Faculty of Engineering & Technology – Electrical & Computer Engineering Department

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Circuits and electronics lab

ENEE2103

Report EXP.4

Sinusoidal Steady State Circuit

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1. Abstract

In this experiment, we will understand more about sinusoidal steady state circuits. We will know how to use oscilloscope, the DMM, the Wattmeter for AC electric quantities measurements. In addition, we will know how to measure the circuit elements impedances, voltage, and current phasors for those circuits, and verify the validity of the Circuit theorems in the sinusoidal steady state and calculate the power of it.

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2. Theory

Impedance

Impedance is a measure of how much alternating current is impeded in a circuit; admittance is a measure of how much current is admitted.[1]

Element	Impedance	Admittance
R	Z= R	Y= $\frac{1}{R}$
L	Z=$j\omega L$	Y =$\frac{1}{j\omega L}$
C	Z= $\frac{1}{j\omega C}$	Y= $j\omega C$

Figure 2.1 Impedance and admittance of elements in circuits

Resistor Impedance

Resistance is a measure of voltage divided by resistance in a resistor. In DC circuits, the linear ratio of voltage to current in a resistor is called its resistance. However, in AC circuits this ratio of voltage to current depends upon the frequency and phase difference or phase angle (φ) of the supply. Therefore, when we use a resistor in AC circuits, then we can say that DC resistance = AC impedance → Z = R. [2]

Inductor Impedance

Impedance of inductor (also called inductance or inductive reactance) is the measure of the opposition to a change of the electrical current in this component. It can be summarized, in a very general way, that an inductor lets the low frequencies signals pass (including the 0 Hz signals) and blocks the high frequencies signals.[3]

Capacitor Impedance

The Impedance of a capacitor (Capacitive reactance) is the measure of the opposition to a change of the electrical current in this component. It can be summarized, in a very

[1] https://www.allaboutcircuits.com/textbook/alternating-current/chpt-5/susceptance-and-admittance/#:~:text=Again%2C%20we%20see%20a%20certain,how%20much%20current%20is%20admitted. In 18/11/2022 at 5:27pm

[2] https://spinningnumbers.org/a/impedance-vs-resistance.html#:~:text=Impedance%20and%20resistance%20are%20similar,by%20current%20for%20any%20component. In 18/11/2022 at 5:39pm

[3] https://electronicsarea.com/what-is-the-impedance-of-an-inductor/ in 18/11/2022 at 5:45pm

general way, that a capacitor lets the highest frequencies signals pass and blocks the low frequencies signals (Including 0 Hz signals).[4]

The formula for capacitive impedance: Z= $\frac{Vm}{\text{Im}}$ =R-j $\frac{1}{2\pi f c}$ ∠tan^-1($\frac{1}{2\pi f CR}$)

Capacitive and Inductive Behavior

AC circuits can be resistive, capacitive or inductive and this depends on the phase difference between current and voltage signals. If current and voltage signals are in phase, then the circuit balanced and resistive, if current leads voltage by a phase shift then it is capacitive and if current lags voltage by a phase shift then it is inductive. In serial RLC circuit, we can find a frequency that makes the circuit balanced between capacitivity and inductivity, which is related to the values of inductance, and capacitance, this frequency called resonance frequency, which makes the total imaginary part in impedance, equals to 0:

$ZL + ZC = 0 \rightarrow j2\pi f L + j\ 2\pi f C1 = 0 \rightarrow j2\pi f L - j\ 2\ \pi f C1 = 0 \rightarrow 2\pi f L = 2\ \pi f C1 \rightarrow f$

Our RLC circuit is resistive circuit and its current signal is in phase with voltage signal in frequency equals to resonance frequency. After that when we increase the value of inductance, the current will lag voltage, hence the circuit will be inductive. In addition, if we increase capacitance's value, current will lag voltage because $ZL > ZC \rightarrow j\ (2\pi f L - 2\ \pi f C1) > 0$ hence it's inductive. If we put a frequency more the resonance frequency, the circuit will be inductive, if we put frequency less than the resonance one, the circuit will be capacitive.[5]

Sinusoidal Steady State Power

As we know from circuit analysis, there is a complex power which is component from two parts: real part that represents the average active part and its unit is watt, and the second part is the imaginary reactive power and its unit is VAR, and this is the equation of complex power: $S = Pavg + jQ$. The equations of average power and reactive power is shown below.

