EEE 2015 ELECTRICS

L03 AC Circuit Analysis&Power Calculations

Behaviors of Basic Circuit Components under AC

Resistor (R)	Coil (L) (Inductor)	Capacitor(C) (Condenser)
Resistor 100 Ω	**Inductor** 100 mH, 159.15 Hz	**Capacitor** 10 μF, 159.15 Hz
R = 100 Ω	R = 0 Ω	R = 0 Ω
X = 0 Ω	X = 100 Ω	X = 100 Ω
Z = 100 Ω ∠ 0°	Z = 100 Ω ∠ 90°	Z = 100 Ω ∠ -90°

Dr. Levent ÇETİN

AC circuit –RL in series

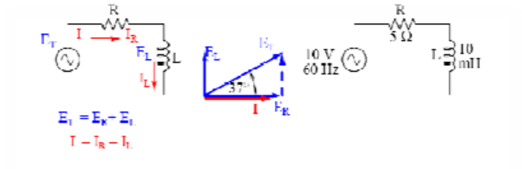


Figure 3.10: Series resistor inductor circuit: Current lags applied voltage by 0° to 90°.

Inductive reactance of the coil

$$X_L = 0 + 3.7699 j\Omega$$

The total effect is called as **impedance**.

$$Z = R + X_L = 5 + 3.7699 j\Omega = 6.262\angle 37.016\Omega$$

$$Z = \frac{V}{I}$$

$$I = \frac{10\angle 0 V}{6.262\angle 37.016\Omega} = 1.597\angle -37.016 A$$

L02 Alternating Voltage and Current

AC circuit –RL in series

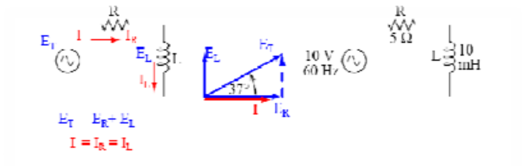


Figure 3.10: Series resistor inductor circuit: Current lags applied voltage by 0° to 90°.

Figure 3.11: Current lags voltage in a series L-R circuit.

$$E = IZ$$
$$E_R = I_R Z_R$$
$$E_R = (1.597\ A \angle -37.016^\circ)(5\ \Omega \angle 0^\circ)$$
$$E_R = 7.9847\ V \angle -37.016^\circ$$

$$E = IZ$$
$$E_L = I_L Z_L$$
$$E_L = (1.597\ A \angle -37.016^\circ)(3.7699\ \Omega \angle 90^\circ)$$
$$E_L = 6.0203\ V \angle 52.984^\circ$$

Notice that the phase angle of E_L is exactly 90° more than the phase angle of the current.

$$E_{total} = E_R + E_L$$
$$E_{total} = (7.9847\ V \angle -37.016^\circ) + (6.0203\ V \angle 52.984^\circ)$$
$$E_{total} = 10\ V \angle 0^\circ$$

AC circuit –RL in parallel

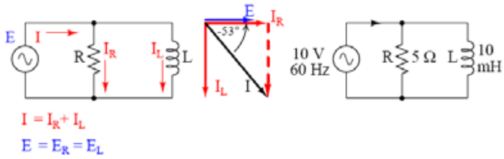


Figure 3.14: *Parallel R-L circuit.*

	R	L	Total	
E	10 + j0 10 ∠ 0°	10 + j0 10 ∠ 0°	10 + j0 10 ∠ 0°	Volts
I				Amps
Z	5 + j0 5 ∠ 0°	0 + j3.7699 3.7699 ∠ 90°		Ohms

Rule of parallel circuits:

$E_{total} = E_R = E_L$

AC circuit –RL in parallel

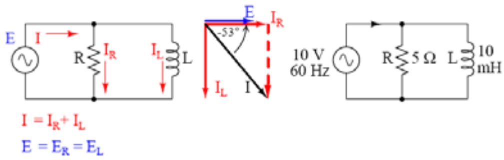


Figure 3.14: *Parallel R-L circuit.*

	R	L	Total	
E	10 + j0 10 ∠ 0°	10 + j0 10 ∠ 0°	10 + j0 10 ∠ 0°	Volts
I	**2 + j0** **2 ∠ 0°**	**0 - j2.6526** **2.6526 ∠ -90°**		Amps
Z	5 + j0 5 ∠ 0°	0 + j3.7699 3.7699 ∠ 90°		Ohms

Ohm's Law (R): $I = \frac{E}{Z}$

Ohm's Law (L): $I = \frac{E}{Z}$

AC circuit –RL in parallel

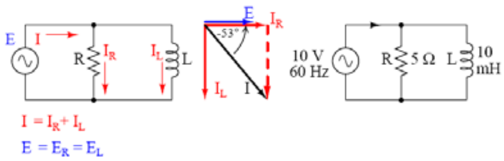


Figure 3.14: *Parallel R-L circuit.*

	R	L	Total	
E	10 + j0 10 ∠ 0°	10 + j0 10 ∠ 0°	10 + j0 10 ∠ 0°	Volts
I	2 + j0 2 ∠ 0°	0 - j2.6526 2.6526 ∠ -90°	**2 - j2.6526** **3.3221** ∠ -52.984°	Amps
Z	5 + j0 5 ∠ 0°	0 + j3.7699 3.7699 ∠ 90°		Ohms

