Voltage/Current Phase Angle

“ELI the ICE man”
Phil Sherrod – W4PHS

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 capacitative reactance.

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

$$\text{Impedance}$$ is the AC equivalent of resistance in DC circuits. Like resistance, high impedance blocks current flow. Impedance consists of \textbf{Resistance} and \textbf{Reactance}.

Inductive reactance \((X_L)\) is \(+j\) (Positive value on \(j\) vertical axis)

Capacitive reactance \((X_C)\) 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 $X_L$ (which is positive) matches $X_C$ (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 $\theta$ 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 = $E \times I$ (Voltage times current)

In an AC circuit with reactance, True Power = $Power Factor \times E \times I$

\[
Power Factor = \frac{True\ Power}{Apparent\ Power} = \cos \theta
\]

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

Where $\theta$ 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.

<table>
<thead>
<tr>
<th>Power with resistance load</th>
<th>Power with pure inductance or capacitance</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
<tr>
<td>With resistance load, power is always positive</td>
<td>Power is positive and negative. Sum is zero.</td>
</tr>
</tbody>
</table>
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.