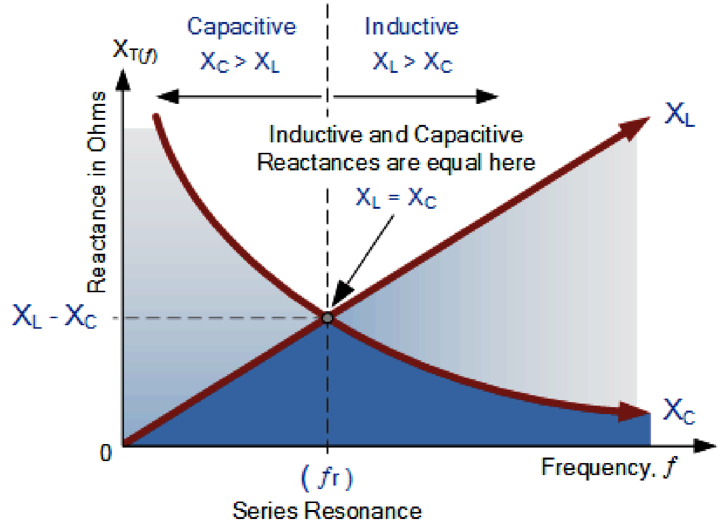
Alternating Current (AC) Circuits II

Resonance

CSE 113



15/04/2024

OUTLINES

- AC Power
- Power Triangle
- AC Power Factor
- Power Factor Correction
- Resonance.
  - Series Resonant Circuit
  - Paralell Resonant Circuit

AC Power

- AC Impedance (***Z***) is a **complex** quantity made up of real **resistance** (***R***) and imaginary **reactance** (***X***):

$$\vec{\mathbf{Z}} = R + jX \qquad (\Omega)$$

- AC Apparent Power (***S***) is a **complex** quantity made up of real **active** (***P***) power and imaginary **reactive** (***Q***) power:

$$\vec{\mathbf{S}} = P + jQ \qquad (VA)$$

AC Power

- **The Active power (P) is the power that is dissipated in the resistance of the load.**
- **It uses the same formula used for DC** (V & I are the ***magnitudes***, not the phasors):

$$P = I^2 R = \frac{V^2}{R} \qquad \text{[watts, W]}$$

WARNING! **#1 mistake with AC power calculations!**

The **Voltage** in the above equation is the Voltage drop across the resistor, not across the entire circuit!

CAUTION!

REAL value of resistance (***R***) is used in REAL power calculations, not IMPEDANCE (***Z***)!

AC Imaginary (Reactive) Power (Q)

- The reactive power (Q) is the power that is exchanged between reactive components (inductors and capacitors).
- The formulas look similar to those used by the active power, but use reactance instead of resistances.

$$Q = I^2 X = \frac{V^2}{X^*} \qquad [\mathrm{VAR}]$$

WARNING! **#1 mistake with AC power calculations!**

The **Voltage** in the above equation is the Voltage drop across the reactance, not across the entire circuit!

- **Units:** Volts-Amps-Reactive (VAR)
- Q is negative for a capacitor by convention and positive for inductor.
- Just like X is negative for a capacitor! (-jXc)

AC Apparent Power (S)

- The Apparent Power (S) is the power that is "appears" to flow to the load.
- The magnitude of apparent power can be calculated using similar formulas to those for active or reactive power:

$$S = VI^* = I^2 Z = \frac{V^2}{Z^*} \qquad [\mathrm{VA}]$$

- Units: Volts-Amps (VA)
- V & I are the magnitudes, not the phasors.

AC Power Relationships

$$\vec{\mathbf{Z}} = R + jX \qquad (\Omega)$$

Notice the relationship between ***Z*** and ***S***:

Apparent power calculated with Z

Real power calculated with R

Reactive power calculated with X

$$\vec{\mathbf{S}} = P + jQ \qquad (VA)$$

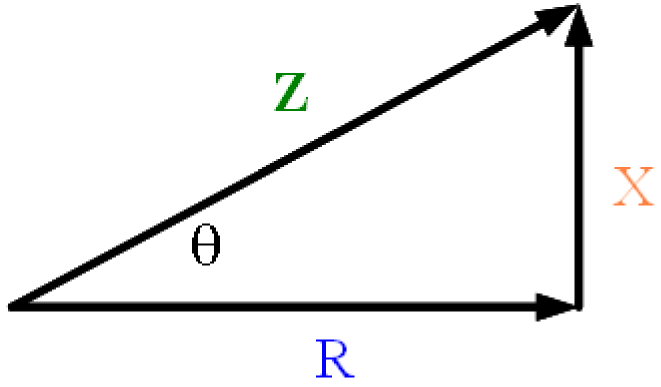
Power Triangle

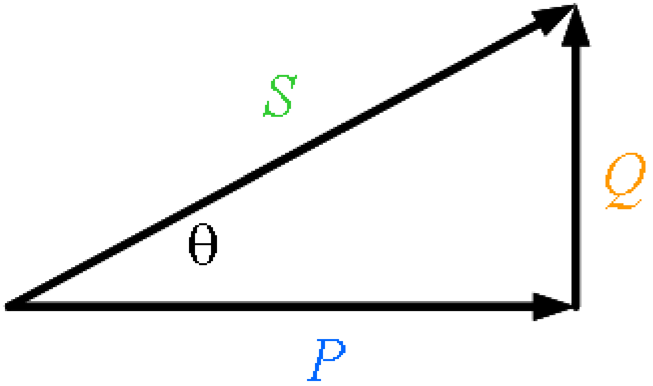
- The **power triangle** graphically shows the relationship between real (***P***), reactive (***Q***) and apparent power (***S***).

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

$$\vec{\mathbf{S}} = P + jQ_L$$

$$\vec{\mathbf{S}} = S\angle\theta$$

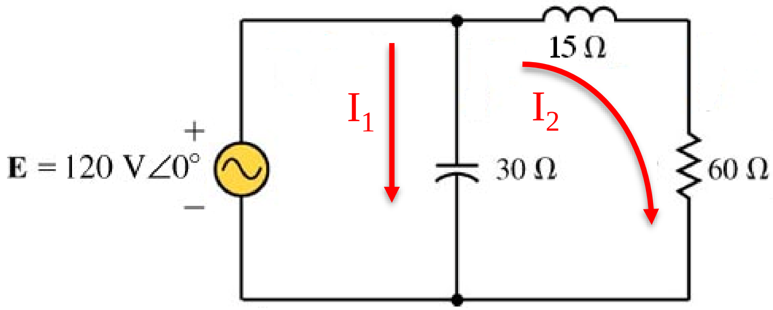




Example Problem 1

Determine the real (*P*) and reactive (*Q*) power of each component.

Determine the apparent (*S*) power delivered by the source.



$$Z_T = Z_{C30} // (Z_{L15} + Z_{R60}) = \left(\frac{1}{30\Omega\angle -90^\circ} + \frac{1}{(15\Omega\angle 90^\circ) + (60\Omega\angle 0^\circ)} \right)^{-1}$$

$$Z_T = 30\Omega\angle -62^\circ$$

$$I_S = \frac{E_S}{Z_T} = \frac{120V\angle 0^\circ}{30\Omega\angle -62^\circ} = 4A\angle 62^\circ$$

$$I_1 = I_S \frac{Z_T}{Z_{C30}} = (4A\angle 62^\circ)\frac{30\Omega\angle -62^\circ}{30\Omega\angle -90^\circ} = 4A\angle 90^\circ$$

$$I_2 = I_S \frac{Z_T}{Z_{L15} + Z_{R60}} = (4A\angle 62^\circ)\left(\frac{30\Omega\angle -62^\circ}{60\Omega + j15\Omega}\right) = 1.94A\angle -14^\circ$$

$$P = I^2 R = \frac{V^2}{R}$$

$$P_{R60} = I_2{}^2 R = (1.94A)^2 * (60\Omega) = \boxed{225.8W}$$

$$Q = I^2 X^* = \frac{V^2}{X^*}$$

$$Q_{L15} = I_2{}^2 X_{L15} = (1.94A)^2 * (15\Omega) = \boxed{56.5VAR}$$

$$Q_{C30} = I_1{}^2 X_{C30} = (4A)^2 * (-30\Omega) = \boxed{-480VAR}$$

$$Q_T = Q_{L15} + Q_{C30} = (56.5 - 480)VAR = \boxed{-423.5VAR}$$

$$S_T = \sqrt{P_T{}^2 + Q_T{}^2} = \sqrt{(225.8)^2 + (-423.5)^2} = \boxed{480VA}$$

θ is from ***Z***

Real Power

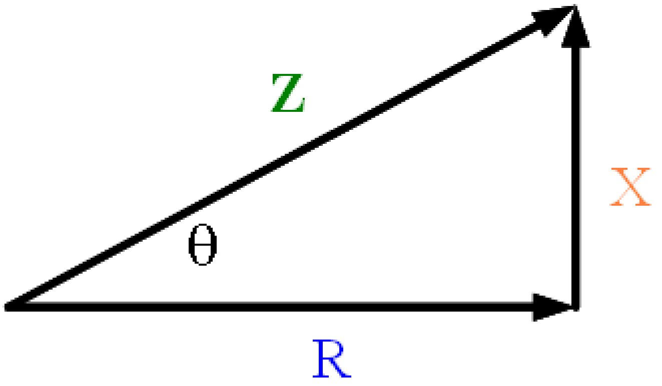
Reactive Power

$$\vec{S} = \left(\vec{V}\right)\left(\vec{I}*\right) = \left(120V\angle 0\right)\left(4A\angle -62\right) = 480VA\angle -62^\circ \Rightarrow 225.35 - j423.81$$