Rule of parallel circuits:

$I_{total} = I_R + I_L$

L02 Alternating Voltage and Current

AC circuit –RL in parallel

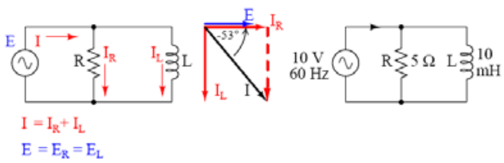


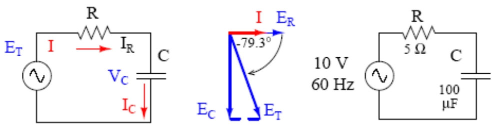
Figure 3.14: *Parallel R-L circuit.*

	R	L	Total	
E	10 + j0 10 ∠ 0°	10 + j0 10 ∠ 0°	10 + j0 10 ∠ 0°	Volts
I	2 + j0 2 ∠ 0°	0 - j2.6526 2.6526 ∠ -90°	2 - j2.6526 3.322 ∠ -52.984°	Amps
Z	5 + j0 5 ∠ 0°	0 + j3.7699 3.7699 ∠ 90°	**1.8122 + j2.4035** **3.0102** ∠ 52.984°	Ohms

Ohm's Law *or* *Rule of parallel circuits:*

$$Z = \frac{E}{I} \qquad Z_{total} = \frac{1}{\frac{1}{Z_R} + \frac{1}{Z_L}}$$

AC circuit –RC in series



$E_T = E_R + E_C$

$I = I_R = I_C$

$$X_c = 0 - 26.5258j\,\Omega$$

$$R = 5 + 0j\,\Omega$$

$$Z = R + X_c = 5 - 26.5258j\,\Omega = 26.993\angle -79.325$$

$$I = \frac{E}{Z}$$

$$I = \frac{10\text{ V} \angle 0^\circ}{26.933\ \Omega \angle -79.325^\circ}$$

$$I = 370.5\text{ mA} \angle 79.325^\circ$$

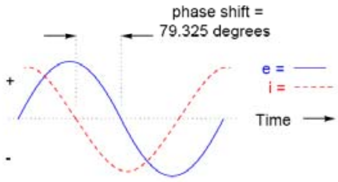
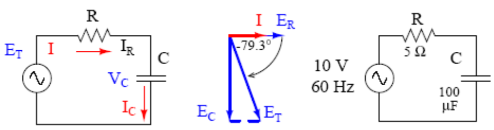


Figure 4.11: *Voltage lags current (current leads voltage)in a series R-C circuit.*

AC circuit –RC in series



$E_T = E_R + E_C$

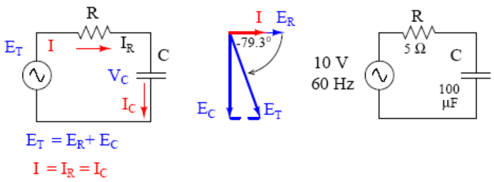
$I = I_R = I_C$

	R	C	Total	
E			10 + j0 10 ∠ 0°	Volts
I			68.623m + j364.06m 370.5m ∠ 79.325°	Amps
Z	5 + j0 5 ∠ 0°	0 - j26.5258 26.5258 ∠ -90°	5 - j26.5258 26.993 ∠ -79.325°	Ohms

	R	C	Total	
E			10 + j0 10 ∠ 0°	Volts
I	**68.623m + j364.06m** **370.5m ∠ 79.325°**	**68.623m + j364.06m** **370.5m ∠ 79.325°**	68.623m + j364.06m 370.5m ∠ 79.325°	Amps
Z	5 + j0 5 ∠ 0°	0 - j26.5258 26.5258 ∠ -90°	5 - j26.5258 26.993 ∠ -79.325°	Ohms

Rule of series circuits:
$I_{total} = I_R = I_C$

AC circuit –RC in series

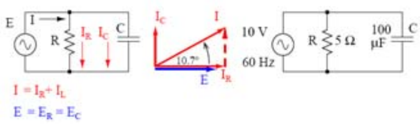


	R	C	Total	
E	**343.11m + j1.8203** **1.8523 ∠ 79.325°**	**9.6569 - j1.8203** **9.8269 ∠ -10.675°**	10 + j0 10 ∠ 0°	Volts
I	68.623m + j364.06m 370.5m ∠ 79.325°	68.623m + j364.06m 370.5m ∠ 79.325°	68.623m + j364.06m 370.5m ∠ 79.325°	Amps
Z	5 + j0 5 ∠ 0°	0 - j26.5258 26.5258 ∠ -90°	5 - j26.5258 26.993 ∠ -79.325°	Ohms

Ohm's Law $E = IZ$ *Ohm's Law* $E = IZ$

As it can be considered easily, the phase shift is 79.325 degrees in this circuit whereas in the circuit that has only one capacitor it was 90 degrees.
The current and the voltage on the resistor is on the same phase as it is mentioned.
However, the current on a capacitor leads voltage by 90 degrees.

