

**Bangladesh University of Engineering and Technology**  
**Electric Circuits II Laboratory (EEE 106)**  
**Simulation Experiment No. 03**  
**Series and Parallel Resonance & Power Factor Correction**

## **Pre Lab**

- 1) Read the lab sheet.
- 2) Bring the text book with you.
- 3) Read the series resonance article from your text book. You should know about the results for the three cases, i.e. when frequency, inductance or capacitance is varied.
- 4) Read the text on parallel resonance from the book. We will be dealing with the parallel RC and RL branch during the lab as in the book.

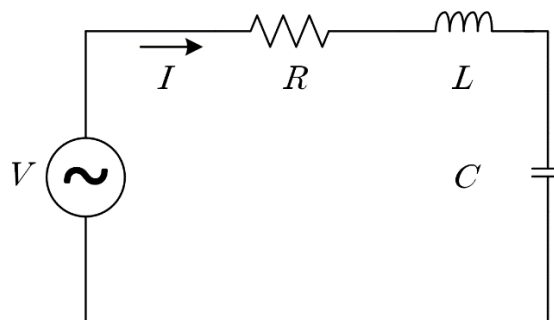
## **Theory**

### ***Resonance:***

A circuit is in resonance when the source power factor is 1. That is the voltage and current are in phase.

### ***Series Resonance:***

A series circuit containing R, L and C is in resonance when the resultant reactance is zero. In such situations the current and voltage becomes in phase.



**Figure 1: Series Resonance.**

Mathematically,  $X_L = X_C$

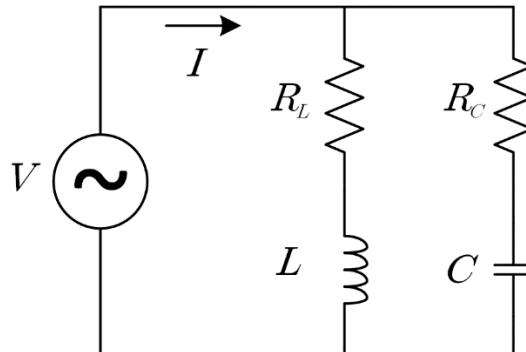
So solving the equation for  $f$  we get,

$$f = \frac{1}{2 \times \pi \times \sqrt{LC}} \dots (1)$$

So resonance in a series RLC circuit can be obtained by varying inductance, capacitance or operating frequency.

**Parallel Resonance:**

In parallel RL and RC branch, in order for the voltage and current to be in the same phase the sum of the admittance of the two branches (RL and RC) should yield only conductance. That is the sum of susceptance of the two branches should be zero.



**Figure 2: Parallel Resonance**

This condition provides a characteristic equation for the circuit:

$$\frac{2\pi fL}{R_L^2 + (2\pi fL)^2} = \frac{\frac{1}{2\pi fC}}{R_C^2 + \left(\frac{1}{2\pi fC}\right)^2} \dots (2)$$

Writing them in terms of impedance:

$$\frac{X_L}{R_L^2 + X_L^2} = \frac{X_C}{R_C^2 + X_C^2} = G$$

Then solving for  $X_L$ ,

$$X_L = \frac{1 \pm \sqrt{1 - 4G^2 R_L^2}}{2G}$$

So, valid solutions (positive and real numbers) from this equation can be obtained when,

$$4G^2 R_L^2 \leq 1$$

So, for a given  $f, R_L, R_C$ , and  $C$  we can calculate  $L$  from the characteristic equation, when the inequality provided above is satisfied. (Can resonance be obtained when the inequality is not satisfied?)

Now, similar conditions can be obtained for any of the parameters given other four parameters have been fixed. These are not stated here, but students should explore on their own.

### Power Factor Correction:

Power factor correction is the addition of a reactive element (usually a capacitor, as most domestic and industrial loads are inductive) in parallel with the load in order to make the power factor closer to unity. Its concept is similar to parallel resonance described above.