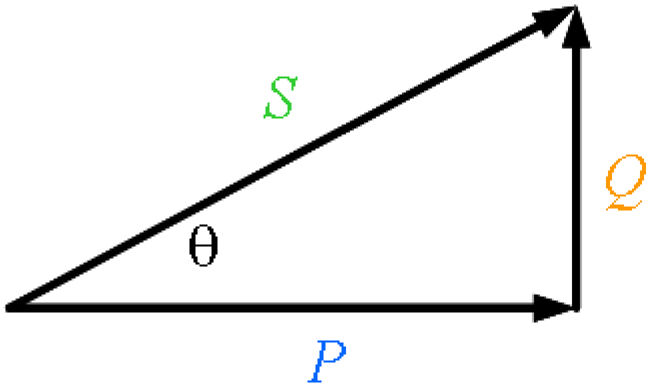
Real and Reactive Power

- The **power triangle** also shows that we can find real (*P*) and reactive (*Q*) power.

$$S = IV \qquad \text{(VA)}$$
$$P = S\cos\theta \qquad \text{(W)}$$
$$Q = S\sin\theta \qquad \text{(VAR)}$$



NOTE: The impedance angle and the "power factor angle" are the same value!



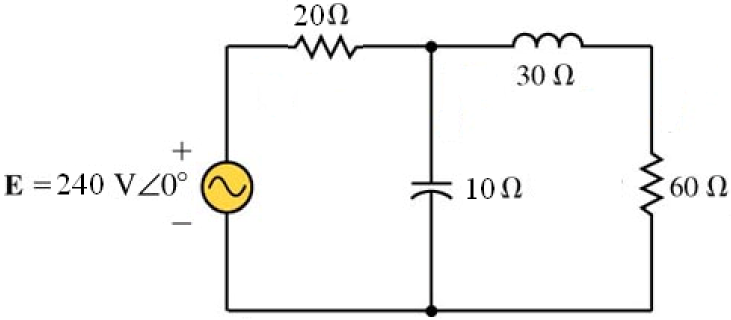
Example Problem 2 [TUTORIAL]

- Determine the apparent (S) power, total real (P) and reactive (Q) power using the following equations:

$$S = VI \qquad \text{(VA)}$$

$$P = S\cos\theta \qquad \text{(W)}$$

$$Q = S\sin\theta \qquad \text{(VAR)}$$



$$Z_T = Z_{R20} + [Z_{C10} // (Z_{L30} + Z_{R60})] = 20\Omega\angle 0^\circ + \left(\frac{1}{10\Omega\angle -90^\circ} + \frac{1}{(30\Omega\angle 90^\circ) + (60\Omega\angle 0^\circ)} \right)^{-1}$$

$$Z_T = 23.9\Omega\angle -26^\circ$$

$$I_S = \frac{E_S}{Z_T} = \frac{240V\angle 0^\circ}{23.9\Omega\angle -26^\circ} = 10A\angle 26^\circ$$

$$S_T = \left|VI^*\right| = \left|(240V\angle 0^\circ)*(10A\angle -26^\circ)\right| = 2.4kVA$$

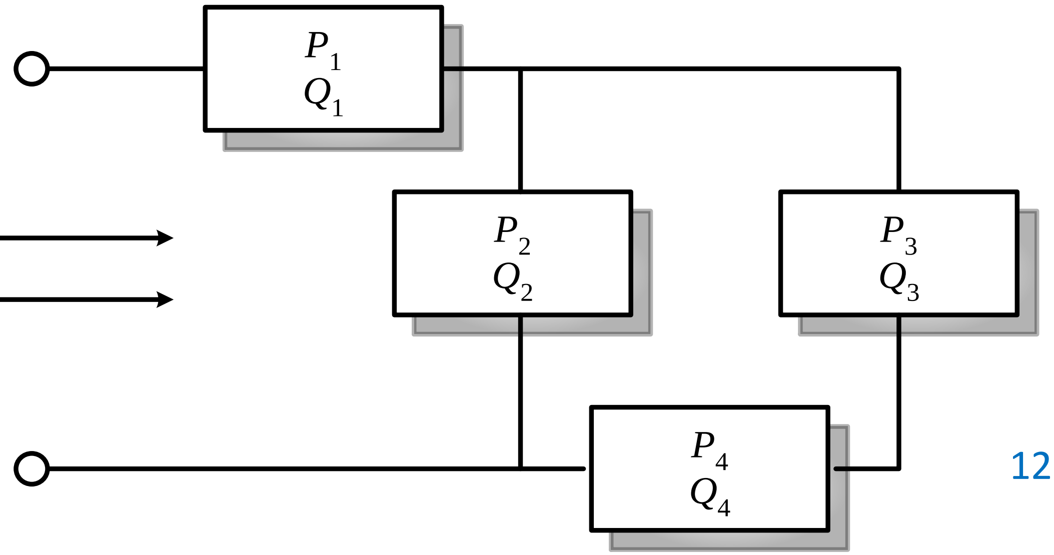
$$P_T = S_T\cos\theta = 2.4kVA*\cos(-26^\circ) = 2157W$$

$$Q_T = S_T\sin\theta = 2.4kVA*\sin(-26^\circ) = -1052VAR$$

Total Power in AC Circuits

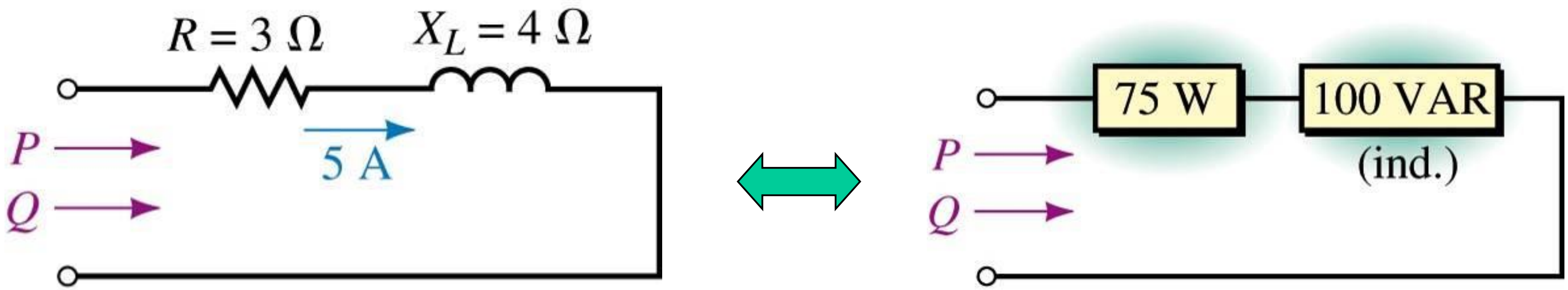
- The total power real (***P_T***) and reactive power (***Q_T***) is simply the sum of the real and reactive power for each individual circuit elements.
- *How elements are connected* ***does not*** *matter for computation of total power.*

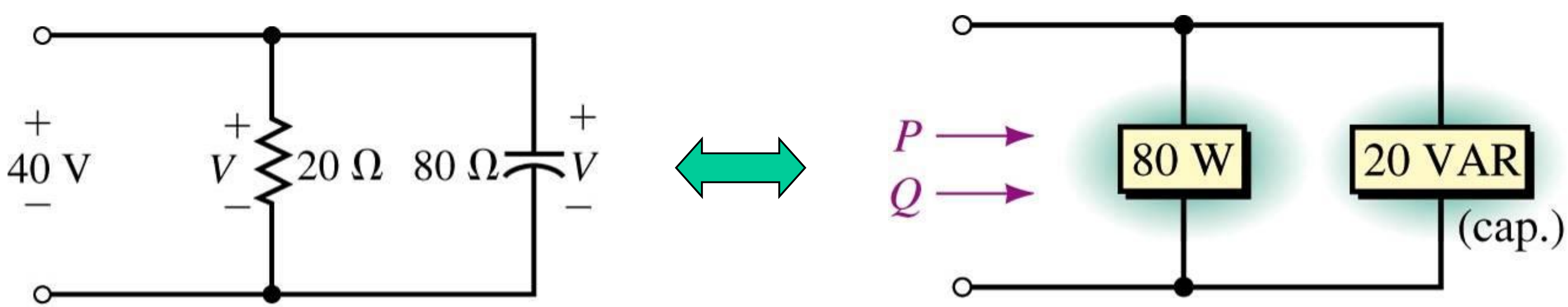
$$P_T = P_1 + P_2 + P_3 + P_4$$
$$Q_T = Q_1 + Q_2 + Q_3 + Q_4$$



Total Power in AC Circuits

- *Sometimes it is useful to redraw the circuit to symbolically express the real and reactive power loads.*





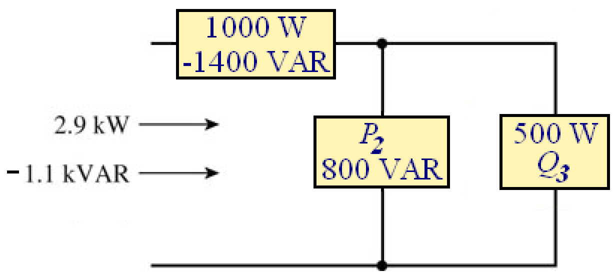
Example Problem 3

a. Determine the unknown real (P_2) and reactive powers (Q_3) in the circuit below.