$$Pavg = VrmsIrms \cos(\phi V - \phi I) = VI/2 \cos(\phi V - \phi I)$$

$$Q = VrmsIrms \sin(\phi V - \phi I) = VI/2 \sin(\phi V - \phi I)$$

For a pure resistance, it does not have any reactive power but it has average power that equals to $VrmsIrms = 12\ VI$, for a pure inductance it does not have any average power but it has reactive power equals to $VrmsIrms = 12\ VI$, for a pure capacitance it does not

[4] https://electronicsarea.com/impedance-of-a-capacitor-capacitive-reactance/ 18/11/2022 at 5:54pm
[5] https://courses.lumenlearning.com/suny-physics/chapter/23-11-reactance-inductive-and-capacitive/ in 18/11/2022 at 6:00pm

have any average power but it has reactive power which equals to $-VrmsIrms = - \ VI$. In any circuit, the total power delivered to a circuit is equal to the total power absorbed.[6]

3. Procedure

Impedance

The aim of this part is to find the impedance of different circuit's components – resistors, capacitors and inductors- and the phase shift of the current and voltage with different frequencies provided.

- **Resistive circuit**: The circuit was designed as shown in the figure 3.1 that has Vp-p=10V, Rx=2.2, R1=1k῎Ω, and have set the signal generator with amplitude 5 V and frequency was changed each time as the following: 1 kHz, 1.5 kHz, and 0.5 kHz.

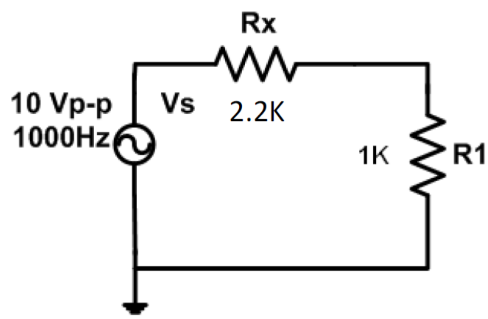

Figure 3.1 Resistive circuit

- **Capacitive circuit**: the circuit was designed as shown in the figure 3.2 that has Vp-p=10V, Rx=2.2, C=100nF, R8=1k῎Ω, and have set the signal generator with amplitude 5 V and frequency was changed each time as the following: 1 kHz, 1.5 kHz, and 0.5 kHz.

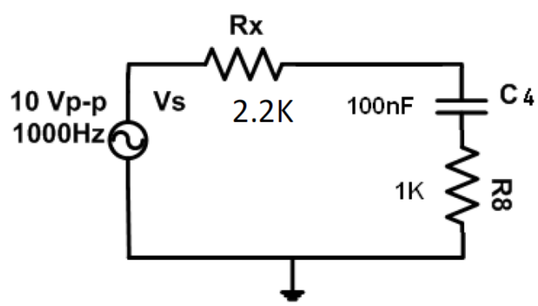

Figure 3.2 Capacitive circuit

[6] https://www.allaboutcircuits.com/technical-articles/sinusoidal-steady-state-power-calculations/ 18/11/2022 at 6:28pm

- **Inductive circuit**: the circuit was designed as shown in the figure 3.3 that has Vp-p=10V, Rx=0.47, L=400mH, R1=1kΩ, and have set the signal generator with amplitude 5 V and frequency was changed each time as the following: 1 kHz, 1.5 kHz, and 0.5 kHz.

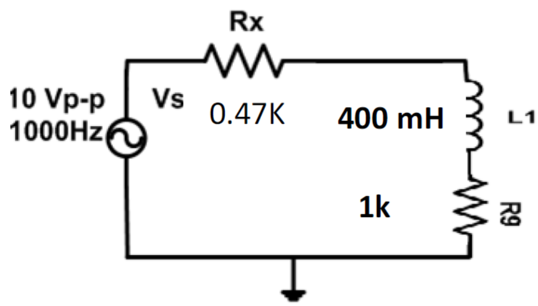

Figure 3.3 Inductive circuit

Capacitive and inductive behavior

The circuit was designed as shown in the figure 3.4 that has Vp-p=10V, L3=10mH, R13=330Ω, C4=100nF, and have set the signal generator with amplitude 5 V and frequency was changed each time as the following: 1 kHz, 2 kHz, 4 kHz, 6 kHz, 8 kHz, and finally frequency resonance.