Since most loads are inductive, a load's power factor is improved or corrected by deliberately installing a capacitor in parallel with the load. The effect of adding the capacitor can be illustrated using either the power triangle or the phasor diagram of the currents involved.

The circuit in Fig. 3(a) has a power factor of  $\cos \theta_1$ , while the one in Fig. 3(b) has a power factor of  $\cos \theta_2$ . It is evident from Fig. 3(c) that adding the capacitor has caused the phase angle between the supplied voltage and current to reduce from  $\theta_1$  to  $\theta_2$ , thereby increasing the power factor. From the magnitudes of the vectors in Fig. 3(c) it is also evident that with the same supplied voltage, the circuit in Fig. 3(a) draws larger current  $I_L$  than the current  $I$  drawn by the circuit in Fig. 3(b). Power companies charge more for larger currents, because they result in increased power losses (by a squared factor, since  $P = I_L^2 R$ ). Therefore, it is beneficial to both the power company and the consumer that every effort is made to minimize current level or keep the power factor as close to unity as possible. By choosing a suitable size for the capacitor, the current can be made to be completely in phase with the voltage, implying unity power factor.

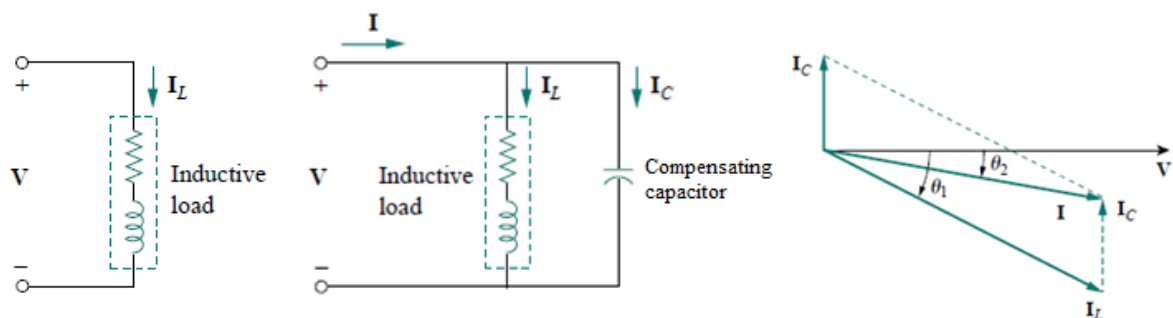


Figure 3: Power factor correction (a) original inductive load (b) inductive load with a compensating capacitor in parallel (c) Phasor Diagram showing the effect of inserting shunt capacitor

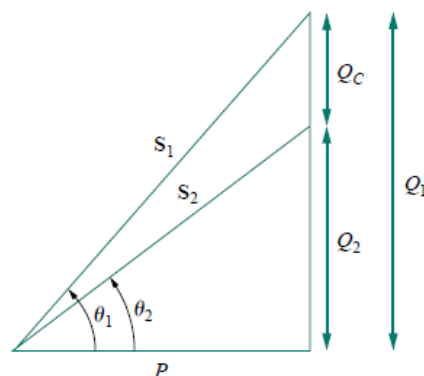


Figure 4: Power triangle illustrating power factor correction

If the original inductive load has apparent power  $S_1$ , then

$$P = S_1 \cos \theta_1$$

$$Q_1 = S_1 \sin \theta_1 = P \tan \theta_1$$

If we desire to increase the power factor from  $\cos \theta_1$  to  $\cos \theta_2$  without altering the real power, then the new reactive power is

$$Q_2 = P \tan \theta_2$$

The reduction in the reactive power caused by the compensating element is given by,

$$Q_{comp} = (Q_1 - Q_2) = P (\tan \theta_1 - \tan \theta_2)$$

If the original load is inductive, the compensator is to be a capacitor and its value can be determined as follows.

$$Q_C = \frac{V^2}{X_C} = \omega V^2 C$$

$$C = \frac{Q_C}{\omega V^2} = \frac{P (\tan \theta_1 - \tan \theta_2)}{\omega V^2}$$