b. Determine total apparent power.

c. Draw the power triangle.

d. Is the unknown element in Load #3 an inductor or capacitor?



a) $P_T = P_1 + P_2 + \ldots + P_N$

Rearrange to find P_2:

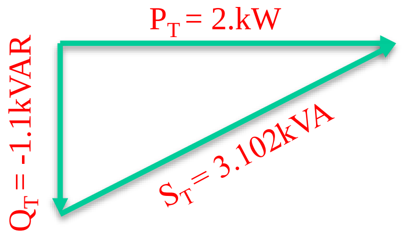
$$P_2 = 2900W - 1000W - 500W = 1400W$$

a) $Q_T = Q_1 + Q_2 + \ldots + Q_N$

Like wise, for Q_3; rearrange to find Q_3:

$$Q_3 = -1100VAR - (-1400VAR) - (800VAR) = -500VAR$$

c) Power Triangle



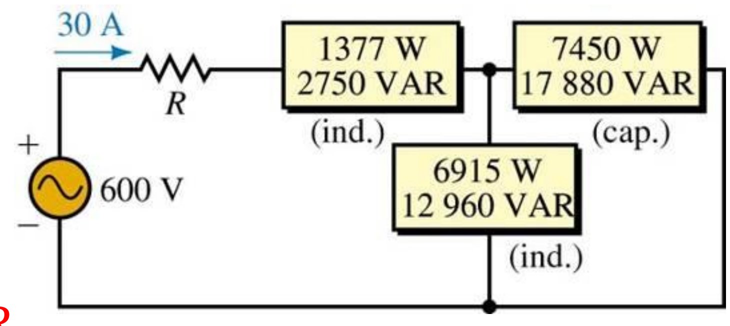
b) $S_T = \sqrt{P_T^{\,2} + Q_T^{\,2}} = \sqrt{(2900)^2 + (-1100)^2} = 3102VA$

d) Because Q3 is negative, it is capacitive

Example Problem 4 [TUTORIAL]

a. Determine the value of R, P_T and Q_T

b. Draw the power triangle and determine S.



$$S_T = V * I = 600V * 30A = 18kVA$$

$$Q_T = 2750VAR - 17880VAR + 12960VAR = -2170VAR$$

$$P_T = \sqrt{S_T^{\ 2} - Q_T^{\ 2}} = \sqrt{18kVA^2 - (-2170VAR)^2} = 17.87kW$$

$$P_T = P_R + P_{L1} + P_{L2} + P_C$$

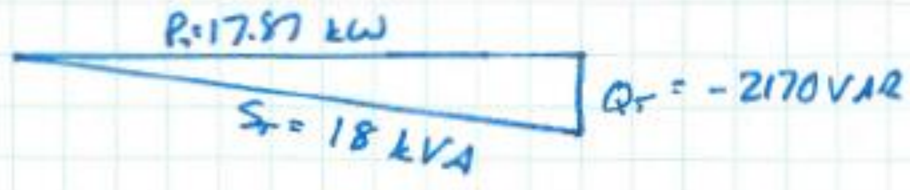
$$=> P_R = P_T - P_{L1} - P_{L2} - P_C$$

$$P_R = 17.87kW - 1377W - 7450W - 6915W = 2127W$$

$$P_R = I_T^{\ 2} * R$$

$$=> R = \frac{P^R}{I^2_{\ T}} = \frac{2127W}{30A^2} = 2.36\Omega$$

$$S_T = \sqrt{P_T^{\ 2} + Q_T^{\ 2}} = \sqrt{17.87kVA^2 + (-2170VAR)^2} = 18kVA$$



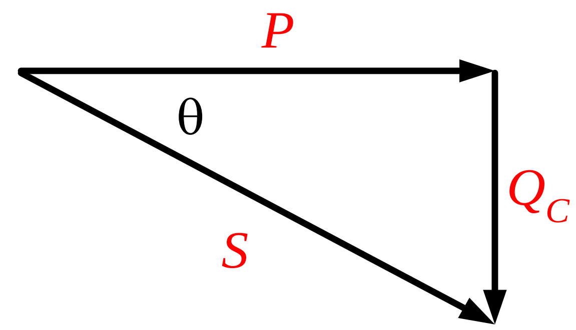
Use of Complex Numbers in Power Calculations

- AC power can be calculated using complex equations.
- Apparent Power can be represented as a complex number.
- The resultant can be used to determine real and reactive power by changing it to rectangular form.

$\mathbf{I}^*$ is complex conjugate of I

$$\vec{\mathbf{S}} = \vec{\mathbf{V}}\vec{\mathbf{I}}^* = P + jQ$$

$$\vec{\mathbf{S}} = \frac{\left|\vec{\mathbf{V}}\right|^2}{\vec{\mathbf{Z}}^*} = \left|\vec{\mathbf{I}}\right|^2 \vec{\mathbf{Z}}$$

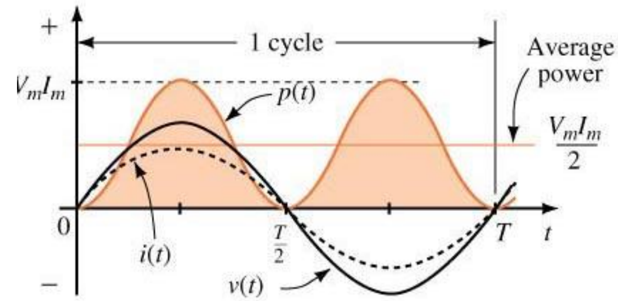


NOTE!

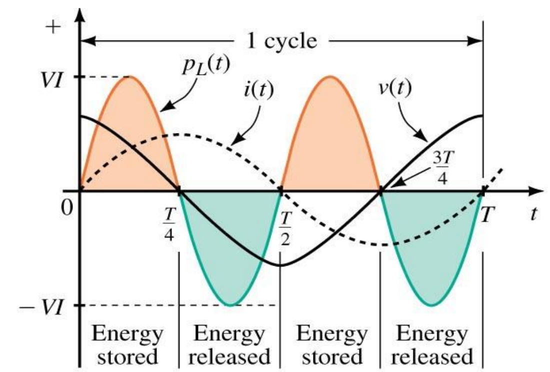
The complex conjugate of Current is used to make the power angle the same as the impedance angle!

Summary

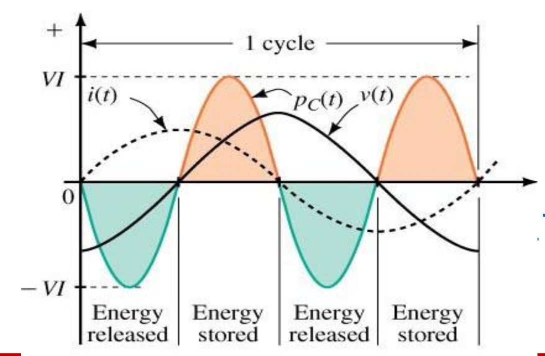
AC Power to a Resistive Load



AC Power to a Inductive Load



AC Power to a Capacitive Load



AC Power Factor

- Power factor (F_P) tells us what portion (or ratio) of the apparent power (S) is actually real power (P).
- Power factor is a ratio given by:

$$F_P = \cos\theta = \boxed{\frac{P}{S}}$$

- Power factor is expressed as a number between 0 to 1.0 (or as a percent from 0% to 100%).
- The closer to 1.0 the power factor gets, the more resistive.
- The closer to 0.0 the power factor gets, the more reactive.

Power Factor

- From the power triangle it can be seen that:

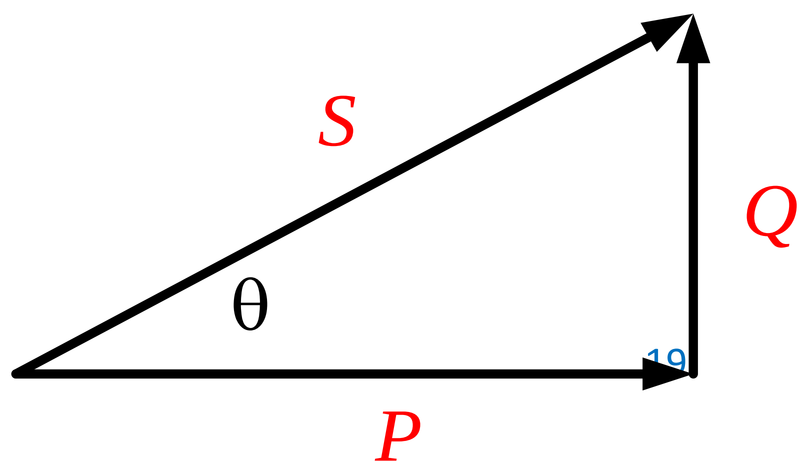
$$F_P = P / S = \cos\,\theta$$

- **Power factor angle** is thus given:

$$\theta = \cos^{-1}(P / S)$$

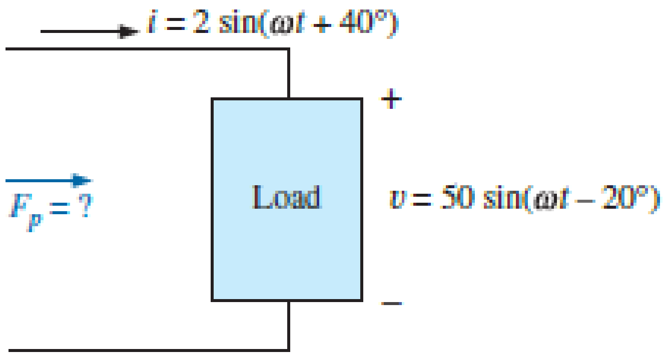
- For a ***pure*** resistance: $\theta = 0^{\circ}$
- For a ***pure*** inductance: $\theta = 90^{\circ}$
- For a ***pure*** capacitance: $\theta = -90^{\circ}$

NOTE: $\boldsymbol{\theta}$ is the phase angle of $\boldsymbol{Z_T}$, not the current or voltage.