AC circuit –RC in parallel

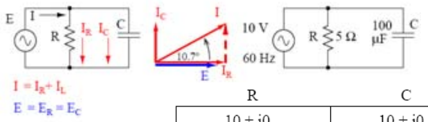


F	R	C	Total	
E			10 + j0 10 ∠ 0°	Volts
I				Amps
Z	5 + j0 5 ∠ 0°	0 - j26.5258 26.5258 ∠ -90°		Ohms

	R	C	Total	
E	**10 + j0** **10 ∠ 0°**	**10 + j0** **10 ∠ 0°**	10 + j0 10 ∠ 0°	Volts
I				Amps
Z	5 + j0 5 ∠ 0°	0 - j26.5258 26.5258 ∠ -90°		Ohms

Rule of parallel circuits:
$E_{total} = E_R = E_C$

AC circuit –RC in parallel



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	R	C	Total	
E	$10 + j0$ $10 \angle 0°$	$10 + j0$ $10 \angle 0°$	$10 + j0$ $10 \angle 0°$	Volts
I	**$2 + j0$** **$2 \angle 0°$**	**$0 + j376.99m$** **$376.99m \angle 90°$**		Amps
Z	$5 + j0$ $5 \angle 0°$	$0 - j26.5258$ $26.5258 \angle -90°$		Ohms

Ohm's Law $I = \frac{E}{Z}$ *Ohm's Law* $I = \frac{E}{Z}$

	R	C	Total	
E	$10 + j0$ $10 \angle 0°$	$10 + j0$ $10 \angle 0°$	$10 + j0$ $10 \angle 0°$	Volts
I	$2 + j0$ $2 \angle 0°$	$0 + j376.99m$ $376.99m \angle 90°$	**$2 + j376.99m$** **$2.0352 \angle 10.675°$**	Amps
Z	$5 + j0$ $5 \angle 0°$	$0 - j26.5258$ $26.5258 \angle -90°$		Ohms

Rule of parallel circuits:
$I_{total} = I_R + I_C$

AC circuit –RC in parallel

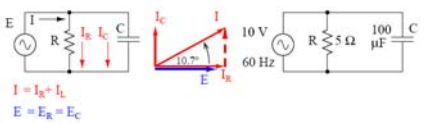


Figure 4.14: Parallel R-C circuit.

	R	C	Total	
E	$10 + j0$ $10 \angle 0°$	$10 + j0$ $10 \angle 0°$	$10 + j0$ $10 \angle 0°$	Volts
I	$2 + j0$ $2 \angle 0°$	$0 + j376.99m$ $376.99m \angle 90°$	$2 + j376.99m$ $2.0352 \angle 10.675°$	Amps
Z	$5 + j0$ $5 \angle 0°$	$0 - j26.5258$ $26.5258 \angle -90°$	**$4.8284 - j910.14m$** **$4.9135 \angle -10.675°$**	Ohms

Ohm's Law $Z = \frac{E}{I}$ *or* *Rule of parallel circuits:* $Z_{total} = \frac{1}{\frac{1}{Z_R} + \frac{1}{Z_C}}$

AC circuit –RLC in series

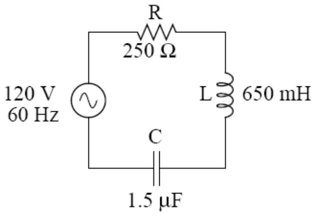


Figure 5.2: *Example series R, L, and C circuit.*

$$X_L = 2\pi f L$$

$$X_L = (2)(\pi)(60\ \text{Hz})(650\ \text{mH})$$

$$X_L = 245.04\ \Omega$$

$$X_C = \frac{1}{2\pi f C}$$

$$X_C = \frac{1}{(2)(\pi)(60\ \text{Hz})(1.5\ \mu\text{F})}$$

$$X_C = 1.7684\ \text{k}\Omega$$

$Z_R = 250 + j0\ \Omega$ *or* $250\ \Omega \angle 0^\circ$

$Z_L = 0 + j245.04\ \Omega$ *or* $245.04\ \Omega \angle 90^\circ$

$Z_C = 0 - j1.7684\text{k}\ \Omega$ *or* $1.7684\ \text{k}\Omega \angle -90^\circ$

AC circuit –RLC in series

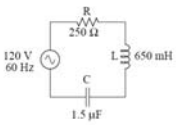


Figure 5.2: *Example series R, L, and C circuit.*

	R	L	C	Total	
E				**120 + j0** **120 ∠ 0°**	Volts
I					Amps
Z	**250 + j0** **250 ∠ 0°**	**0 + j245.04** **245.04 ∠ 90°**	**0 - j1.7684k** **1.7684k ∠ -90°**		Ohms

	R	L	C	Total	
E				120 + j0 120 ∠ 0°	Volts
I					Amps
Z	250 + j0 250 ∠ 0°	0 + j245.04 245.04 ∠ 90°	0 - j1.7684k 1.7684k ∠ -90°	**250 - j1.5233k** **1.5437k ∠ -80.680°**	Ohms

Rule of series circuits:
$Z_{total} = Z_R + Z_L + Z_C$

	R	L	C	Total	
E				120 + j0 120 ∠ 0°	Volts
I				**12.589m + 76.708m** **77.734m ∠ 80.680°**	Amps
Z	250 + j0 250 ∠ 0°	0 + j245.04 245.04 ∠ 90°	0 - j1.7684k 1.7684k ∠ -90°	250 - j1.5233k 1.5437k ∠ -80.680°	Ohms

Ohm's Law
$I = \frac{E}{Z}$

AC circuit –RLC in series

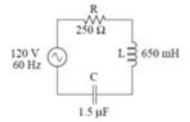


Figure 5.2: Example series R, L, and C circuit.

