Name : Archit Agrawal
Student ID : 202052307

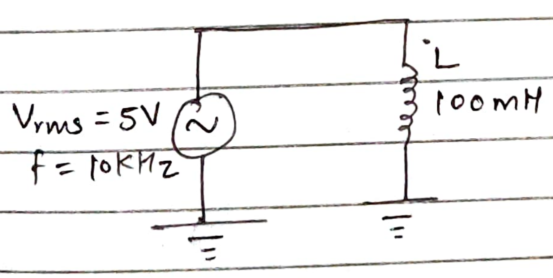
Date:
Page: 1

EE160: Experiment 1

Objective -: Design and simulate the given circuits in SPICE. Plot the voltages (across each element), currents (through each element), and total current. Find the phase difference between source/input voltage (V_s) and all other voltages and currents from your simulations. Calculate the voltages and currents theoretically. Draw the phasor diagram from your theoretical calculations. Compare the theoretical results with the simulation results. Also, plot the total power ($V_s \times I_{total}$) of the circuit

Mathematical Expressions and Theoretical Calculations

CIRCUIT 1 :



$$Z = jX_L$$

$$X_L = \omega L = 2\pi(10k)(100m)$$
$$= 6.28\,K\Omega$$

$$\therefore Z = j(6.28K)\,\Omega$$

Name: Archit Agrawal
Student ID: 202052307

Date:
Page: 2

$$\therefore \bar{I_s} = \frac{\bar{V_s}}{\bar{Z}} = \frac{5\angle 0^\circ}{(6.28k)\angle 90^\circ}$$

$$\bar{I_s} = 0.796\angle -90^\circ \text{ mA}$$

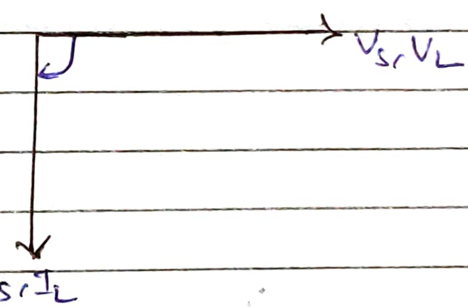
$$\bar{V_s} = 5\angle 0^\circ$$

$\therefore$ I_s lags V_s by 90° or V_s leads I_s by 90°.

the current through inductor is equal to I_s and voltage across it is V_s in this circuit.

$$\therefore \bar{I_L} = \bar{I_s}$$
$$\bar{V_L} = \bar{V_s}$$

Phasor Diagram

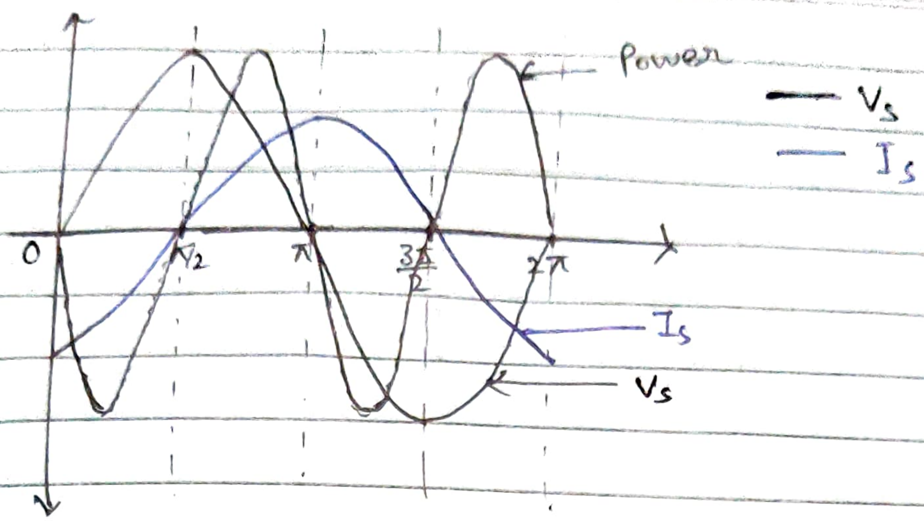


Time Domain

$V_L = V_s = 5\sqrt{2}\sin(\omega t + 0^\circ)$ (as $V_{rms} = 5V$)