However, if the original load is capacitive, the compensator is to be an inductor and its value can be determined as follows.

$$Q_L = \frac{V^2}{X_L} = \frac{V^2}{\omega L}$$

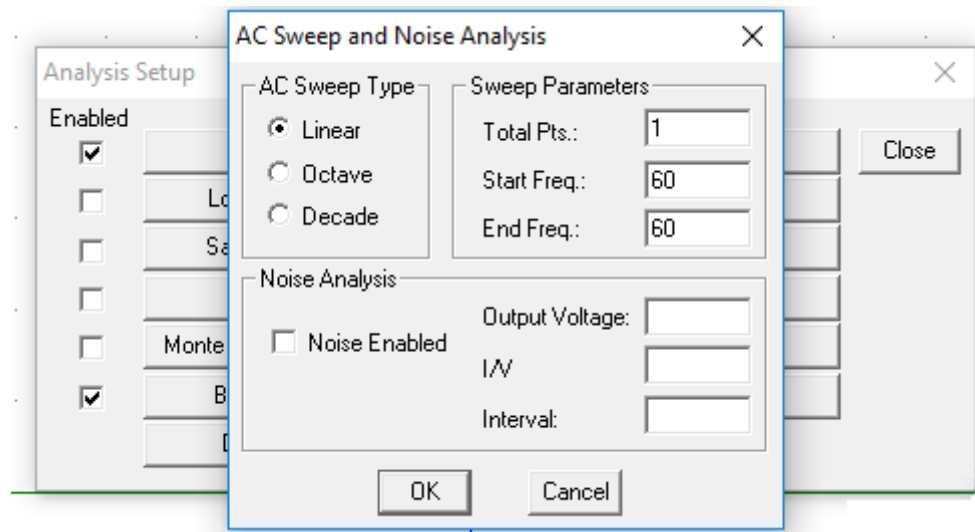
$$L = \frac{V^2}{\omega Q_L} = \frac{V^2}{\omega P (\tan \theta_1 - \tan \theta_2)}$$

The ability to adjust the power factor of one or more loads in a power system can significantly affect the operating efficiency of the power system. The lower the power factor of a system, the greater the losses in the power lines feeding it. Most loads on a typical power system are induction motors, so power systems are almost invariably lagging in power factor. Having one or more leading loads (overexcited synchronous motors) on the system can be useful for the following reasons:

- A leading load can supply some reactive power  $Q$  for nearby lagging loads, instead of it coming from the generator. Since the reactive power does not have to travel over the long and fairly high-resistance transmission lines, the transmission line current is reduced and the power system losses are much lower.
- Since the transmission lines carry less current, they can be smaller for a given rated power flow. A lower equipment current rating reduces the cost of a power system significantly.

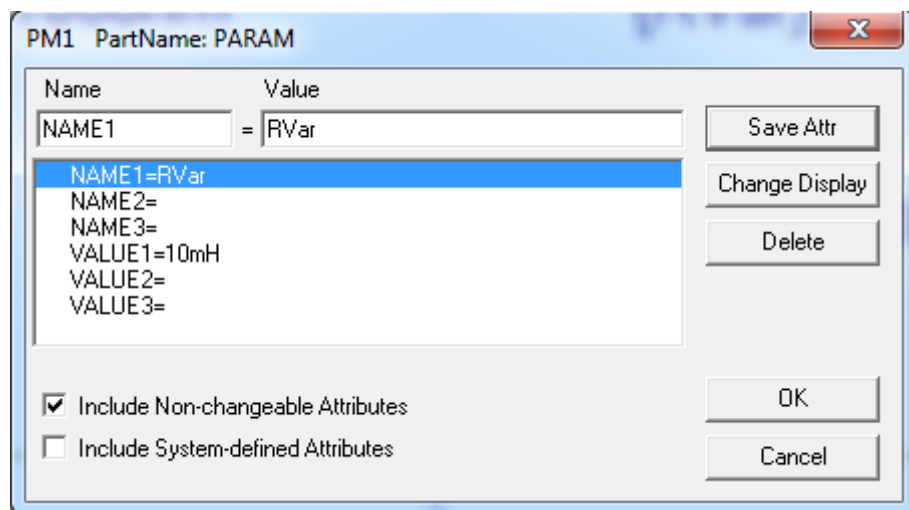
## Frequency Analysis

From Analysis Setup > AC Sweep. Then you should be able to choose the frequency sweep characteristics.

