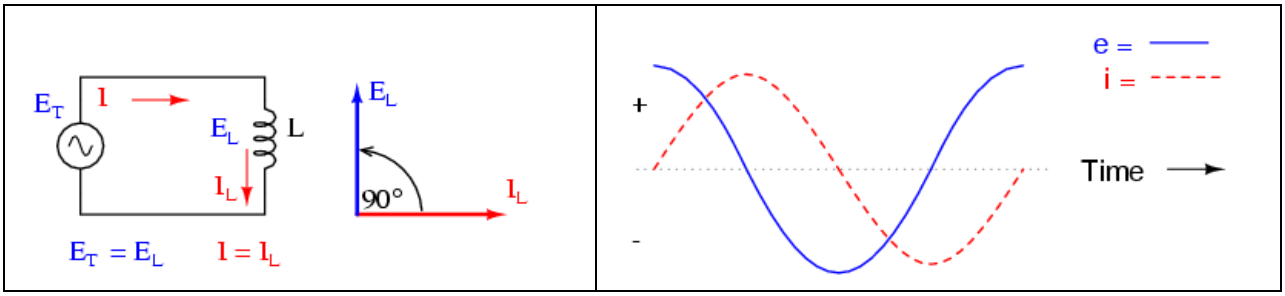
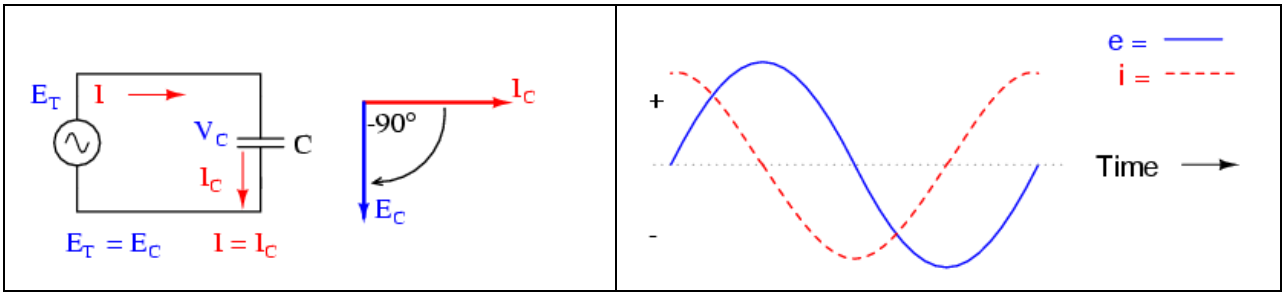
When an AC current flows through a **resistor**, the voltage and current are in phase. However, when you introduce inductance or capacitance, a phase shift occurs and the phase angle depends on the amount of inductive and capacative reactance.

When AC current flows through a pure **inductor**, the voltage leads the current (current lags the voltage) by 90º. (**ELI**)



When AC current flows through a pure **capacitor**, the current leads the voltage (voltage lags the current) by 90º. (**ICE**)



Impedance is the AC equivalent of resistance in DC circuits. Like resistance, high impedance blocks current flow. Impedance consists of **Resistance** and **Reactance**.

Inductive reactance ($\mathbf{X_L}$) is $+j$ (Positive value on *j* vertical axis)

Capacitive reactance ($\mathbf{X_C}$) is $-j$ (Negative value on *j* vertical axis)

Resistance is positive value on horizontal axis.

Total impedance is $Z = R \pm jX$ Where *R* is the resistance and *X* is the total reactance.

Impedances in series can be added together algebraically. In the case where $\mathbf{X_L}$ (which is positive) matches $\mathbf{X_C}$ (which is negative) then the total reactance is zero, and the circuit is **resonant**.

An impedance in the form $R \pm jX$ can be converted to **polar coordinates**, $r \angle \theta$ where '*r*' is the magnitude and θ is the phase angle.

Power Factor

True Power is the actual power dissipated and **Apparent Power** is the power calculated by independently measuring voltage and current. True Power is measured in Watts. Apparent power is measured in Volt-Amps (VA).