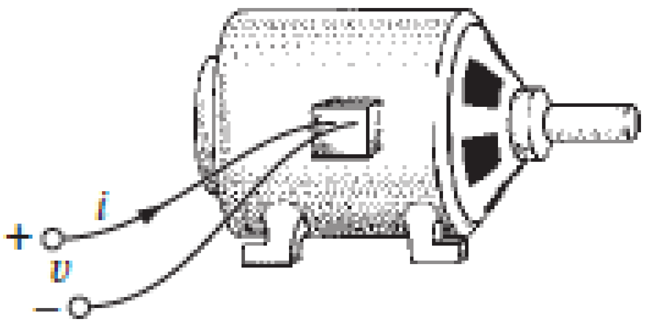


Power Factor Leading or Lagging

- The term leading and lagging are defined in ***reference to the current*** through the load.
  - If the ***current leads*** the voltage across the load then the load has a ***leading power factor***.
  - If the ***current lags*** the voltage across the load then the load has a ***lagging power factor***.



$$F_P = \cos\theta$$
$$F_P = \cos((-20°) - 40°)$$
$$F_P = \cos 60° = 0.5 \quad \text{leading}$$

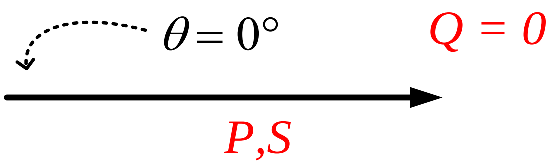


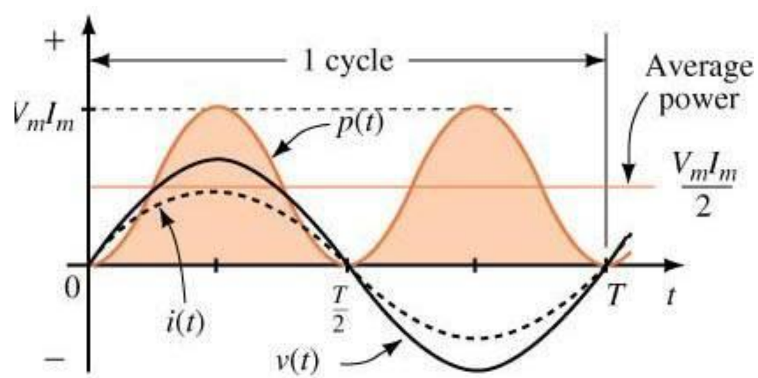
$v = 120\sin(\omega t + 80°)$
$i = 5\sin(\omega t + 30°)$

$$F_p = \cos\theta$$
$$F_p = \cos(80° - 30°)$$
$$F_p = \cos 50° = 0.64 \quad \text{lagging}$$

Unity Power Factor (F_P = 1)

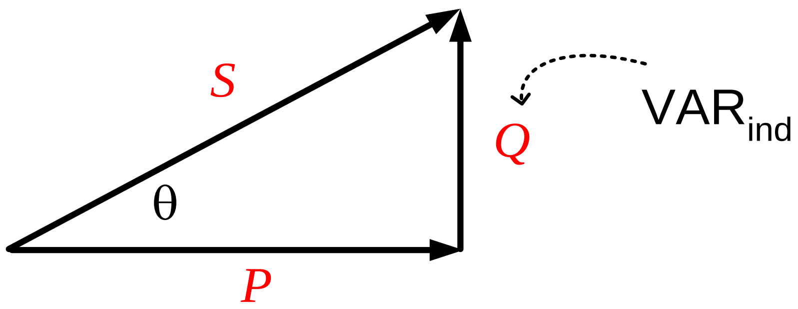
- Unity Power Factor implies that *all* of a load's apparent power is real power ($S = P$).
- If $F_P = 1$, then $\theta = 0°$.
- It could also be said that the load looks purely *resistive*.
- Load current and voltage are *in phase*.

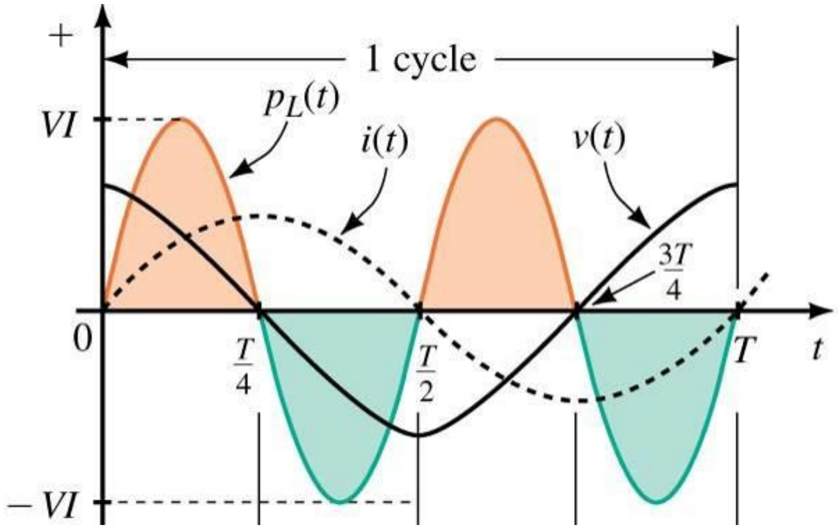




Lagging Power Factor ($\theta > 0^o$)

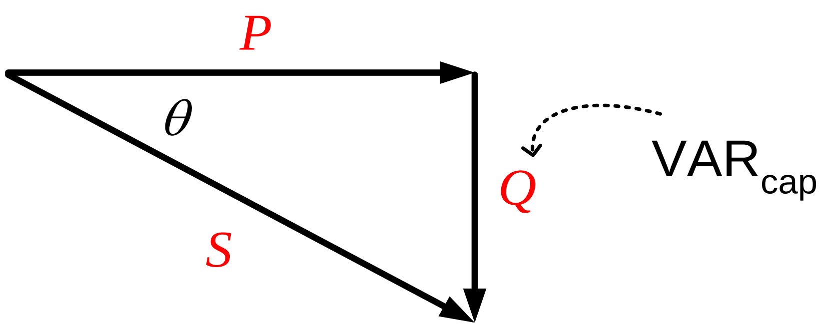
- The load current lags load voltage: **ELI**
- Implies that the load looks *inductive*.

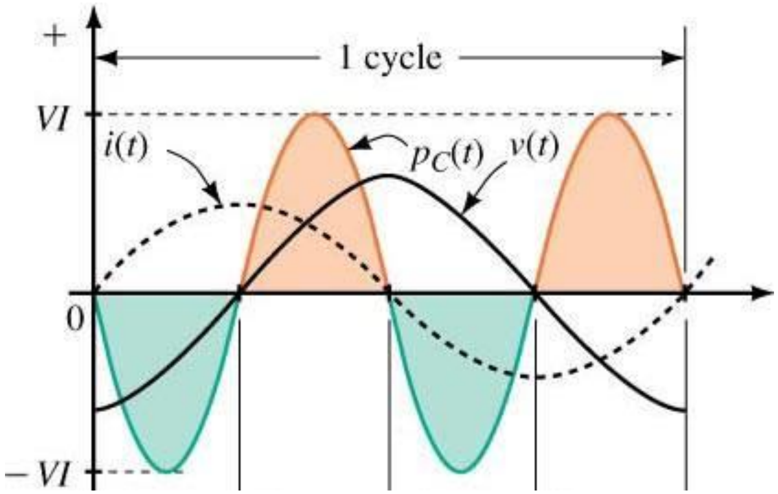




Leading Power Factor ($\theta < 0^o$)

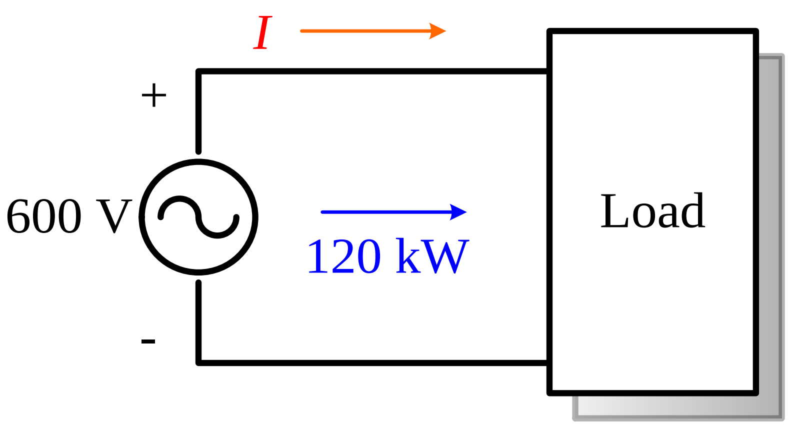
- The load current leads load voltage: ***ICE***
- Implies that the load looks ***capacitive***.