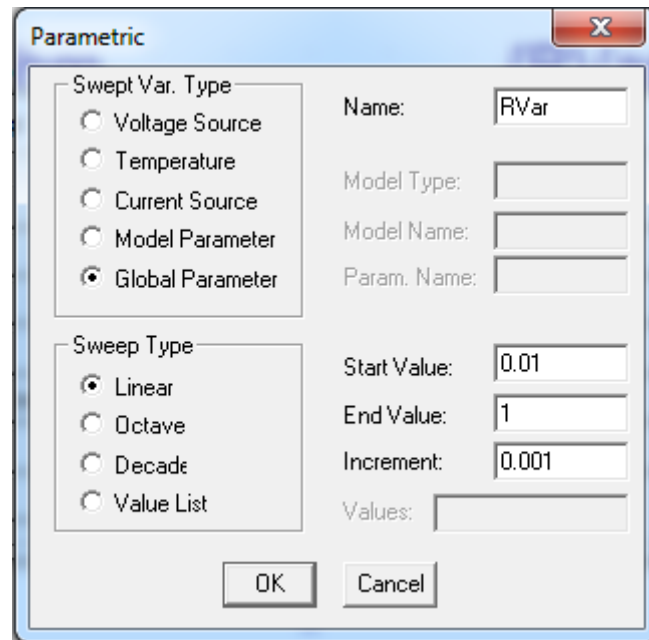


## Parametric Analysis (Review)

- 1) Parametric analysis allows you to run another type of analysis (transient, sweeps) while using a range of component values using the **global parameter** setting. The best way to demonstrate this is with an example, we will use an inductor, but any other standard part would work just as well (capacitor, resistor).
- 2) First, double-click the value label of the Inductor that is to be varied. This will open a "Set Attribute Value" dialog box. Enter the name **{RVar}** (including the curly braces) in place of the component value. This indicates to PSpice that the value of the inductor is a global parameter called RVAL. In order to define the RVAL parameter it is necessary to place a global parameter list somewhere on the schematic page. To do this, choose "**Get New Part**" from the menu and select the part named **param**.



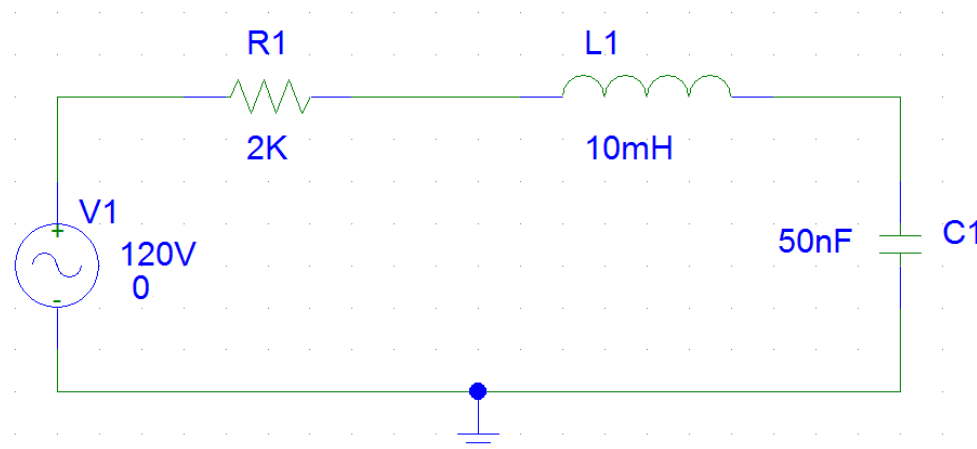
- 3) Place the box anywhere on the schematic page. Now double-click on the word **PARAMETERS** in the box title to bring up the parameter dialog box. Set the NAME1= value to **RVar** (no curly braces) and the VALUE1= value to the nominal inductance value (10mH for example). This nominal value is required, but it is only used if the DC bias point detail is computed. Otherwise, the value is ignored by PSpice.