In a circuit with a pure resistance, True Power = E * I (Voltage times current)

In an AC circuit with reactance, True Power = *Power Factor* * E * I

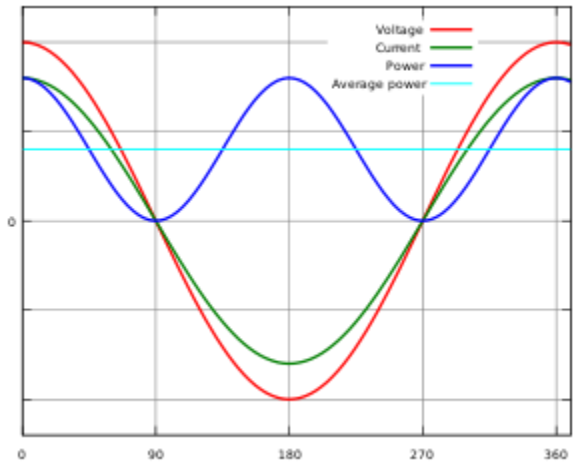
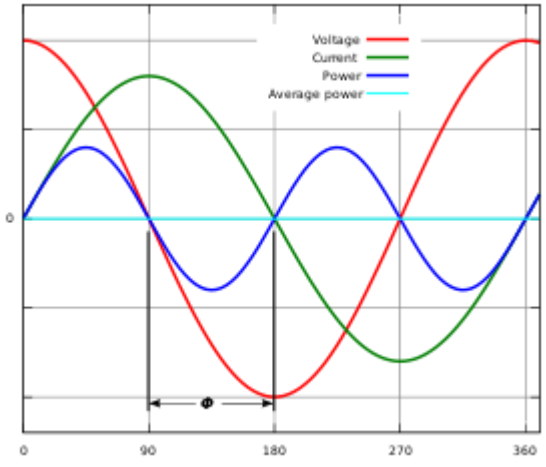
$$Power\ Factor = \frac{True\ Power}{Apparent\ Power} = \cos\theta$$

$$True\ Power = Power\ Factor * Apparent\ Power = \cos\theta * Apparent\ Power$$

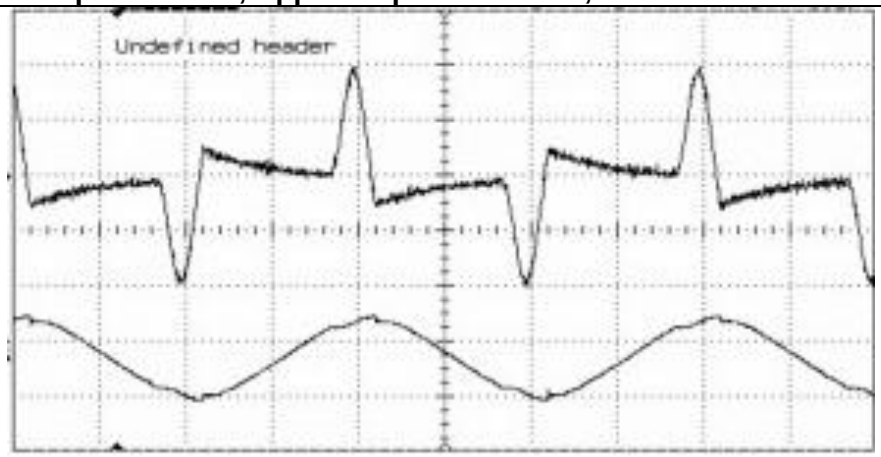
Where θ is the phase angle.

For resistance, $\theta = 0$ and $\cos\theta = 1$, so **Power Factor = 1**

For pure capacitance or inductance, $\theta = \pm 90$ and $\cos\theta = 0$, so **Power Factor = 0**
In other words, **inductors and capacitors don't dissipate power – they store it**. So power is dissipated only by current flowing through resistors.

Power with resistance load	Power with pure inductance or capacitance
	
With resistance load, power is always positive	Power is positive and negative. Sum is zero.

Current (top) and voltage (bottom) for CFL bulb. Current is non-sinusoidal.
Real power = 9W, Apparent power = 14VA, Power factor = 0.65



Good news: Residential power meters measure true power (watts).

Bad news: Apparent power wastes power in the electric power grid.