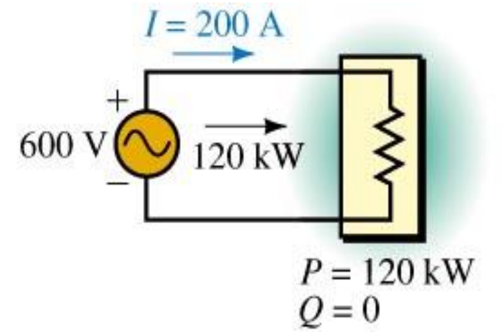
Why is Power Factor Important?

- Consider the following example: A generator is rated at 600 V and supplies one of two possible loads.
  - Load1: P=120kW, F_P=1
  - Load 2: P = 120 kW, F_p= 0.6
- Determining how much current (I) is required is one such reason...

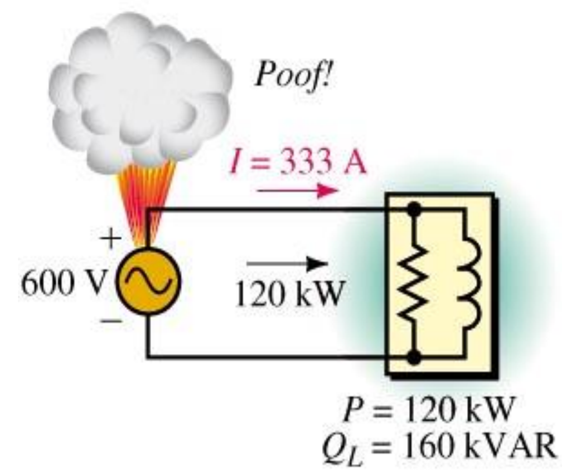


Why is Power Factor Important?

- For the load with *Fp* = 1, the generator had to supply 200 A
- For the load with *Fp* = 0.6, the generator had to supply 133 more amperes in order to do the same work (*P*)!
- Larger current means larger equipment (wires, transformers, generators) which cost more.
- Larger current also means larger transmission losses (think I^2R).



(a) $S = 120$ kVA



(b) $S = \sqrt{(120)^2 + (160)^2} = 200$ kVA
The generator is overloaded

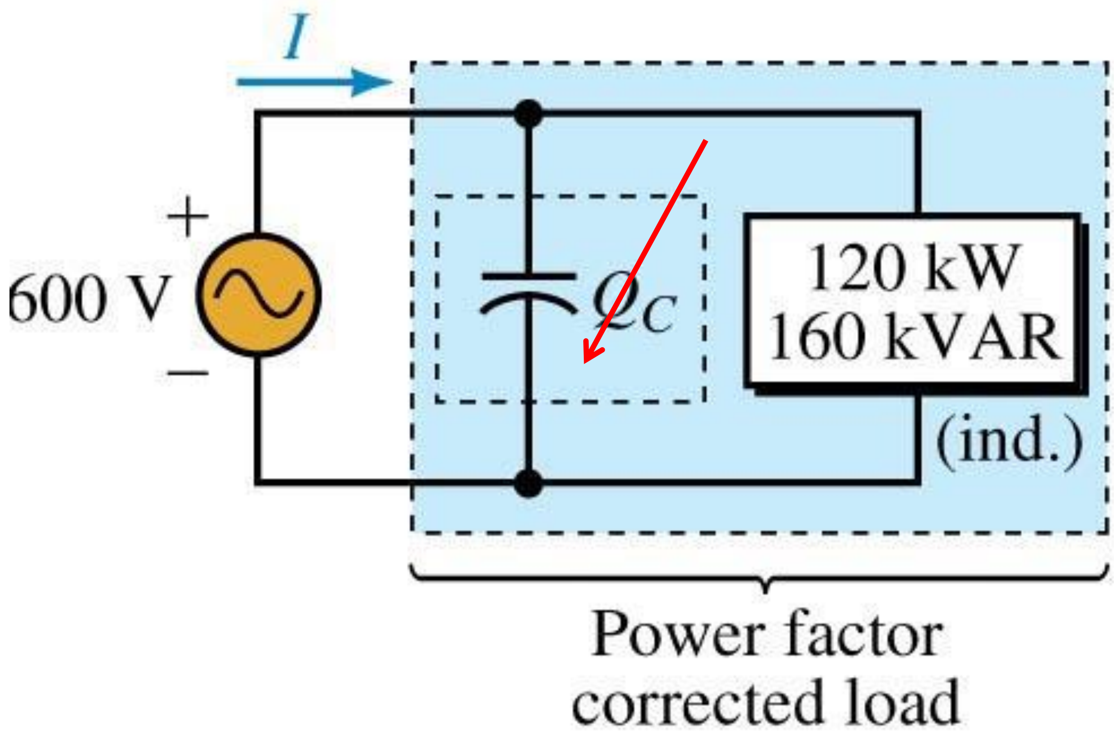
Why is Power Factor Important?

- Because of the wide variation in possible current requirements due to power factor, most large electrical equipment is rated using **apparent power** (***S***) in volt-amperes (*VA*) instead of **real power** (***P***) in watts (*W*).
- Is it possible to change the power factor of the load?

The answer is yes…through power factor correction…

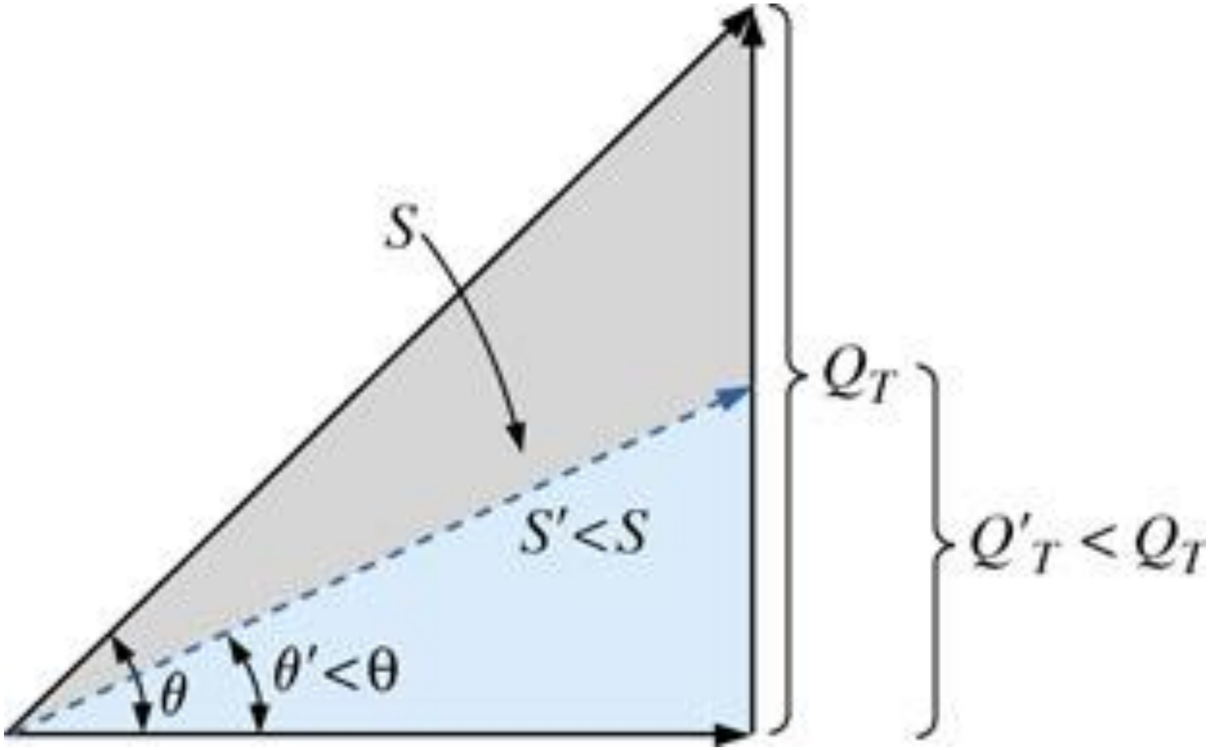
Power-Factor Correction

- In practice, almost all loads (commercial, industrial and residential) look ***inductive*** (due to motors, fluorescent lamp ballasts, etc.).
- Hence, almost all power factor correction consists of adding ***capacitance***.



Power-Factor Correction

- How it changes the power triangle:



Demonstrating the impact of power-factor correction on the power triangle of a network.

Power-Factor Correction Solution Steps

1. Calculate the reactive power (Q) of the load.
2. Insert a component in parallel of the load that will cancel out that reactive power.

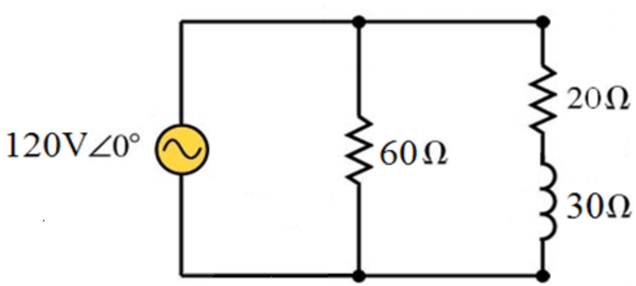
   e.g. If the load has Q_{LD} = 512 VAR, insert a capacitor with Q_C = -512 VAR.