	R	L	C	Total	
E				120 + j0 120 ∠ 0°	Volts
I	12.589m + 76.708m 77.734m ∠ 80.680°	12.589m + 76.708m 77.734m ∠ 80.680°	12.589m + 76.708m 77.734m ∠ 80.680°	12.589m + 76.708m 77.734m ∠ 80.680°	Amps
Z	250 + j0 250 ∠ 0°	0 + j245.04 245.04 ∠ 90°	0 - j1.7684k 1.7684k ∠ -90°	250 - j1.5233k 1.5437k ∠ -80.680°	Ohms

Rule of series circuits:
$I_{total} = I_R = I_L = I_C$

$E_R + E_L + E_C$ *should equal* E_{total}

$$\begin{array}{rl} 3.1472 + j19.177\ \text{V} & E_R \\ -18.797 + j3.0848\ \text{V} & E_L \\ +\quad 135.65 - j22.262\ \text{V} & E_C \\ \hline 120 + j0\quad \text{V} & E_{total} \end{array}$$

	R	L	C	Total	
E	3.1472 + j19.177 19.434 ∠ 80.680°	-18.797 + j3.0848 19.048 ∠ 170.68°	135.65 - j22.262 137.46 ∠ -9.3199°	120 + j0 120 ∠ 0°	Volts
I	12.589m + 76.708m 77.734m ∠ 80.680°	12.589m + 76.708m 77.734m ∠ 80.680°	12.589m + 76.708m 77.734m ∠ 80.680°	12.589m + 76.708m 77.734m ∠ 80.680°	Amps
Z	250 + j0 250 ∠ 0°	0 + j245.04 245.04 ∠ 90°	0 - j1.7684k 1.7684k ∠ -90°	250 - j1.5233k 1.5437k ∠ -80.680°	Ohms
	Ohm's Law E = IZ	*Ohm's Law* E = IZ	*Ohm's Law* E = IZ		

It should be considered that the amplitude of the voltage on the capacitor is greater than the voltage supplied to the circuit. The influence of the impedance in the whole circuit is smaller than the influence of impedance of any single component. This case causes higher voltages on single components.

AC circuit –RLC in paralel

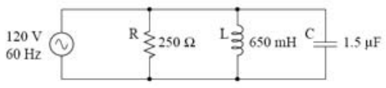
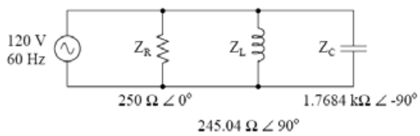


Figure 5.5: Example R, L, and C parallel circuit.



	R	L	C	Total	
E				120 + j0 120 ∠ 0°	Volts
I					Amps
Z	250 + j0 250 ∠ 0°	0 + j245.04 245.04 ∠ 90°	0 - j1.7684k 1.7684k ∠ -90°		Ohms

	R	L	C	Total	
E	120 + j0 120 ∠ 0°	120 + j0 120 ∠ 0°	120 + j0 120 ∠ 0°	120 + j0 120 ∠ 0°	Volts
I					Amps
Z	250 + j0 250 ∠ 0°	0 + j245.04 245.04 ∠ 90°	0 - j1.7684k 1.7684k ∠ -90°		Ohms

Rule of parallel circuits:
$E_{total} = E_R = E_L = E_C$

AC circuit –RLC in paralel

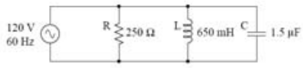
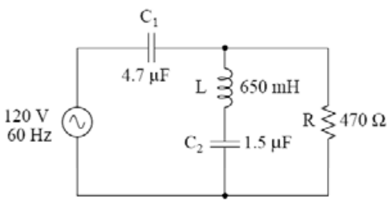


Figure 5.5: Example R, L, anc

	R	L	C	Total	
E	$120 + j0$ $120 \angle 0°$	$120 + j0$ $120 \angle 0°$	$120 + j0$ $120 \angle 0°$	$120 + j0$ $120 \angle 0°$	Volts
I	**$480m + j0$** **$480m \angle 0°$**	**$0 - j489.71m$** **$489.71m \angle -90°$**	**$0 + j67.858m$** **$67.858m \angle 90°$**		Amps
Z	$250 + j0$ $250 \angle 0°$	$0 + j245.04$ $245.04 \angle 90°$	$0 - j1.7684k$ $1.7684k \angle -90°$		Ohms
	Ohm's Law $I = \frac{E}{Z}$	Ohm's Law $I = \frac{E}{Z}$	Ohm's Law $I = \frac{E}{Z}$		

	R	L	C	Total	
E	$120 + j0$ $120 \angle 0°$	$120 + j0$ $120 \angle 0°$	$120 + j0$ $120 \angle 0°$	$120 + j0$ $120 \angle 0°$	Volts
I	$480m + j0$ $480 \angle 0°$	$0 - j489.71m$ $489.71m \angle -90°$	$0 + j67.858m$ $67.858m \angle 90°$	**$480m - j421.85m$** **$639.03m \angle -41.311°$**	Amps
Z	$250 + j0$ $250 \angle 0°$	$0 + j245.04$ $245.04 \angle 90°$	$0 - j1.7684k$ $1.7684k \angle -90°$	**$141.05 + j123.96$** **$187.79 \angle 41.311°$**	Ohms

