EE2111A Activity Sheet - Week 5 Studio 1

Start	Duration	Activity
0:00	45 mins	Briefing
0:45	45 mins	Activity #1: Visualization using Python notebook - waveforms in series RLC circuit and their phasors
1:30	45 mins	Activity #2: Tutorial problems
2:15	15 mins	Debriefing

Learning Objectives

To be able to

- explain the concept of phasor, and
- apply phasor and impedance to analyzing ac circuits.

Key Concepts

Phasor:

Phasor is an abstraction of a sinusoidal waveform retaining the information about amplitude and phase, but discarding the frequency information. The following convention is used in the EPP lecture notes for defining the phasor:

$$x(t) = Asin(\omega t + \phi) \Longleftrightarrow \bar{X} = Ae^{j\phi}, \quad j = \sqrt{-1}.$$

$$Ae^{j\phi} = A\angle\phi = A\cos\phi + jA\sin\phi.$$

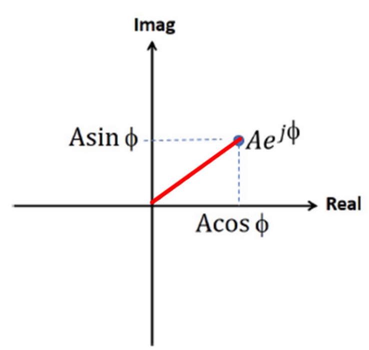

Figure 1: Phasor is expressed as a complex number $A\cos\phi + jA\sin\phi$, where A and ϕ are the amplitude and the phase, respectively of the sine wave.

Impedance:

Impedance of a component or a circuit is the ratio between the phasor of the sinusoidal voltage ($\bar{V}$) across it and the phasor of the sinusoidal current ($\bar{I}$) flowing through it:

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

Impedance of the three basic components (resistor, inductor, and capacitor):

$$
\begin{aligned}
Z_R &= R \\
Z_L &= +j\omega L \\
Z_C &= \frac{1}{j\omega C} = -j\frac{1}{\omega C}
\end{aligned}
$$

With increasing frequency, the impedance of inductor increases, but impedance of capacitor decreases. Inductor impedes the current flow more at higher frequency, and capacitor impedes the current flow less at higher frequency.

AC circuit analysis using phasor and impedance

- Replace each source with its phasor and each component with its impedance. As a result, the AC circuit with sinusoidal source is transformed into a time-independent (DC) circuit with complex-valued sources and components.
- AC circuit in phasor dimain can be analyzed using the methods of DC circuit analysis. The result thus obtained is the phasor of the voltage (or current) of interest.
  - The magnitude and the argument of the resulting phasor are the amplitude and the phase of the voltage (or current) of interest.
  - The frequency is the same as the frequency of the source.

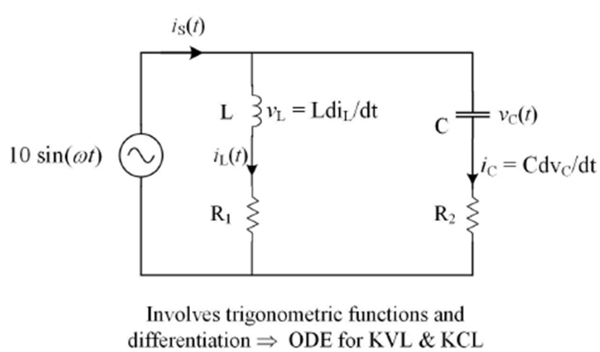

Figure 2: Time domain: The Kirchoff's equations in AC circuit are ordinary differential equations with sinusoidal forcing function.

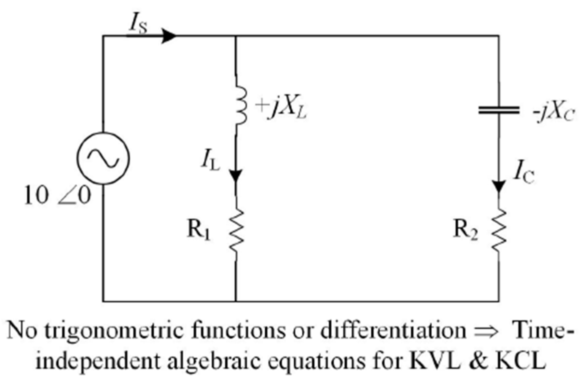

Figure 3: Phasor domain: The Kirchoff's equations are algebraic equations and do not contain any trigonometric function.

Activity #1: Visualization using iPython notebook - waveforms in series RLC circuit and their phasors

1. Run the iPython notebook

   $AC\_visualization\_2020 \cdot ipynb$

   Execution of this iPython notebook different waveforms in a series RLC circuit driven by a sinusoidal voltage source and the phasors of the waveforms.