3. Calculate the reactance (X) that will give this value of Q Normally the $Q=V^2/X$ formula will work.
4. Calculate the component value (F or H) required to provide that reactance.

Example Problem 5

a. Determine the value of the capacitance (in F) required to bring the power factor up to unity (freq of 60 Hz).

b. Determine load current before and after correction.



a)

$$Z_T = \frac{1}{\frac{1}{60\Omega} * \frac{1}{20\Omega + j30\Omega}} = 25.3\Omega\angle 35.8°$$

$$I_T = \frac{E_S}{Z_T} = \frac{120V\angle 0°}{25.3\Omega\angle 35.8°} = 4.74A\angle -35.8°$$

Sign Change

$$S_T = E_s * (I^*_T) = (120\angle 0°) * (4.74A\angle 35.8°)$$

$$S_T = 568.7VA\angle 35.8 = \underbrace{462W}_{P_T} + \underbrace{j332VAR}_{Q_T}$$

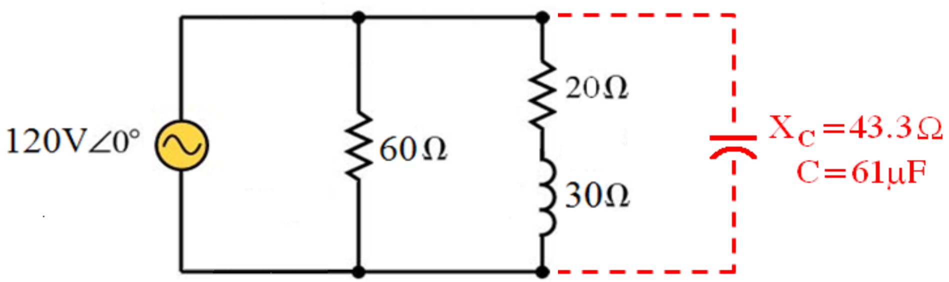
$$F_P = \frac{P}{S} = \frac{462W}{568.7VA} = 0.81 \quad \text{or} \quad 81\%$$

b) Because the Q_T = 332 VAR, we can insert a capacitor with Q_C = -332 VAR

Example Problem 5 cont…

a. Determine the value of the capacitance (in F) required to bring the power factor up to unity (freq of 60 Hz).

b. Determine load current before and after correction.



Notice that $X_C \neq X_L$!
Notice that $X_C \neq X_{LD}$!

b) Because the Q_T = 332 VAR, we can insert a capacitor with Q_C = -332 VAR

$$Q_{TUnity} = -332VAR => \frac{V^2}{X_C}$$

$$X_C = \frac{V^2}{|Q_{TUnity}|} = \frac{(120V)^2}{332} = 43.3\Omega$$

$$X_{CUnity} = \frac{1}{2\pi f C_{Unity}} =>$$

$$C_{Unity} = \frac{1}{2\pi f X_{CUnity}} = \frac{1}{2\pi(60Hz)(43.3\Omega)} = \boxed{61.1\mu F}$$

c) Adding a unity cap changes Z_T:

$$Z_{TUnity} = \frac{1}{\frac{1}{60\Omega} * \frac{1}{20\Omega + j30\Omega} + \frac{1}{-j43.4\Omega}} = 31.2\Omega\angle 0°$$

NEW Current:

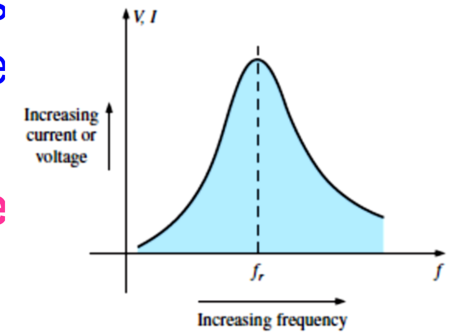
$$I_T = \frac{E_S}{Z_T} = \frac{120V\angle 0°}{31.2\Omega\angle 0°} = \boxed{3.85A\angle 0°}$$

OLD Current:

$$I_T = \frac{E_S}{Z_T} = \frac{120V\angle 0°}{25.3\Omega\angle 35.8°} = 4.74A\angle -35.8°$$

Resonance

- ***Resonant*** (or ***tuned***) ***circuits***, are fundamental to the operation of a wide variety of electrical and electronic systems in use today.
- The resonant circuit is a combination of ***R***, ***L***, and ***C*** elements having a frequency response characteristic similar to the one below:



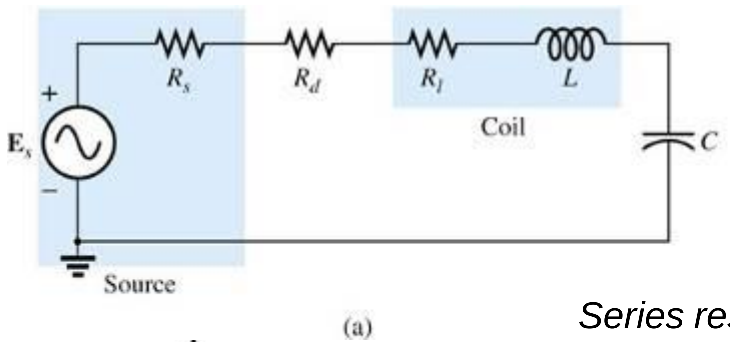
- **The resonant electrical circuit must have both inductance and capacitance.**
- **In addition, resistance will always be present due either to the lack of ideal elements or to the control offered on the shape of the resonance curve.**
- **When resonance occurs due to the application of the proper frequency (fr), the energy absorbed by one reactive element is the same as that released by another reactive element within the system.**
- **Remember:**

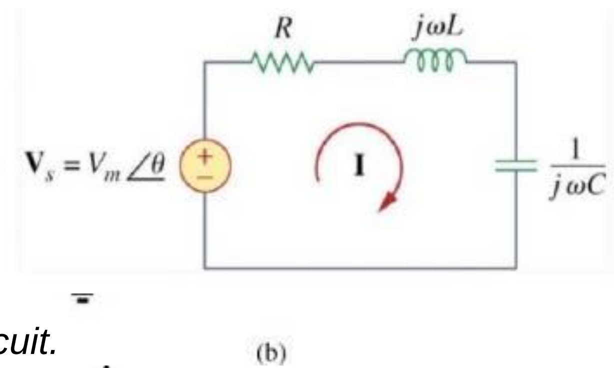
$$X_C = \frac{1}{wC} = \frac{1}{2\pi fC} => Z_C = -jX_C$$

$$X_L = wL = 2\pi fL => Z_L = jX_L$$

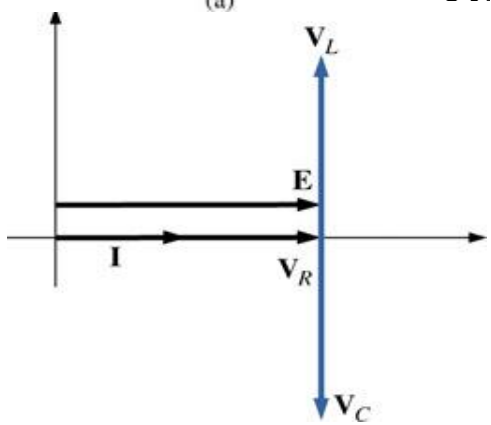
Series Resonant Circuit

- The basic format of the series resonant circuit is a series R-L-C combination in series with an applied voltage source.

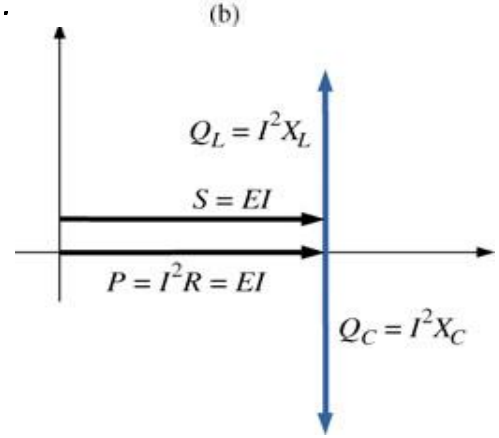




Series resonant circuit.



Phasor diagram for the series resonant circuit at resonance.



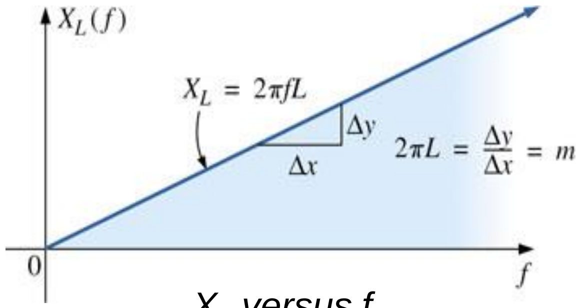
Power triangle for the series resonant circuit at resonance.