AC circuit –Complex Circuit



Reactances and Resistances:

$X_{C1} = \frac{1}{2\pi f C_1}$ $X_{C1} = \frac{1}{(2)(\pi)(60\text{ Hz})(4.7\ \mu F)}$ $X_{C1} = 564.38\ \Omega$	$X_L = 2\pi f L$ $X_L = (2)(\pi)(60\text{ Hz})(650\text{ mH})$ $X_L = 245.04\ \Omega$
$X_{C2} = \frac{1}{2\pi f C_2}$ $X_{C2} = \frac{1}{(2)(\pi)(60\text{ Hz})(1.5\ \mu F)}$ $X_{C2} = 1.7684\text{ k}\Omega$	$R = 470\ \Omega$

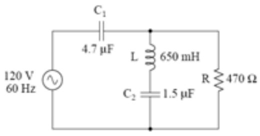
$Z_{C1} = 0 - j564.38\ \Omega$ *or* $564.38\ \Omega \angle -90°$

$Z_L = 0 + j245.04\ \Omega$ *or* $245.04\ \Omega \angle 90°$

$Z_{C2} = 0 - j1.7684k\ \Omega$ *or* $1.7684\text{ k}\Omega \angle -90°$

$Z_R = 470 + j0\ \Omega$ *or* $470\ \Omega \angle 0°$

AC circuit –Complex Circuit



	C_1	L	C_2	R	Total	
E					120 + j0 120 ∠ 0°	Volts
I						Amps
Z	0 - j564.38 564.38 ∠ -90°	0 + j245.04 245.04 ∠ 90°	0 - j1.7684k 1.7684k ∠ -90°	470 + j0 470 ∠ 0°		Ohms

The calculation of impedance in this circuit should be completed step by step.
First, serial connection branch of C_2 and L,
afterwards the parallel branch of resistor and last the serial capacitor effects should be calculated.

	L -- C_2	R // (L -- C_2)	*Total* C_1 -- [R // (L -- C_2)]	
E			120 + j0 120 ∠ 0°	Volts
I				Amps
Z	**0 - j1.5233k** **1.5233k ∠ -90°**	**429.15 - j132.41** **449.11 ∠ -17.147°**	**429.15 - j696.79** **818.34 ∠ -58.371°**	Ohms

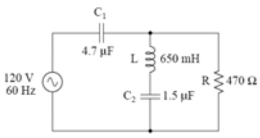
Rule of series circuits: $Z_{L\text{--}C2} = Z_L + Z_{C2}$

Rule of parallel circuits: $Z_{R//(L\text{--}C2)} = \dfrac{1}{\dfrac{1}{Z_R} + \dfrac{1}{Z_{L\text{--}C2}}}$

Rule of series circuits: $Z_{total} = Z_{C1} + Z_{R//(L\text{--}C2)}$

L02 Alternating Voltage and Current

AC circuit –Complex Circuit



Calculate current drawn from source and passing through C_1

	L -- C_2	R // (L -- C_2)	*Total* C_1 -- [R // (L -- C_2)]	
E			120 + j0 120 ∠ 0°	Volts
I			**76.899m + j124.86m** **146.64m ∠ 58.371°**	Amps
Z	0 - j1.5233k 1.5233k ∠ -90°	429.15 - j132.41 449.11 ∠ -17.147°	429.15 - j696.79 818.34 ∠ -58.371°	Ohms

Ohm's Law $I = \dfrac{E}{Z}$

Same current is passing through L-C_2 branch

	L -- C_2	R // (L -- C_2)	*Total* C_1 -- [R // (L -- C_2)]	
E			120 + j0 120 ∠ 0°	Volts
I		**76.899m + j124.86m** **146.64m ∠ 58.371°**	76.899m + j124.86m 146.64m ∠ 58.371°	Amps
Z	0 - j1.5233k 1.5233k ∠ -90°	429.15 - j132.41 449.11 ∠ -17.147°	429.15 - j696.79 818.34 ∠ -58.371°	Ohms

Rule of series circuits: $I_{total} = I_{C1} = I_{R//(L\text{--}C2)}$

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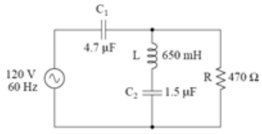


Voltage drop on L-C_2 branch

	L -- C_2	R // (L -- C_2)	*Total* C_1 -- [R // (L -- C_2)]	
E		**49.533 + j43.400 65.857 ∠ 41.225°**	120 + j0 120 ∠ 0°	Volts
I		76.899m + j124.86m 146.64m ∠ 58.371°	76.899m + j124.86m 146.64m ∠ 58.371°	Amps
Z	0 - j1.5233k 1.5233k ∠ -90°	429.15 - j132.41 449.11 ∠ -17.147°	429.15 - j696.79 818.34 ∠ -58.371°	Ohms