2. The values of R, L, and C can be varied using the sliders shown. The ranges are

   - $R(0\Omega \leq R \leq 5000\Omega)$
   - $L(0mH \leq L \leq 5000mH)$
   - $C(0.01\mu F \leq C \leq 1000\mu F)$

3. The amplitude (range: $0V \rightarrow 10V$) and frequency (range: $0 \rightarrow 100Hz$) of the input voltage can be varied by using the corresponding slider.

4. By default, the display shows source voltage and loop current - in both time domain and phasor. You can visualize the waveforms v_R, v_L, and v_C by clicking on the the corresponding button.

5. Use sliders to vary the values of different components and observe how it affects the amplitude of current and its phase shift with respect to the source voltage. **Keep the frequency of the source voltage fixed at some value, e.g., 50 Hz when you vary the component values.**

   Q1 How does the current phasor change as the value of L is varied, keeping other two components unchanged?

   Q2 How does the current phasor change as the value of C is varied, keeping other two components unchanged?

   Q3 How do the current phasor change as the value of R is varied, keeping other two components unchanged.

6. With the values of R, L, and C fixed, vary the frequency of the source voltage, keeping the amplitude unchanged, and observe how the amplitude of the current varies. While doing this, determine the frequency at which the current becomes in-phase with the source voltage. This frequency is the **resonant frequency** and it satisfies the condition

$$\omega_r = \frac{1}{\sqrt{LC}} \Leftrightarrow f_r = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

E-Logbook:

The e-logbook should contain at the least the following:

1. Image of one of the visualization cases (item 5)

2. Answer to the questions Q1-Q3 in item 5.

3. What is the frequency at which the current becomes in-phase with the source voltage? Include the visualization image at this frequency (item 6).

Activity #2:Tutorial problems on AC circuit analysis

For the questions below, all voltages and currents are in the steady-state.

1. For the circuit shown in Fig.4,

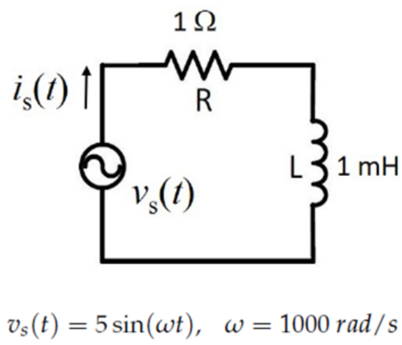

Figure 4: Problem 1

   a. Determine the phasors of the source current, the voltage across inductor, and the voltage across resistor.
   b. Express them in time domain.
   c. Does the current lag or lead the source voltage? What is the phase difference?

2. For the circuit shown in Fig.5,

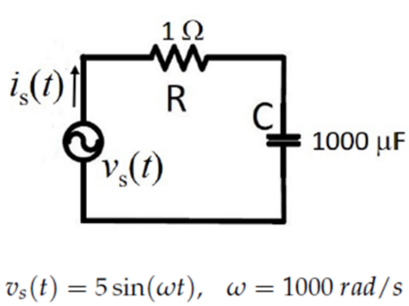

Figure 5: Problem 2

   a. Find unknown current and voltages in the circuit.
   b. Sketch the phasor diagram showing the phasors of source voltage, voltage across the resistor, voltage across the capacitor, and the current.
   c. Does the current lag or lead the source voltage? What is the phase difference?

3. For the circuit shown in Fig.6,

   a. Determine the source current.

$$v_s(t) = 10\sin(\omega t), \quad \omega = 500\, rad/s,$$

and $R = 1\,\Omega$, $L = 1\,mH$, and $C = 1000\,\mu F$.

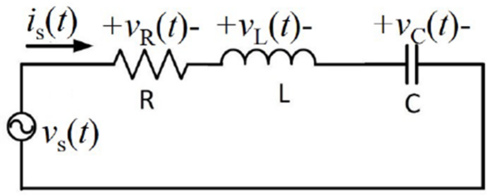

Figure 6: Problem 3

b. Find the phasors of v_S, v_R, v_L and v_C.

c. What is resonant frequency for this circuit? What is the phase shift between source voltage and source current at the resonant frequency?

4. For the circuit shown in Fig.7,

$$v_s(t) = 10\sin(\omega t), \quad \omega = 500\, rad/s,$$

and $R = 1\,\Omega$, $L = 1\,mH$, and $C = 1000\,\mu F$.

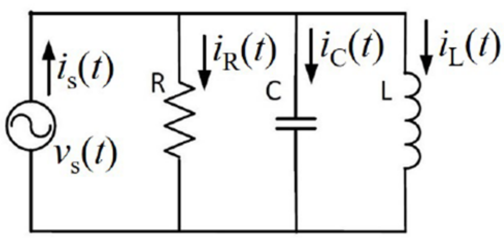

Figure 7: Problem 4

a. Find the current phasor for each of the three branches.

b. Determine the phasor of the source current.

c. Sketch the phasor diagram showing all four current phasors and the voltage phasor.

E-Logbook:

1. Answers to the questions with all workings clearly shown.