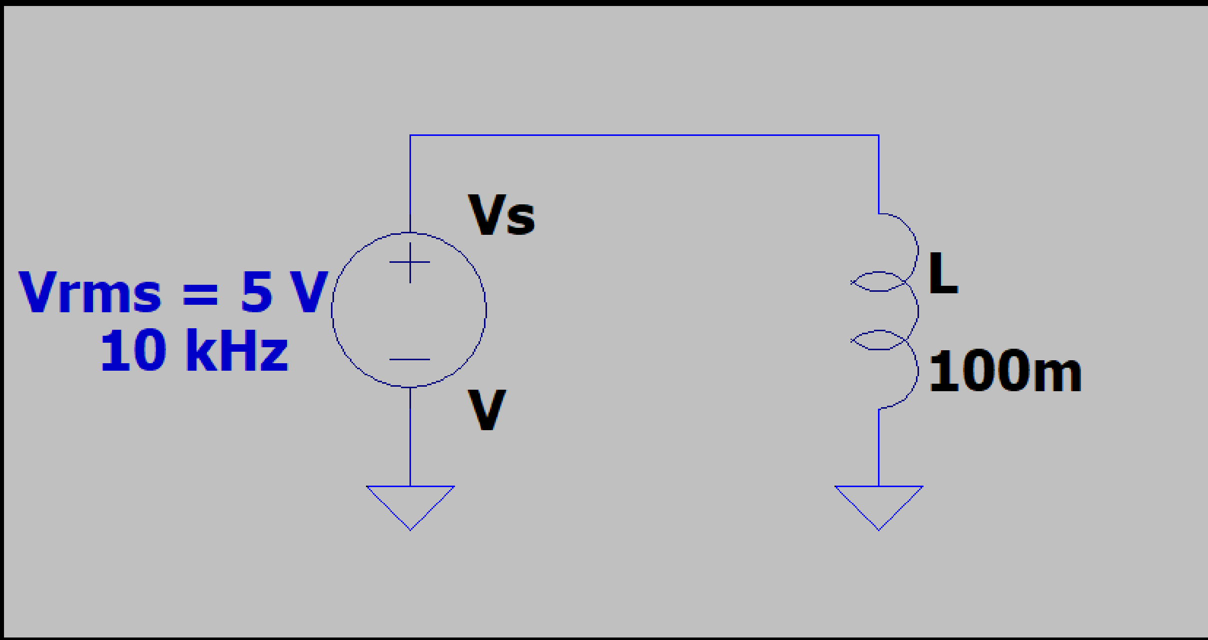
$I_L = I_s = 0.796\sqrt{2}\sin(\omega t - 90^\circ)$