- 4) Finally, go to the "Analysis Setup" menu and enable "Parametric" analysis. Open the Parametric setup dialog box and enter the sweep parameters: Name: **RVar** Swept variable type: Global Parameter. Make sure the other analysis type(s) are selected in the analysis setup menu (transient, sweeps). PSpice will now automatically perform the simulation over and over, using a new value for **Rvar** during each run.

## Example Circuit 1

- 1) Draw the circuit in Schematics. Voltage source is VAC with 120V RMS and 0 degree phase.



- 2) Use equation (1) to find the resonant frequency of the circuit.
- 3) Choose a suitable frequency range and perform frequency sweep. Choose a large frequency range in order to get an idea of the asymptotic behavior of the circuit in terms of frequency.
- 4) Plot magnitude of the current. The things you should notice
  - a) The value of current is max at resonant frequency.
  - b) From resonant frequency if you move in either direction the current is decreasing.
- 5) Add a plot to window. Plot the phase of the current. You should notice:
  - a) The value of phase at resonant frequency.
  - b) The limiting value of phase when you are going left from the resonant frequency.
  - c) The limiting value of phase when you are going right from the resonant frequency.
- 6) Now, in a new probe window, plot the following quantities in terms of frequency in the same plot,
  - a)  $V_L$  vs.  $f$
  - b)  $V_C$  vs.  $f$
  - c)  $V_R$  vs.  $f$
  - d)  $I$  vs.  $f$

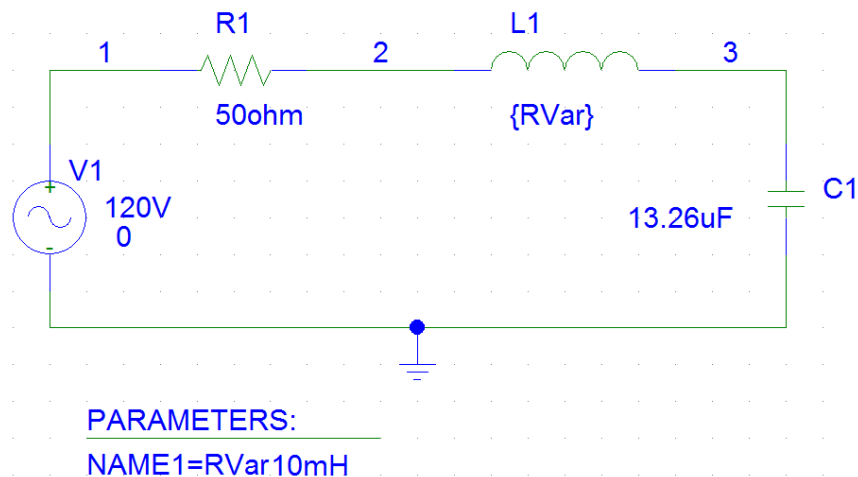
The scale of the  $I$  vs  $f$  curve may be very low. In that case multiply the value of  $I$  by a constant.

You should notice the following:

- a) The curves should have the same shape as you have seen in the book.
- b) Maximum of the inductor voltage occurs after resonant frequency as explained in the theory.
- c) Maximum of the capacitor voltage occurs before resonant frequency.
- d) At resonant frequency the inductor and capacitor have the same voltage.