Ohm's Law
E = IZ

Same Voltage drops on parallel R branch

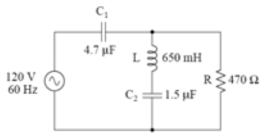
	L -- C_2	R // (L -- C_2)	*Total* C_1 -- [R // (L -- C_2)]	
E	**49.533 + j43.400 65.857 ∠ 41.225°**	49.533 + j43.400 65.857 ∠ 41.225°	120 + j0 120 ∠ 0°	Volts
I		76.899m + j124.86m 146.64m ∠ 58.371°	76.899m + j124.86m 146.64m ∠ 58.371°	Amps
Z	0 - j1.5233k 1.5233k ∠ -90°	429.15 - j132.41 449.11 ∠ -17.147°	429.15 - j696.79 818.34 ∠ -58.371°	Ohms

Rule of parallel circuits:
$E_{R//(L--C2)} = E_R = E_{L--C2}$

Dr. Levent ÇETİN

L02 Alternating Voltage and Current

AC circuit –Complex Circuit



	L -- C_2	R // (L -- C_2)	*Total* C_1 -- [R // (L -- C_2)]	
E	49.533 + j43.400 65.857 ∠ 41.225°	49.533 + j43.400 65.857 ∠ 41.225°	120 + j0 120 ∠ 0°	Volts
I	**-28.490m + j32.516m 43.232m ∠ 131.22°**	76.899m + j124.86m 146.64m ∠ 58.371°	76.899m + j124.86m 146.64m ∠ 58.371°	Amps
Z	0 - j1.5233k 1.5233k ∠ -90°	429.15 - j132.41 449.11 ∠ -17.147°	429.15 - j696.79 818.34 ∠ -58.371°	Ohms

Ohm's Law
$I = \frac{E}{Z}$

	C_1	L	C_2	R	Total	
E					120 + j0 120 ∠ 0°	Volts
I						Amps
Z	0 - j564.38 564.38 ∠ -90°	0 + j245.04 245.04 ∠ 90°	0 - j1.7684k 1.7684k ∠ -90°	470 + j0 470 ∠ 0°		Ohms

	C_1	L	C_2	R	
E	70.467 - j43.400 82.760 ∠ -31.629°	**7.968 - j6.981 10.594 ∠ 221.22°**	**57.501 + j50.382 76.451 ∠ 41.225**	49.533 + j43.400 65.857 ∠ 41.225°	Volts
I	76.899m + j124.86m 146.64m ∠ 58.371°	-28.490m + j32.516m 43.232m ∠ 131.22°	-28.490m + j32.516m 43.232m ∠ 131.22°	105.39m + j92.341m 140.12m ∠ 41.225°	Amps
Z	0 - j564.38 564.38 ∠ -90°	0 + j245.04 245.04 ∠ 90°	0 - j1.7684k 1.7684k ∠ -90°	470 + j0 470 ∠ 0°	Ohms

Ohm's Law
E = IZ

Ohm's Law
E = IZ

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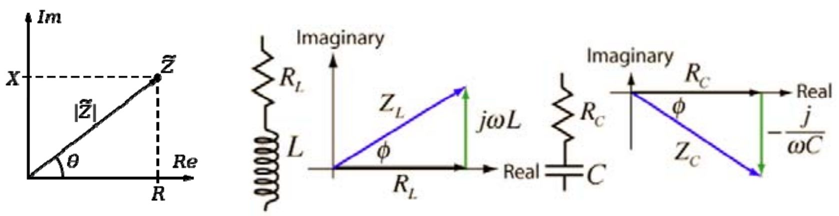
Power in AC circuit

Since it was mentioned, there is a phase shift between current and voltage in AC circuits. The reason is the complex number impedance as it was stated.
So there are three definitions in AC circuits which are related with power.
These are:

- True power (active power),
- Reactive power,
- Apparent power.

Impedance Calculations:



Inductive Circuit   Capacitive Circuit

Power in AC circuit

P = true power $P = I^2R$ $P = \frac{E^2}{R}$

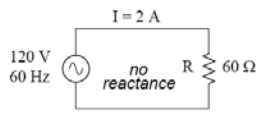
*Measured in units of **Watts***

Q = reactive power $Q = I^2X$ $Q = \frac{E^2}{X}$

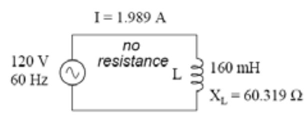
*Measured in units of **Volt-Amps-Reactive (VAR)***

S = apparent power $S = I^2Z$ $S = \frac{E^2}{Z}$ $S = IE$

*Measured in units of **Volt-Amps (VA)***



P = true power = I^2R = 240 W
Q = reactive power = I^2X = 0 VAR
S = apparent power = I^2Z = 240 VA



P = true power = I^2R = 0 W
Q = reactive power = I^2X = 238.73 VAR
S = apparent power = I^2Z = 238.73 VA

Power in AC circuit

$\mathbf{P}$ = true power $\quad P = I^2R \quad P = \frac{E^2}{R}$

*Measured in units of **Watts***

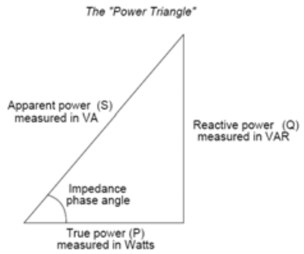
The power quantities are scalar quantities. if we consider the 90 degrees of direction angle between the resistor and the reactance and phase shift in the circuit. **This perpendicular triangle is called as 'Power Triangle**