Name: Archit Agrawal
Student ID: 2010S2307

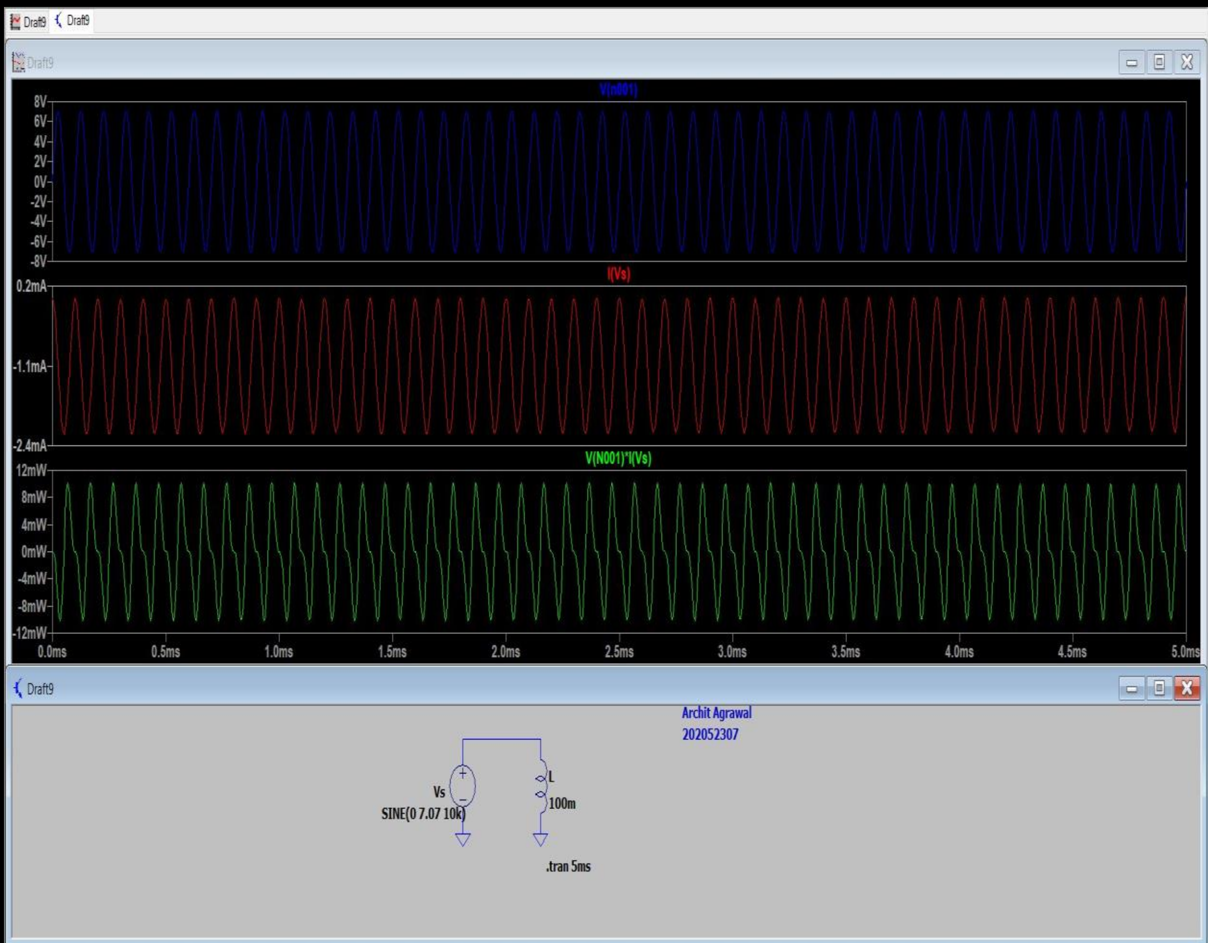


In 1st and 3rd ~~half~~ quarter of power cycle, energy is returned to the circuit while in 2nd and 4th ~~half~~ quarter of power cycle, energy is stored