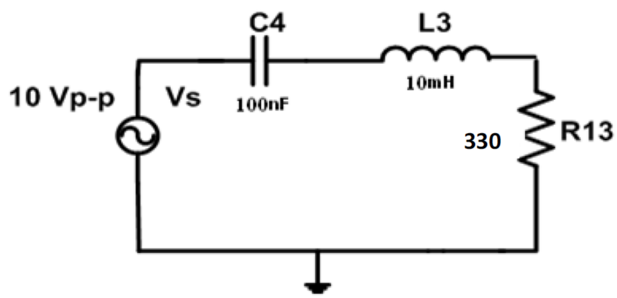

Figure 3.4 Capacitive and inductive behavior circuit

Adding extra 100nF capacitor in parallel to C4, and doubling the value of L3

Instead of adding extra capacitor, it can be added by increasing the value of the original capacitor by 100nF so that to be C4=200nF in the figure 3.4.

Sinusoidal steady state power

The circuit was designed as shown in the figure 3.5 that has Vrms=1Vrms, C2=470nF, Rc=10 Ω, R2=220Ω, L1=120mH, R1=220 Ω, and have set the signal generator with amplitude 2.5 V and frequency 2 kHz.

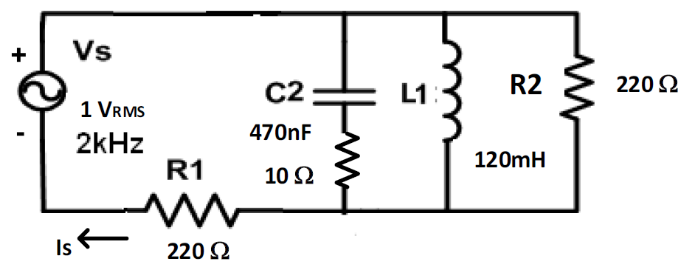

Figure 3.5 Sinusoidal steady state power ciruict

4. Data calculation and results

Impedance

Resistive circuit:

The results was obtained from the lab and written in the table 4-1.

F(kHz)	Vrms	Irms (mA)	Δt (us)	Phase shift	Impedance from exp. (KΩ)
0.5	3.3447	1.047	0	0	3.194
1	3.472	1.055	0	0	3.291
1.5	3.471	1.055	0	0	3.290

Table 4-1 results of resistive circuit

Practical value was included in the table 4-1 and was calculated according to: Z= $\frac{Vm}{\text{Im}}$

$$\text{From theory: } Z = \frac{Vm}{\text{Im}} = R = 2.2k + 1k\ \Omega\ \angle 0 = 3.2k\Omega\ \angle 0$$

Discussion:

As we can see from results of the actual experiment, the phase shift still 0 all times, the Vrms and Irms didn't make a valuable change after changing the value of frequency, this is related to that the impedance of the resistive circuit is the same as the value of equivalent resistor in the circuit. We also noticed that the results are not exactly the same as the theoretical value of Z, and this is because the resistors we used are not exactly the written value.

Capacitive circuit

The results was obtained from the lab and written in the table 4-2.

F(kHz)	Vrms	Irms (mA)	Δt (us)	Phase shift	Impedance from exp. (KΩ)
0.5	3.454	0.795	249	41.8	4.345

1	3.47	0.97	73	-23.5	3.577
1.5	3.464	1	34	-16.9	3.464

Table 4-2 results of capacitive circuit

Practical value was included in the table 4-2 and was calculated according to: Z= $\frac{Vm}{\mathrm{Im}}$

From theory: Z= $\frac{Vm}{\mathrm{Im}}$ =R-j $\frac{1}{2\pi fc}$ ∠tan^-1($\frac{1}{2\pi fCR}$)

- ✓ F=0.5 KHz:

Z=Rx+R8+$\frac{1}{j2\pi fc}$=2.2k+1k+$\frac{1}{j2\pi(100n)(0.5k)}$=3.2k-j3.185k

|Z|=$\sqrt{3.2k^2 + 3.185k^2}$=4.514 kΩ

Phase shift= tan^-1($\frac{1}{2\pi(0.5k)(100n)(3.2k)}$) =44.86

- ✓ F=1 KHz:

Z=Rx+R8+$\frac{1}{j2\pi fc}$=2.2k+1k+$\frac{1}{j2\pi(100n)(1k)}$=3.2k-j1.592k

|Z|=$\sqrt{3.2k^2 + 1.592k^2}$=3.574 kΩ

Phase shift= tan^-1($\frac{1}{2\pi(1k)(100n)(3.2k)}$) =26.45

- ✓ F=1.5 KHz:

Z=Rx+R8+$\frac{1}{j2\pi fc}$=2.2k+1k+$\frac{1}{j2\pi(100n)(1.5k)}$=3.2k-j1.062k

|Z|=$\sqrt{3.2k^2 + 1.062k^2}$=3.372 kΩ

Phase shift= tan^-1($\frac{1}{2\pi(1.5k)(100n)(3.2k)}$) =18.35

Discussion:

As we can see, the formula shows that impedance depends on frequency, it decreases when the frequency increases and changes the value in capacitive circuit alongside with the voltage and current so the circuit so the circuit isn’t in phase and has a shift between the voltage and current, and the voltage lags the current.

Inductive circuit

The results was obtained from the lab and written in the table 4-3.

F(kHz)	Vrms	Irms (mA)	Δt (us)	Phase shift	Impedance from exp. (KΩ)
0.5	3.4	1.68	252	40	2.024
1	3.48	1.148	165	60.2	3.031
1.5	3.5	0.86	127	67.2	4.069

Table 4-3 Results of inductive circuit

Practical value was included in the table 4-3 and was calculated according to: Z= $\frac{Vm}{\text{Im}}$

From theory: Z= $\frac{Vm}{\text{Im}}$= $R + j2\pi f L\ \Omega \angle$ tan^-1($\frac{2\pi f L}{R}$)

- ✓ F=0.5 kHz

Z=0.47k+1k+$j2(0.5\text{k})(400\text{m})$=1.47k+j1.256k (Ω)

|Z|=$\sqrt{1.47k^2 + 1.256k^2}$=1.933 kΩ

Phase shift= tan^-1($\frac{2\pi(0.5k)(400m)}{1.47k}$)=40.5

- ✓ F=1 kHz

Z=0.47k+1k+$j2(1\text{k})(400\text{m})$=1.47k+j2.512k (Ω)

|Z|=$\sqrt{1.47k^2 + 2.512k^2}$=2.91 kΩ

Phase shift= tan^-1($\frac{2.512k}{1.47k}$)=59.66

- ✓ F=1.5 kHz

Z=0.47k+1k+$j2(1.5\text{k})(400\text{m})$=1.47k+j3.768 k(Ω)

|Z|=$\sqrt{1.47k^2 + 3.768k^2}$=4.04 kΩ

Phase shift= tan^-1($\frac{3.768k}{1.47k}$) =68.687

Discussion:

It is noticed that the impedance here depends on the frequency, it increases when the frequency increases and changes value in inductive circuit alongside with the voltage and current so the circuit isn't in phase and it has a shift between the voltage and current and the current lags voltage.

Capacitive and inductive behavior

The results was obtained from the lab and written in the table 4-4.

F	1k	2k	4k	6k	8k	Fo=3.327k
Δt (us)	230	80	16	13	15	0
Θvs- θis	-76	-58	-17	23	45.8	0

Table 4-4 Results of inductive and capacitive circuit

From theory: phase shift= (Δt*360)/T, T=1/f.

F=1 kHz: T=1ms → phase shift=(230u*360)/1m=82.8

F=2 kHz: T=0.5ms → phase shift=(80u*360)/0.5m=57.6

F=4 kHz: T=0.25ms → phase shift=(16u*360)/0.25m=23.04

F=6 kHz: T=0.166ms → phase shift=(14u*360)/0.166m=28.2

F=8 kHz: T=0.125ms → phase shift=(15u*360)/0.125m=43

- ✓ To determine circuit behavior for each frequency value is shown in table 4-5:

F	1k	2k	4k	6k	8k
ZC	-j1592	-j796	-j398	-j265	-j199
ZL	j62.8	j125.6	j251.2	j376.8	j502.4
Behavior	Capacitive	Capacitive	Capacitive (almost Fo)	Inductive	Inductive

Table 4-5 circuit behavior calculations

Discussion:

It is noticed that the circuit was capacitive behavior until passing the frequency resonance then it behaved as inductive circuit. So we can say: |Z| <=Fo (Capacitive) & |Z|>Fo (Inductive).

Adding extra 100nF Capacitor and doubling the value of inductor.