$\mathbf{Q}$ = reactive power $\quad Q = I^2X \quad Q = \frac{E^2}{X}$

*Measured in units of **Volt-Amps-Reactive (VAR)***

$\mathbf{S}$ = apparent power $\quad S = I^2Z \quad S = \frac{E^2}{Z} \quad S = IE$

*Measured in units of **Volt-Amps (VA)***



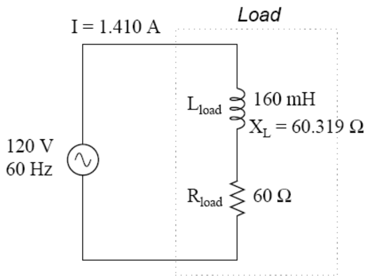
A part of the power cannot be converted to electrical work in an AC circuit. The generated effective power is just as the true power. **Power factor** is the cosine of the angle between the true and apparent powers (cos ϕ). This value is equal to 1 in only circuits those have just resistors. But if there is a reactance, then the value is between 0 and 1.

Power in AC circuit

$\mathbf{P}$ = true power $\quad P = I^2R \quad P = \frac{E^2}{R}$
*Measured in units of **Watts***

$\mathbf{Q}$ = reactive power $\quad Q = I^2X \quad Q = \frac{E^2}{X}$
*Measured in units of **Volt-Amps-Reactive (VAR)***

$\mathbf{S}$ = apparent power $\quad S = I^2Z \quad S = \frac{E^2}{Z} \quad S = IE$
*Measured in units of **Volt-Amps (VA)***



$$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}$$

$$\text{Power factor} = \frac{119.365\ \text{W}}{169.256\ \text{VA}}$$

$$\text{Power factor} = 0.705$$

P = true power = I^2R = 119.365 W

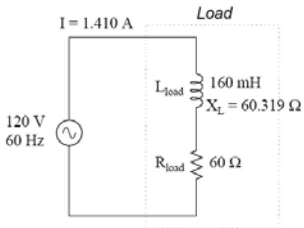
Q = reactive power = I^2X = 119.998 VAR

S = apparent power = I^2Z = 169.256 VA

The power factor value shows that the **70.5 % of the power used from the grid is served for the purpose.**

Compensation in AC circuit

P = true power $P = I^2R$ $P = \frac{E^2}{R}$ *Measured in units of* ***Watts***	Q = reactive power $Q = I^2X$ $Q = \frac{E^2}{X}$ *Measured in units of* ***Volt-Amps-Reactive (VAR)***	S = apparent power $S = I^2Z$ $S = \frac{E^2}{Z}$ $S = IE$ *Measured in units of* ***Volt-Amps (VA)***



P = true power = I^2R = 119.365 W

Q = reactive power = I^2X = 119.998 VAR

S = apparent power = I^2Z = 169.256 VA

$$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}$$

$$\text{Power factor} = \frac{119.365\ \text{W}}{169.256\ \text{VA}}$$

Power factor = 0.705

The power factor value shows that the **70.5 % of the power used from the grid is served for the purpose.**

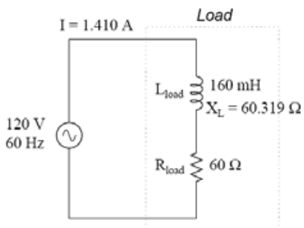
This situation is not wanted.
So, in circuit design stage, it must be noted that the power factor is approximately equal to 1.

For this reason, the capacitive and inductive reactance values should be approximately equal to each other.

If this is not possible, a capacitor or an inductor should be externally added to the circuit. **This improvement is called as compensation.**

Compensation in AC circuit

P = true power $P = I^2R$ $P = \frac{E^2}{R}$ *Measured in units of* ***Watts***	Q = reactive power $Q = I^2X$ $Q = \frac{E^2}{X}$ *Measured in units of* ***Volt-Amps-Reactive (VAR)***	S = apparent power $S = I^2Z$ $S = \frac{E^2}{Z}$ $S = IE$ *Measured in units of* ***Volt-Amps (VA)***



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S = apparent power = I^2Z = 169.256 VA

$$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}$$

$$\text{Power factor} = \frac{119.365\ \text{W}}{169.256\ \text{VA}}$$

Power factor = 0.705

The circuit is inductive so a **parallel** capacitor should be added so that the total reactance of the circuit becomes approximately zero

$$Q = \frac{E^2}{X}$$

. . solving for X . . .

$$X = \frac{E^2}{Q}$$

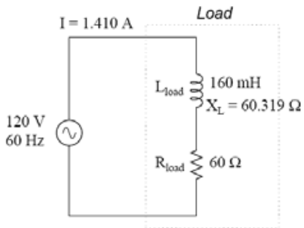
$$X = \frac{(120\ \text{V})^2}{119.998\ \text{VAR}}$$

$$X = 120.002\ \Omega$$

In parallel branches voltage is constant so the necessary reactance value can be calculated using voltage based power formula

Compensation in AC circuit

P = true power $P = I^2R$ $P = \frac{E^2}{R}$ *Measured in units of* ***Watts***	Q = reactive power $Q = I^2X$ $Q = \frac{E^2}{X}$ *Measured in units of* ***Volt-Amps-Reactive (VAR)***	S = apparent power $S = I^2Z$ $S = \frac{E^2}{Z}$ $S = IE$ *Measured in units of* ***Volt-Amps (VA)***



P = true power = I^2R = 119.365 W

Q = reactive power = I^2X = 119.998 VAR

S = apparent power = I^2Z = 169.256 VA

$$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}$$

$$\text{Power factor} = \frac{119.365\ \text{W}}{169.256\ \text{VA}}$$

Power factor = 0.705

The calculated reactance value is used to find capacitor value

$$X_C = \frac{1}{2\pi f C}$$

. . . solving for C . . .