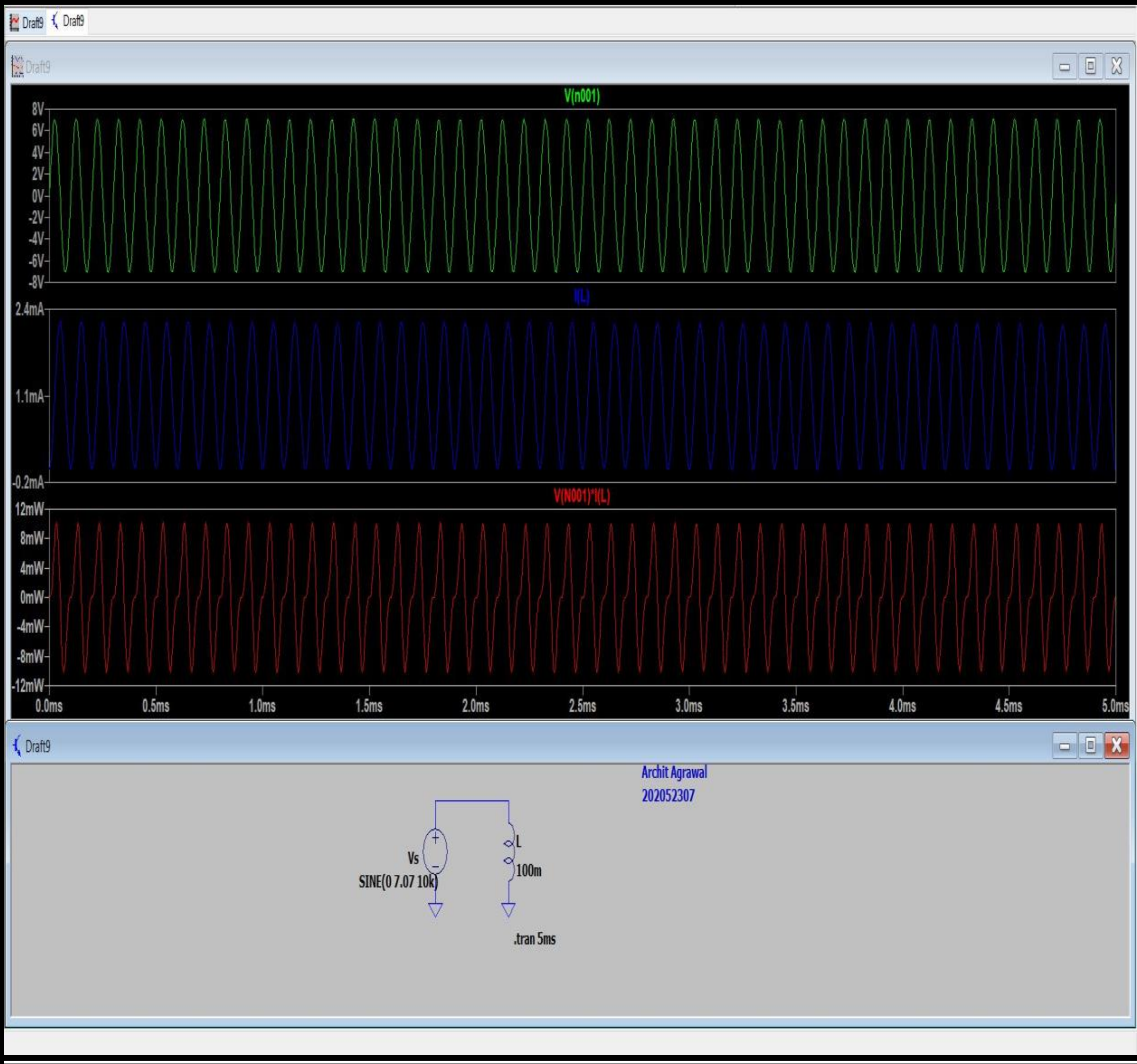
CIRCUIT



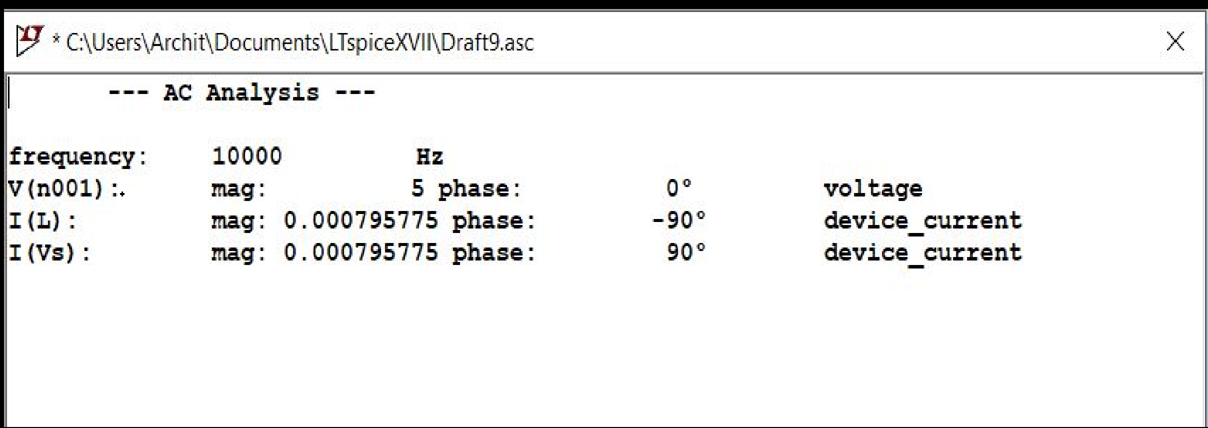
Source Voltage, total current and total power



Voltage, Current and Power across Inductor



AC Analysis



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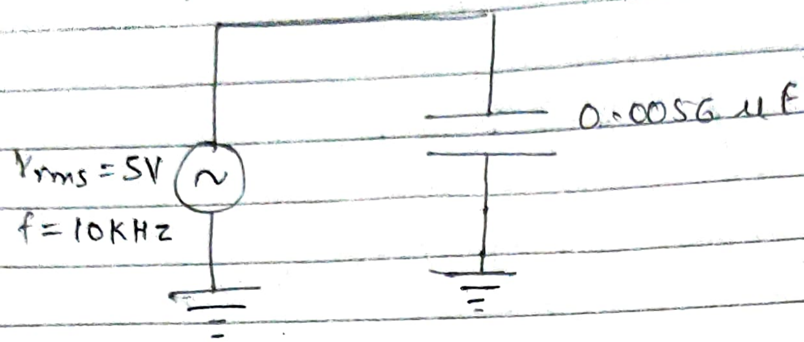
```
       --- AC Analysis ---

frequency:     10000          Hz
V(n001):.      mag:           5 phase:         0°        voltage
I(L):          mag: 0.000795775 phase:       -90°        device_current
I(Vs):         mag: 0.000795775 phase:        90°        device_current
```

Name: Archit Agrawal
Student ID: 202052307

CIRCUIT 2 :



$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi(10K)(0.0056\mu)} = 28.42\,K\Omega$$

$$Z = -j(28.42K)$$

$$\bar{Z} = 28.42 \angle -90^\circ \; K\Omega$$

$$\therefore \bar{I_s} = \frac{\bar{V_s}}{Z} = \frac{5\angle 0^\circ}{28.42\angle -90^\circ}$$

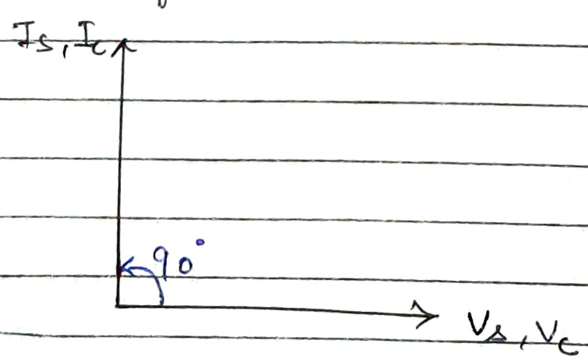
$$\bar{I_s} = 0.176 \angle 90^\circ \; mA$$

$$\bar{V_s} = 5 \angle 0^\circ \; V$$

I_s leads V_s by 90°

In this circuit $I_c = I_s$ and $V_c = V_s$.