Z_T Versus Frequency

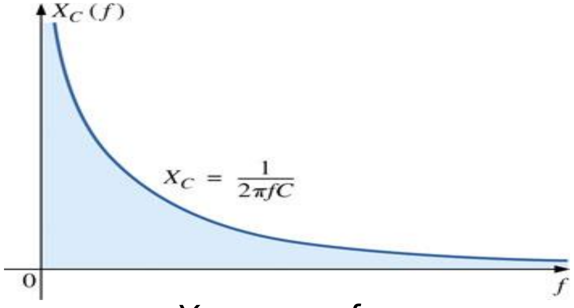
- Knowing that X_C and X_L are dependent upon frequency it can be stated:
  - Capacitor Impedance decreases as frequency increases.
  - Inductor Impedance increases as frequency increases.
- This implies that the total impedance of the series *R*-*L*-*C* circuit below, at any frequency, is determined by:

$$Z_T = \sqrt{R^2 + (X_L - X_C)^2}$$

$$\boxed{Z_T = R + jX_L - jX_C}$$



X_L versus f



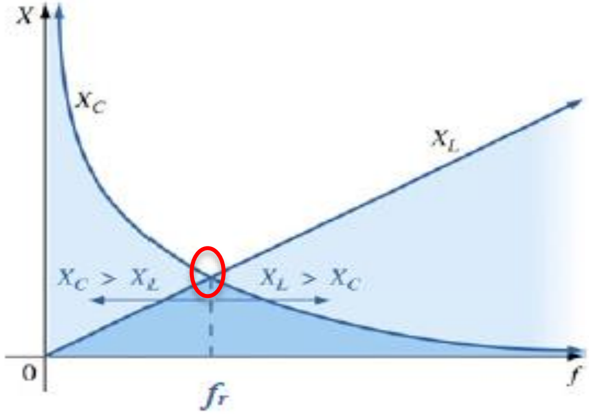
X_C versus f

Z_T Versus Frequency cont.

- The total-impedance-versus-frequency curve for the series resonant circuit below can be found by applying the impedance-versus-frequency curve for each element of the equation previously shown, written in the following form:

$$Z_T(f) = \sqrt{[R(f)]^2 + [X_L(f) - X_C(f)]^2}$$

- When X_L=X_C the resonant frequency (f_r) can be found.



Frequency response of X_L and X_C of a series R-L-C circuit on the same set of axes

The Resonant Frequency (f_r)

- **To find f_r, set the impedances equal and solve:**

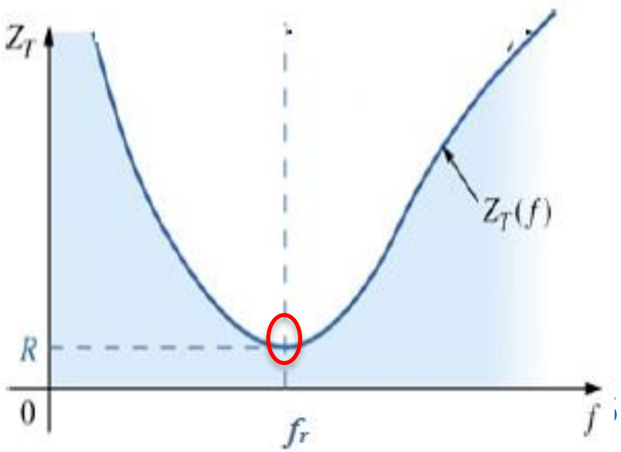
$$X_C = X_L$$

$$\frac{1}{\omega C} = \omega L => \omega C = \frac{1}{\omega L} => \omega^2 = \frac{1}{LC}$$

$$\omega = \frac{1}{\sqrt{LC}}, \text{since } \omega = 2\pi f$$

$$\boxed{f_r = \frac{1}{2\pi\sqrt{LC}}}$$

- **This is the key equation for resonance. Total impedance at this point is shown to the right:**



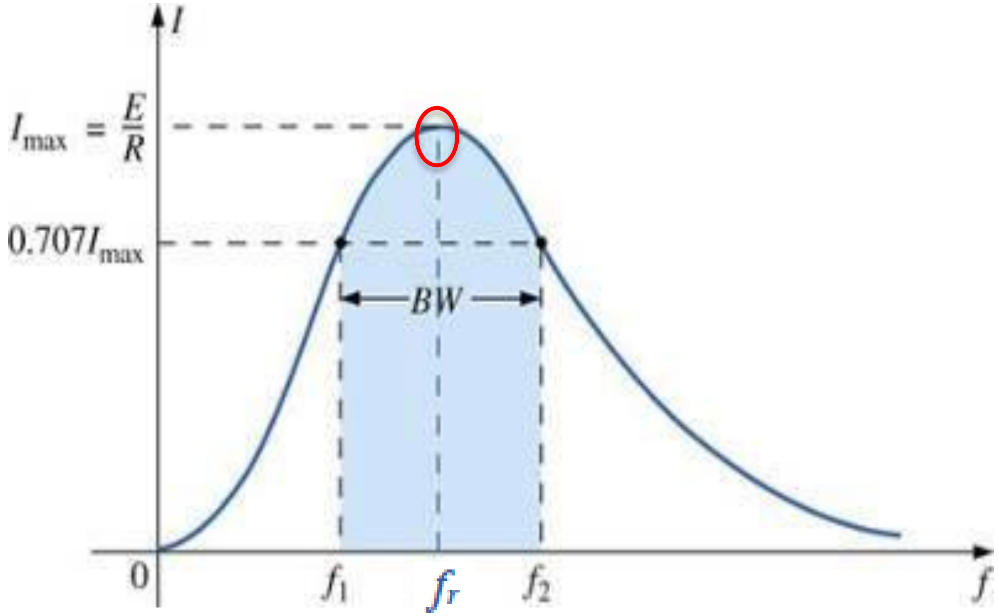
Z_T versus f

Current Versus Frequency

- If impedance is minimum at f_r, current will be at a maximum:

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

- If we now plot the magnitude of the current versus frequency for a *fixed* applied voltage E, we obtain the curve showing that current is maximum at f_r:

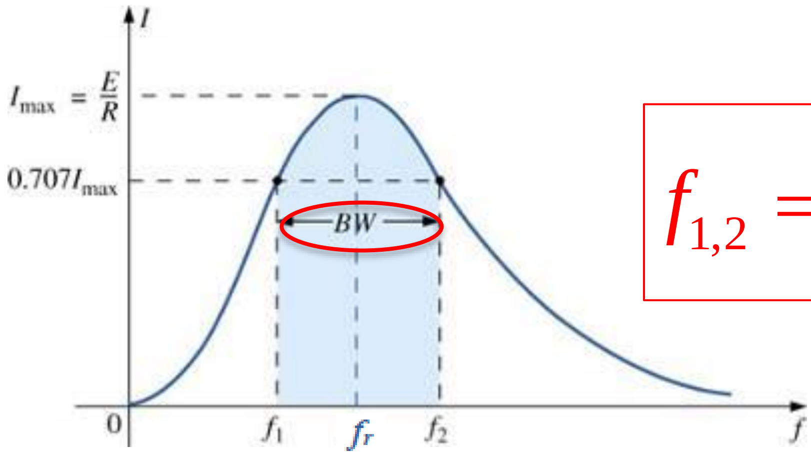


I versus f for the series resonant circuit

Bandwidth (BW)

- Band frequencies are those that define the points on the resonance curve that are 0.707 ($\frac{1}{\sqrt{2}} = 0.707$) of the peak current or voltage.
- Bandwidth (BW) is the range of frequencies between the band, or ½ power frequencies. Defined by:

$$BW = f_2 - f_1$$

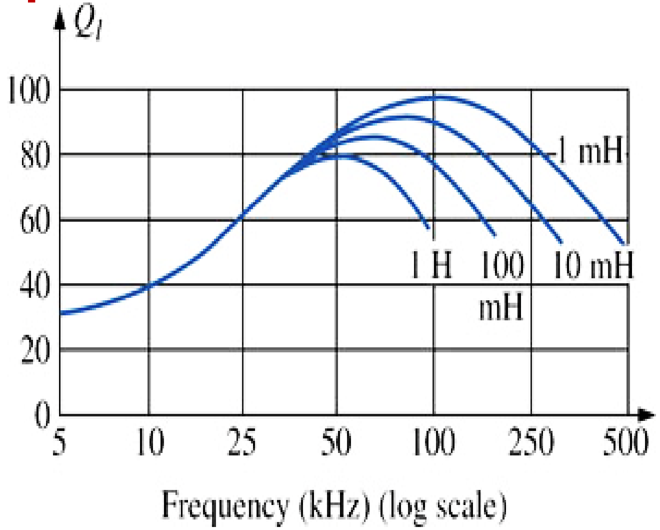


$$\boxed{f_{1,2} = f_r \pm \frac{BW}{2}}$$

The Quality Factor (Q)

- The *quality factor (Q)* of a series resonant circuit is defined as the ratio of the reactive power of either the inductor or the capacitor to the average power of the resistor at resonance.
- Q can be found several ways:

$$Q = \frac{f_r}{BW} = \frac{X_L}{R} = \frac{\omega_r L}{R} = \frac{2\pi f_r L}{R}$$



Q_l versus frequency for a series of inductors

- This also gives an alternate way to find BW:

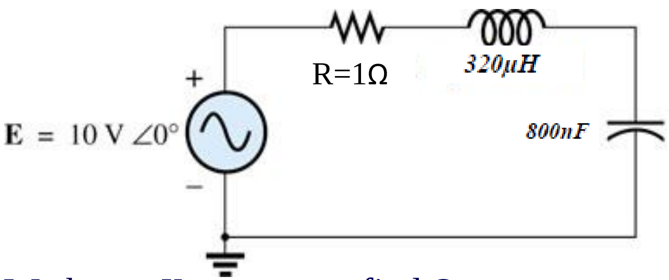
$$BW = \frac{f_r}{Q}$$

OUTLINES

- AC Power and Power Triangle
- AC Power Factor and Power Factor Correction
- Resonance.
  - Series Resonant Circuit
  - Paralell Resonant Circuit

Example Problem 6

Determine ***f*$_r$, *Q*, *BW*** and the current (***I***) at resonance. Plot the current vs. frequency and label ***f*$_r$, *f*$_1$, *f*$_2$** and ***BW***.