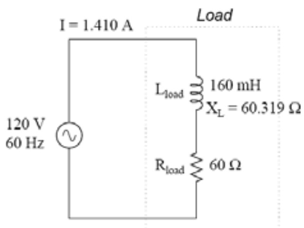
$$C = \frac{1}{2\pi f X_C}$$

$$C = \frac{1}{2\pi(60\ \text{Hz})(120.002\ \Omega)}$$

$$C = 22.105\ \mu\text{F}$$

Compensation in AC circuit

P = true power $P = I^2R$ $P = \frac{E^2}{R}$ *Measured in units of* ***Watts***	Q = reactive power $Q = I^2X$ $Q = \frac{E^2}{X}$ *Measured in units of* ***Volt-Amps-Reactive (VAR)***	S = apparent power $S = I^2Z$ $S = \frac{E^2}{Z}$ $S = IE$ *Measured in units of* ***Volt-Amps (VA)***



P = true power = I^2R = 119.365 W

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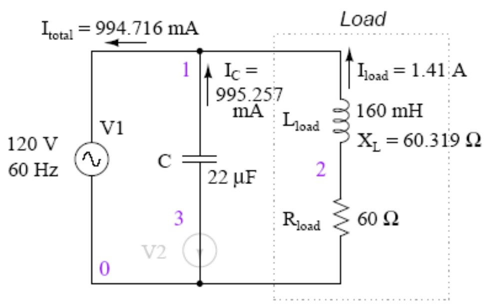
$$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}$$

$$\text{Power factor} = \frac{119.365\ \text{W}}{169.256\ \text{VA}}$$

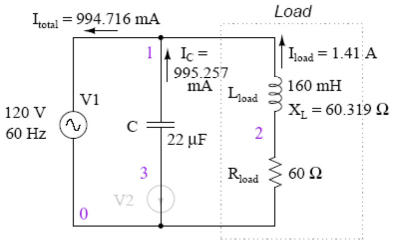
Power factor = 0.705

The capacitor value found is not a standart value for capacitors, so the closest standart value shold be chosen (22 µF) and connected in parallel with the circuit.



Compensation in AC circuit

P = true power $P = I^2R$ $P = \frac{E^2}{R}$ *Measured in units of **Watts***	Q = reactive power $Q = I^2X$ $Q = \frac{E^2}{X}$ *Measured in units of **Volt-Amps-Reactive (VAR)***	S = apparent power $S = I^2Z$ $S = \frac{E^2}{Z}$ $S = IE$ *Measured in units of **Volt-Amps (VA)***



$Z_{total} = Z_C \,//\, (Z_L -- Z_R)$

$Z_{total} = (120.57\ \Omega \angle -90^\circ) \,//\, (60.319\ \Omega \angle 90^\circ -- 60\ \Omega \angle 0^\circ)$

$Z_{total} = 120.64 - j573.58m\ \Omega$ *or* $120.64\ \Omega \angle 0.2724^\circ$

P = true power = I^2R = 119.365 W

S = apparent power = I^2Z = 119.366 VA

$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}$

$\text{Power factor} = \frac{119.365\ \text{W}}{119.366\ \text{VA}}$

Power factor = 0.9999887

this improvement made the power factor closer to 1. Besides, the current is decreased.

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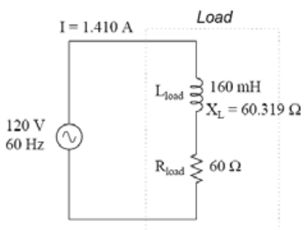
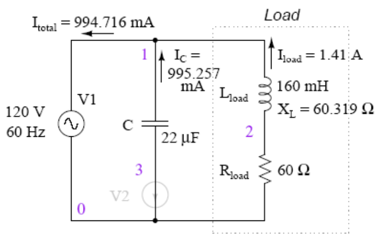
Compensation in AC circuit

P = true power $P = I^2R$ $P = \frac{E^2}{R}$ *Measured in units of **Watts***	Q = reactive power $Q = I^2X$ $Q = \frac{E^2}{X}$ *Measured in units of **Volt-Amps-Reactive (VAR)***	S = apparent power $S = I^2Z$ $S = \frac{E^2}{Z}$ $S = IE$ *Measured in units of **Volt-Amps (VA)***





P = true power = I^2R = 119.365 W

Q = reactive power = I^2X = 119.998 VAR

S = apparent power = I^2Z = 169.256 VA

Power factor = True / Appare

P = true power = I^2R = 119.365 W

S = apparent power = I^2Z = 119.366 VA

$\text{Power factor} = \frac{119.365\ \text{W}}{169.256\ \text{VA}}$

Power factor = 0.705

$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}$

$\text{Power factor} = \frac{119.365\ \text{W}}{119.366\ \text{VA}}$

Power factor = 0.9999887

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