## Example Circuit 2

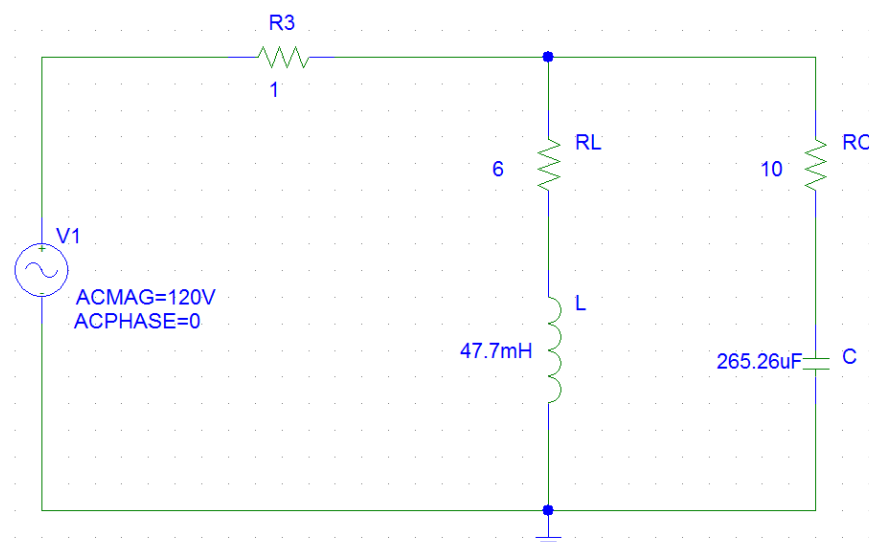
- 1) Draw the circuit in schematics.



- 2) We want to find the resonance at 60Hz. Using equation (1) find the value of the inductance which causes resonance.
- 3) Using the obtained value perform a parameter sweep on  $L$  at 60Hz that is use linear frequency sweep at that frequency. Use reasonably large range.
- 4) In the probe window plot the following curves in the same plot:
  - a)  $V_L$  vs.  $L$
  - b)  $V_C$  vs.  $L$
  - c)  $V_R$  vs.  $L$
  - d)  $I$  vs.  $L$

As previously, if shape of any of the curve cannot be understood from the plot, use necessary scaling.

## Example Circuit 3



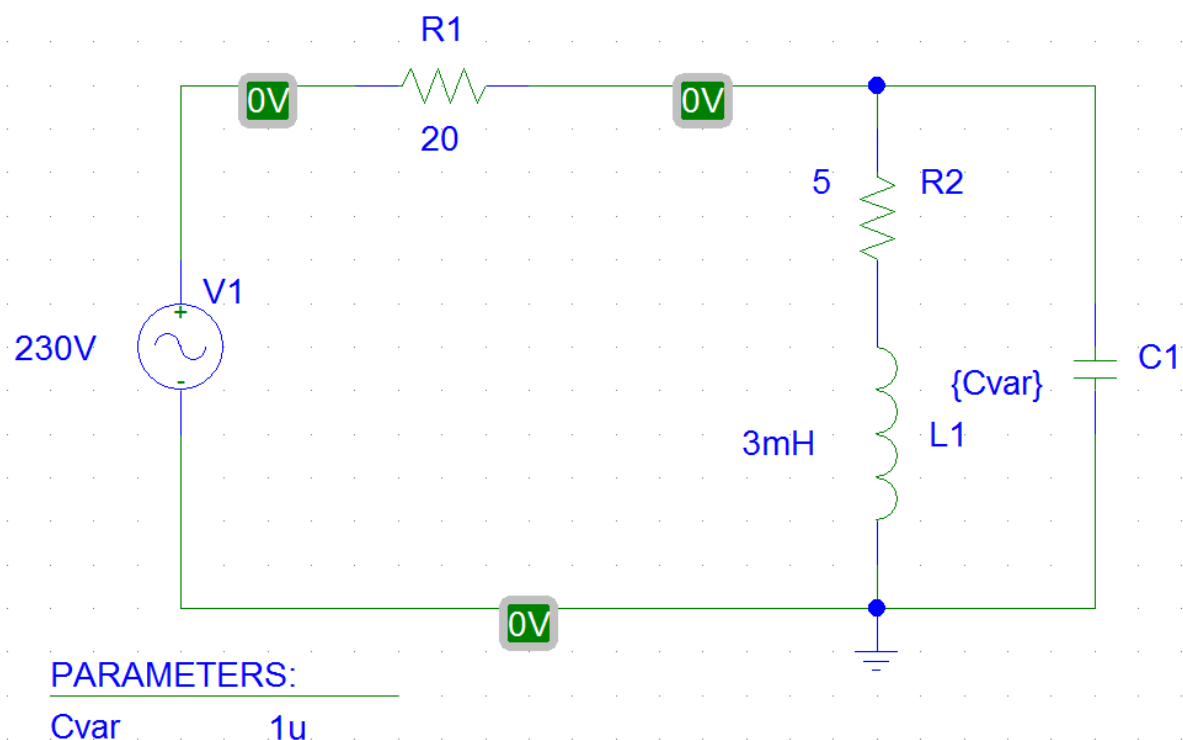
- 1) The following circuit has been constructed in such a way that resonance is obtained at 60Hz frequency. Verify this from equation 2.