$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(320\mu H)(800nF)}} = \boxed{10kHz}$$

$$X_L = \omega_r L = 2\pi f_r L = 2\pi(10kHz)(320\mu H) = 20\Omega$$

Because we are at f_r we know that $X_L = X_C$, but just to show it:

$$X_C = \frac{1}{\omega_r C} = \frac{1}{2\pi f_r C} = \frac{1}{2\pi(10kHz)(800nH)} = 20\Omega$$

We know X_L so we can find Q:

$$Q = \frac{X_L}{R} = \frac{20\Omega}{1\Omega} = \boxed{20}$$

We know Q so we can find BW:

$$BW = \frac{f_r}{Q} = \frac{10kHZ}{20} = \boxed{500Hz}$$

Now find I_{max}:

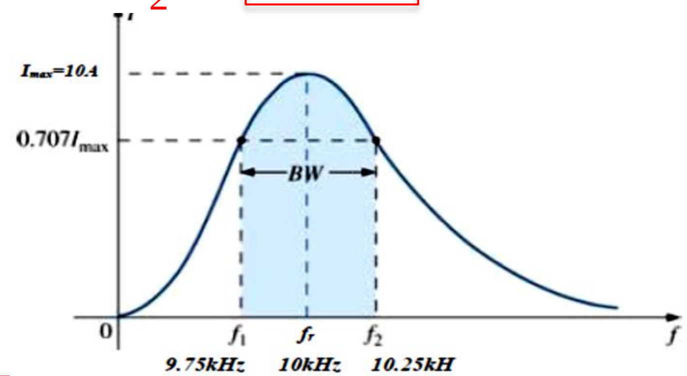
$$I = \frac{E}{Z_T} = \frac{10V}{1\Omega} = \boxed{10A}$$

Remember, since $X_L = X_C$ at resonance, they cancel out for Z_T and only R is left.

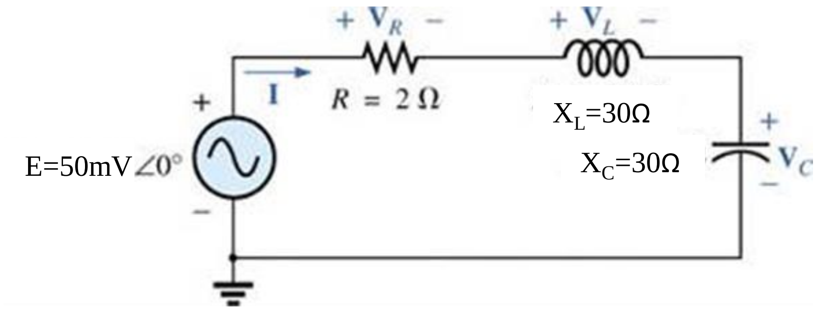
Now let's find f_1 and f_2 and then plot:

$$f_{1,2} = f_r \pm \frac{BW}{2} \Rightarrow f_2 = 10kHz + \frac{500Hz}{2} = \boxed{10.25kHz}$$

$$\Rightarrow f_1 = 10kHz - \frac{500Hz}{2} = \boxed{9.75kHz}$$



Example Problem 7 [TUTORIAL]



a) Find ***I*****,** ***V*****$_R$,** ***V*****$_C$,** ***V*****$_L$** at resonance.

b) Determine **Q** for the circuit.

c) If the ***f*****$_r$** is 5 kHz, what is the ***BW***?

d) With ***f*****$_r$** = 5kHz what are the values of **L** and **C**?

e) What is the power dissipated in the circuit at the ***half-power*** frequency?

a) $Z_T = R + jX_L - jX_C = 2\Omega + j30\Omega - j30\Omega = 2\Omega$

$$I = \frac{E}{Z_T} = \frac{50mV\angle 0^\circ}{2\Omega\angle 0^\circ} = \boxed{25mA\angle 0^\circ}$$

$$V_R = I * R = (25mA\angle 0^\circ)*(2\Omega\angle 0^\circ) = \boxed{50mV\angle 0^\circ}$$

$$V_L = I * X_L = (25mA\angle 0^\circ)*(30\Omega\angle 90^\circ) = \boxed{750mV\angle 90^\circ}$$

$$V_C = I * X_C = (25mA\angle 0^\circ)*(30\Omega\angle -90^\circ) = \boxed{750mV\angle -90^\circ}$$

This shows that at resonance $V_C = V_L$

b) $Q = \dfrac{X_L}{R} = \dfrac{30\Omega}{2\Omega} = \boxed{15}$

c) $BW = \dfrac{f_r}{Q} = \dfrac{5kHZ}{15} = \boxed{333.3Hz}$

d) $X_L = 2\pi f_r L =>$

$$L = \frac{X_L}{2\pi f_r} = \frac{30\Omega}{2\pi(5kHz)} = \boxed{955\mu H}$$

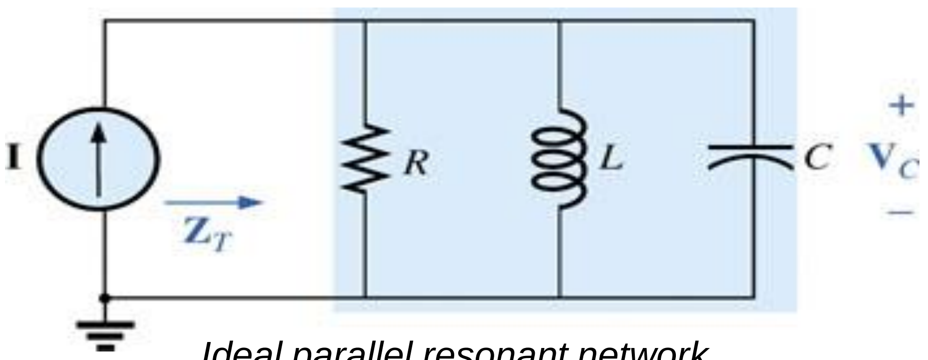
$$X_C = \frac{1}{2\pi f_r C} =>$$

$$C = \frac{1}{2\pi f_r X_C} = \frac{1}{2\pi(5kHz)(30\Omega)} = \boxed{1.06\mu F}$$

e) $P = I_{0.707}{}^2 * R = (25mA * 0.707)*(2\Omega) = \boxed{35.4mW}$

Parallel Resonant Circuit

- The basic format of the parallel resonant circuit is a parallel R-L-C combination with an applied current source.
- The parallel resonant circuit has the basic configuration shown below:



Ideal parallel resonant network

Parallel Resonant Circuit

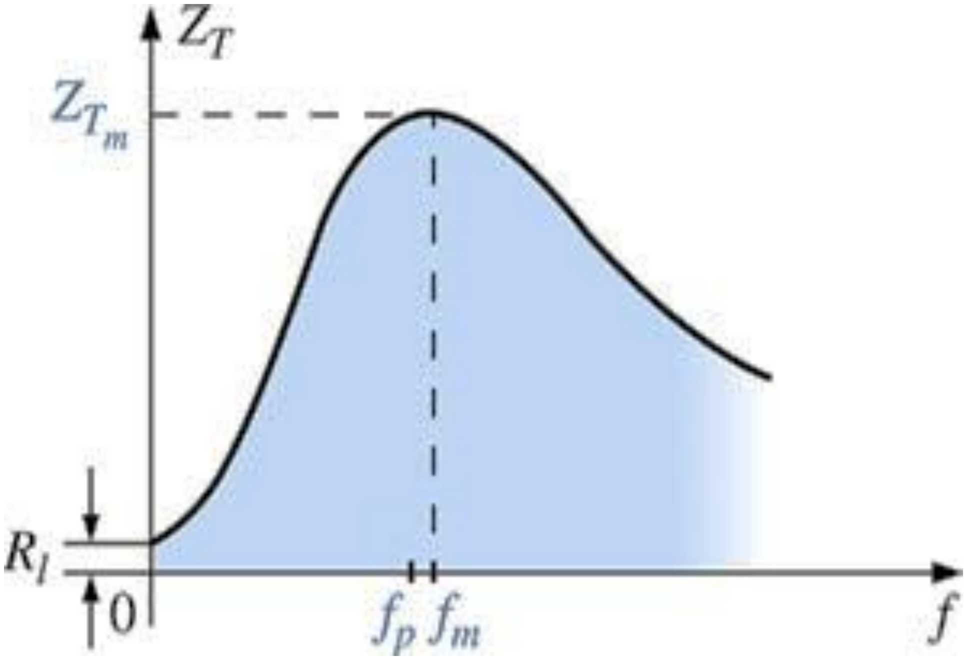
- **Unity Power Factor, f_p:**

$$f_p = f_r\sqrt{1-\frac{R_l^2 C}{L}}$$

- **Maximum Impedance, f_m:**

$$f_m = f_r\sqrt{1-\frac{1}{4}\left(\frac{R_l^2 C}{L}\right)}$$

$$f_r > f_p > f_m$$



Z_T versus frequency for the parallel resonant circuit