Phasor Diagram

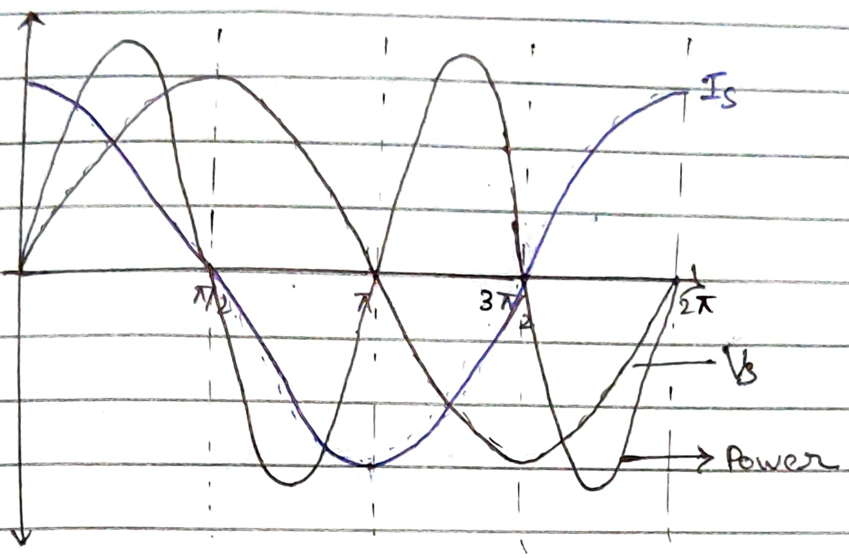


Name: Archit Agrawal
Student ID: 2020052307

Time Domain

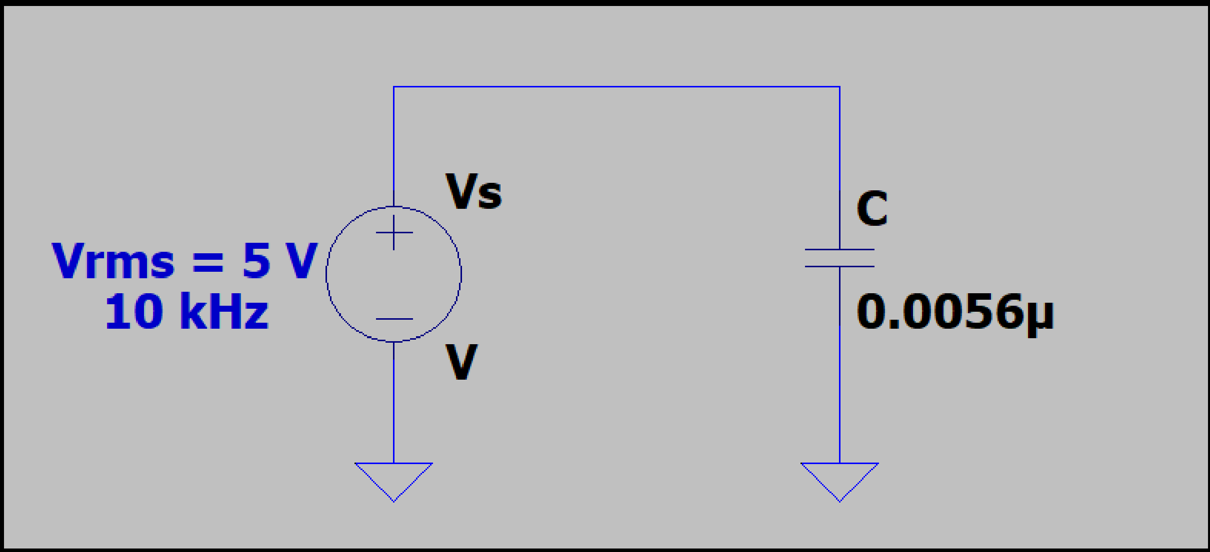
$V_c = V_s = 5\sqrt{2}\ \sin(\omega t)\ V$