The difference in data is shown in table 4-6

F	1k	2k	4k	6k	8k

ZC	-j796.2	-j398.1	-j199.04	-j132.7	-j99.5
ZL	j125.6	j251.2	j502.4	j753.6	j1004.8
Behavior	Capacitive	Capacitive	Inductive	Inductive	Inductive

Table 4-6 circuit behavior calculations after changing in elements

Discussion:

It’s noticed that increasing the capacitance at resonance frequency made the circuit inductive, since $Z_C < Z_L$ again, and a new resonance frequency was obtained for the new circuit, where Fo=3.437 kHz. The figures 4.1 & 4.2 show Fo for both experiments. In addition, when doubling the value of inductance with input frequency set to resonance frequency. It’s noticed that increasing the inductance at resonance frequency made the circuit inductive, since $Z_C < Z_L$, and new resonance frequency was got for the new circuit.

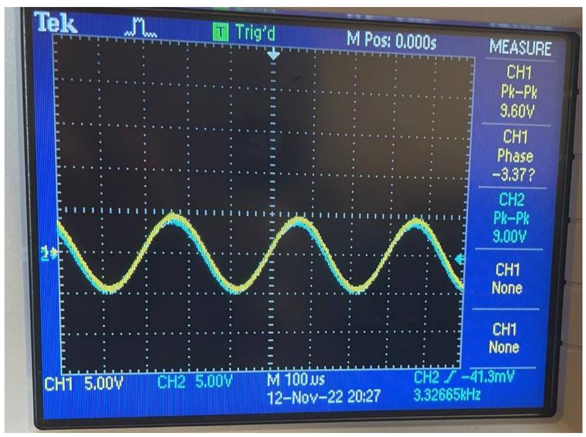

Figure 4.1 Frequency resonance before changing in elements

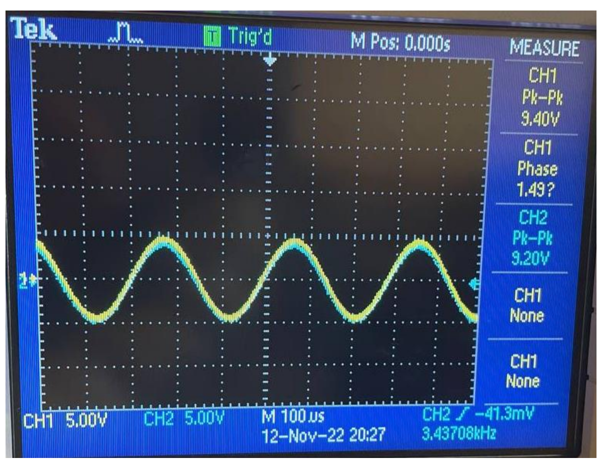

Figure 4.2 Frequency resonance after changing in elements

Sinusoidal steady state power

The results was obtained from the lab and written in the table 4-6.

V(R1)	V(L)	I(L)	I(R2)	Vs	Is	**Θvs- θis**	Vc	Ic	**Θvc- θic**
2.39	0.934	11.5	4.15	2.98	10.67	5	0.94	10.6	85

Table 4-7 results of Sinusoidal steady state power circuit

- Active power (R2) = I_2 R =(4.15m)^2*220 = 3.789 m watt
- Active power (R1) = I_2 R =(10.67)^2*220 = 25.05 m watt
- Reactive Power (Qc)=Vrms*Irms Sin (Øv - Øi) = 9.926 m watt
- Reactive Power (QL)=Vrms*Irms Sin (Øv - Øi) = -10.7 mwatt

Discussion:

In the experiment, it was clear that the current and voltage of the resistor are almost in phase, since =5=~0 as shown in the table 4-7. Also it is noticed that the phase shift between the voltage and current of the capacitor is high =85 and the voltage lags the current, so the circuit is capacitive.

Conclusion

To conclude the work in this experiment, impedances of different circuit's components were measured and studied. For example impedance of resistors, capacitors and inductors. In addition, the phasor domain that simplifies the sinusoidal steady state was studied alongside with the behavior of the voltage and current of different components of the sinusoidal source and the phase shift between them. The results were summarized as the resistance doesn't change in the time domain and the circuit is then called resistive. While if there's some inductance or capacitance, the impedance will be expressed in complex numbers with the resistance as the real part and the inductance or capacitance as the imaginary part and so there will be some phase shift. Then the current will lead the voltage in the capacitor while the voltage will lead in the inductor. In addition, the principle of resonance frequency that can be found in RLC circuits when Zc=Zl was studied adding to the effect of frequency on the impedance above and below the resonance. Finally, the sinusoidal steady state power was understood and measured and the validity of the conservation of energy law was verified.