- 2) Draw the circuit in schematic and perform a frequency sweep in a suitable frequency range (1Hz to 100Hz for example).
- 3) You should observe the following:
  - a) The phase of the current  $I(R3)$  is zero at resonance frequency.
  - b) The maximum impedance and consequently minimum current is not at resonant frequency.
- 4) You should be able to explain the observations you made in (3).

### Example Circuit 4

- 1) This circuit is a common form of transmission line in single phase. The Resistance R1 is the line resistance and the RL branch may constitute a electric machine. And the capacitor C1 is the capacitor used for power factor correction.

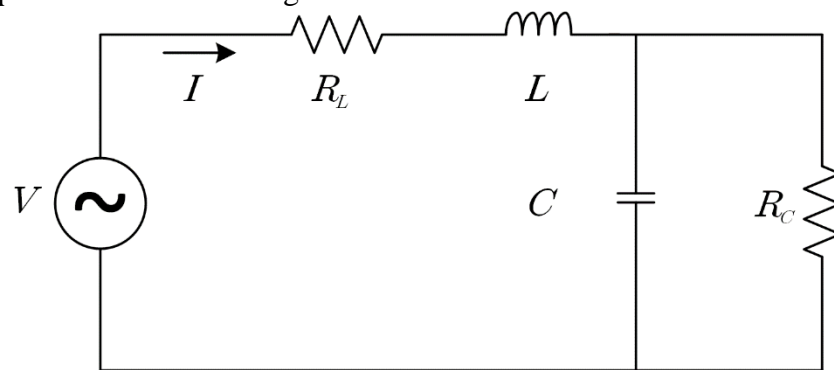


- 2) In this example we are interested at 50Hz frequency.
- 3) First draw the circuit without the capacitor C1. Perform a steady state analysis at 50Hz and calculate the power absorbed in the resistance R1. Note down this value.
- 4) Now add the capacitor C1 and perform a parametric sweep on the capacitor in suitable range (for example, 1uF to 1mF) so that resonance is obtained at 50Hz.
- 5) Now calculate the power absorbed in resistance R1 near the resonant frequencies. The following observations should be made:
  - a) At resonance the power absorbed in resistance R1 is lower than that was observed in (3).
  - b) The capacitance at which the absorbed power is lowest is not the capacitance at which resonance is obtained.
- 6) Explain your observations.

## Post Lab

Along with the lab works include these in your lab report including necessary explanations and figures.

- 1) In the circuit of “Example Circuit 2” use  $L=25\text{mH}$ . Then perform a parametric sweep on the Capacitance and find the capacitance at which resonance is obtained. Does this match with the value obtained from Eq. (1). Also, plot the following graphs:
  - a.  $V_L$  vs.  $C$
  - b.  $V_C$  vs.  $C$
  - c.  $V_R$  vs.  $C$
  - d.  $I$  vs.  $C$
- 2) Find the equation of the following circuit for the resonant condition:



For a fixed value of  $f$ ,  $R_L$ ,  $L$ , and  $R_C$  find the condition(s), if any, that will guarantee valid solution(s) for  $C$  from that equation.