$I_c = I_s = 0.176\sqrt{2}\ \sin(\omega t + 90^\circ)\ mA$

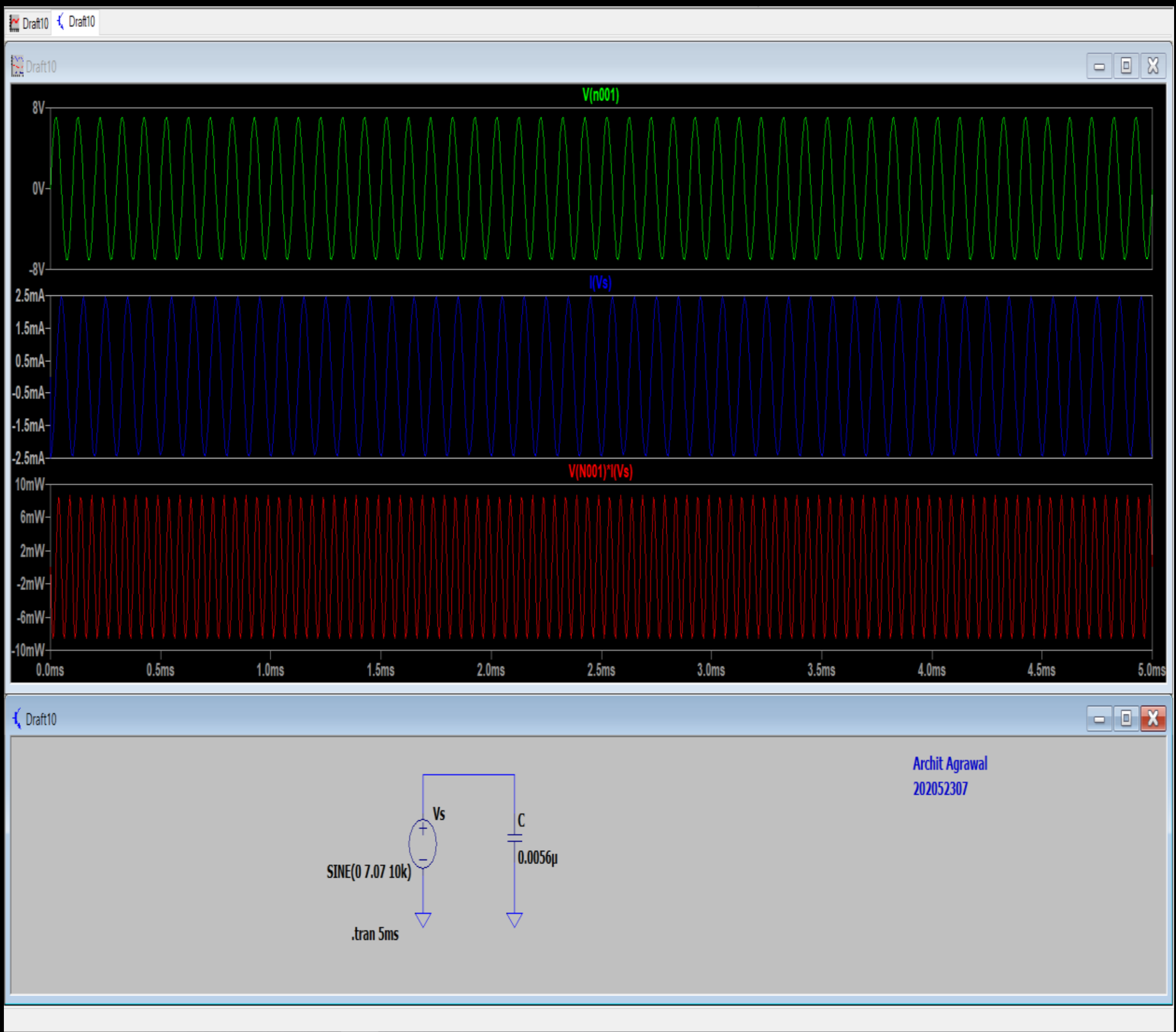


In 1st and 3rd quarter of power cycle, energy is stored while in 2nd and 4th quarter of cycle, energy is released.

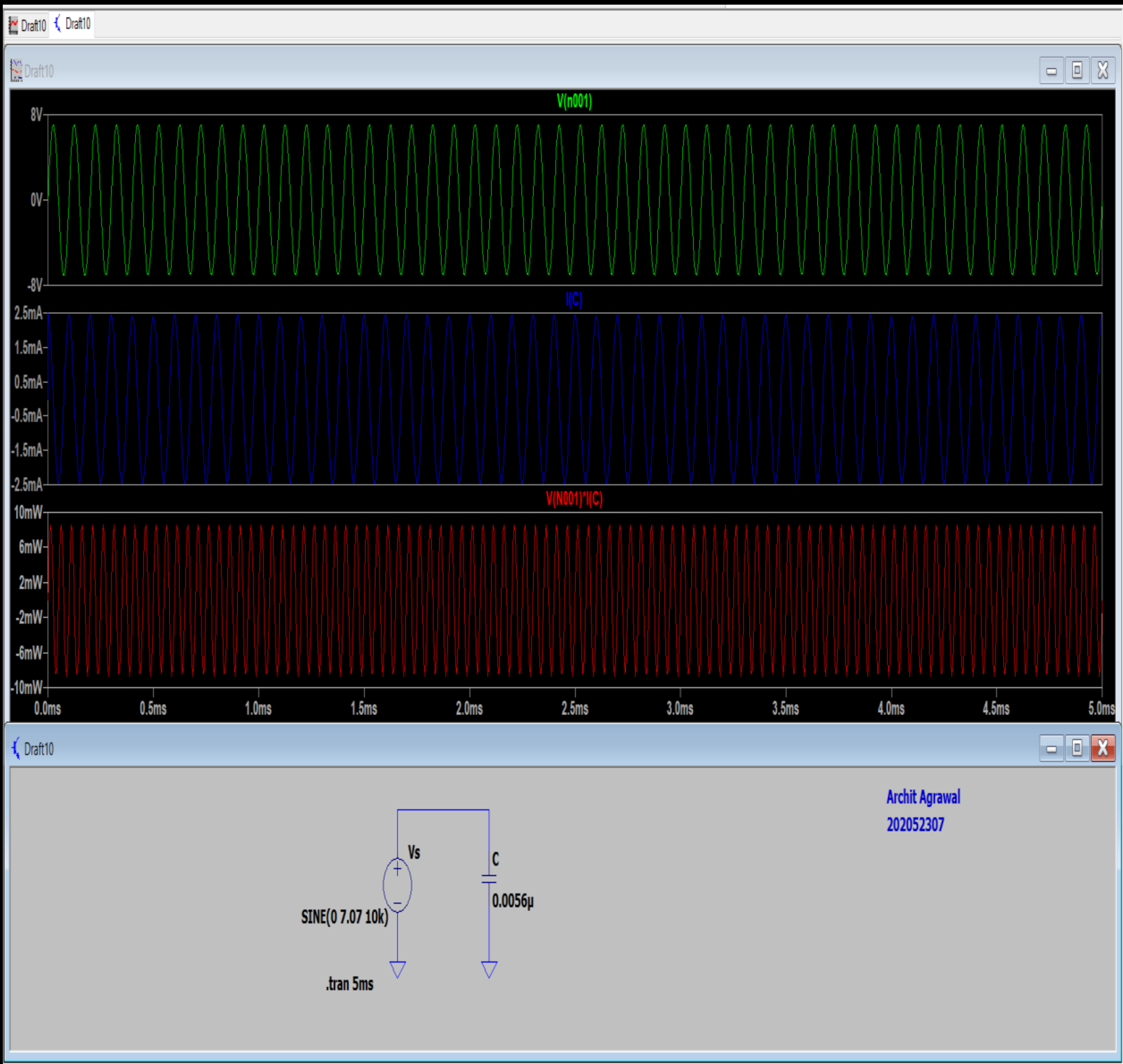
CIRCUIT



Source Voltage, total current and total power



Voltage, Current and Power across Capacitor



AC Analysis

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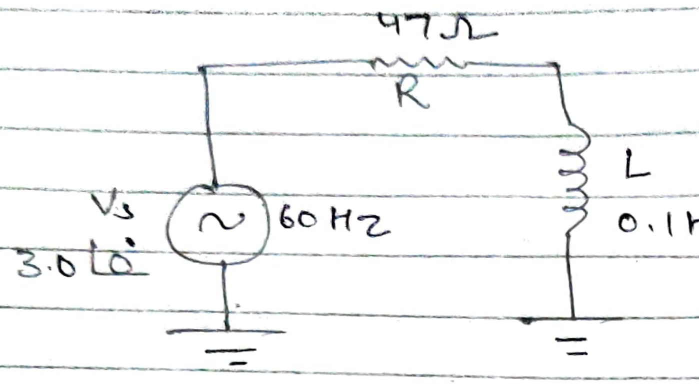
```
       --- AC Analysis ---

frequency:     10000          Hz
V(n001):       mag:           5 phase:         0°        voltage
I(C):          mag:  0.00175929 phase:        90°        device_current
I(Vs):         mag:  0.00175929 phase:       -90°        device_current
```

Name: Archit Agrawal
Student ID: 202052307

CIRCUIT 3:



$X_L = \omega L = 2\pi(60) \times 0.1$
$= 37.68\ \Omega$

$\therefore\ Z = 47 + j(37.68)\ \Omega$
$\overline{Z} = 60.24 \angle 38.69^\circ$

$\overline{I_s} = \dfrac{\overline{V_s}}{Z} = \dfrac{3 \angle 0^\circ}{60.24 \angle 38.69^\circ}$

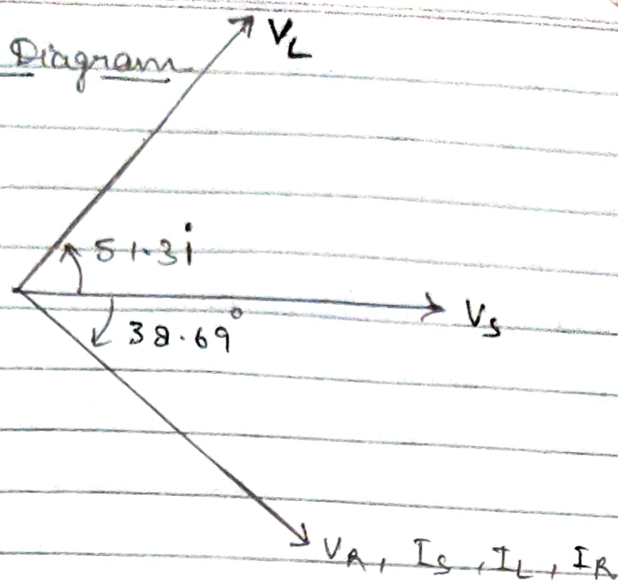
$\overline{I_R} = \overline{I_L} = \overline{I_s} = 49.8 \angle -38.69^\circ\ mA$

$\overline{V_R} = \overline{I_s} \cdot Z_R$
$= 49.8 \angle -38.69^\circ \times 47 \angle 0^\circ\ mV$
$= 2.34 \angle -38.69^\circ\ V$

$\overline{V_L} = \overline{I_s} \cdot Z_L$
$= 49.8 \angle -38.69^\circ \times 37.68 \angle 90^\circ\ mV$
$= 1.877 \angle 51.31^\circ$

Name : Archit Agrawal
Student ID : 2020522307

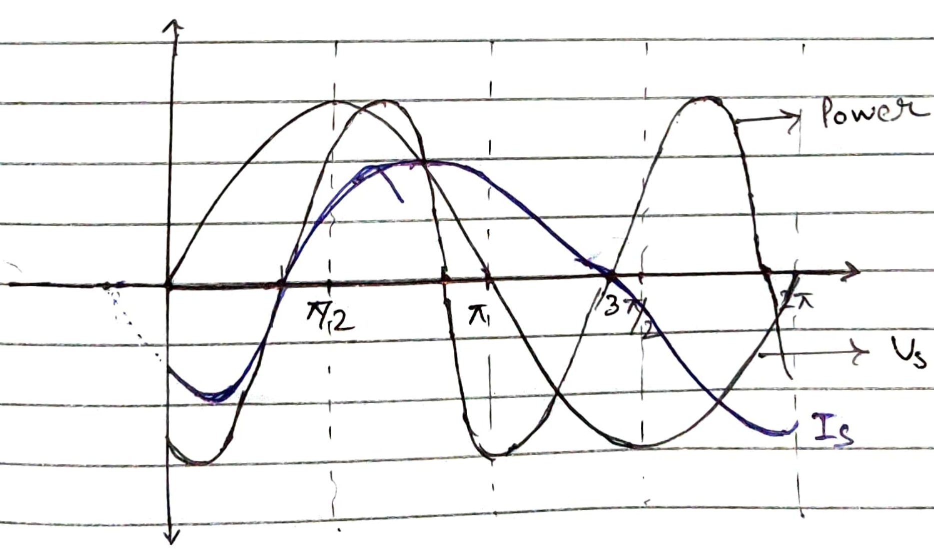
Phasor Diagram



⇒ I_s lags ~~~~ V_s by $38.69°$.
⇒ V_L ~~lag~~ leads V_s by $51.31°$.
⇒ V_R lags V_s by $38.69°$.
⇒ V_R is in phase with I_R.

Time Domain

$$I_s = 49.8\sqrt{2}\ \sin(\omega t - 38.69°)\ mA$$
$$V_R = 2.34\sqrt{2}\ \sin(\omega t - 38.69°)\ V$$
$$V_L = 1.877\sqrt{2}\ \sin(\omega t + 51.31°)\ V$$
$$V_s = 3\sqrt{2}\ \sin(\omega t)\ V$$



Name: Archit Agrawal
Student ID: 202052307

$(I_s)_m = 49.8\sqrt{2}\ mA = 70.42\ mA$

$(V_s)_m = 4.24\ V$

True Power (P) = $I_{rms}^2 R$

$= (49.8)^2 \times 47\ mW$

$= 116.56\ mW$

Reactive Power (Q) = $I_{rms}^2 X_L$

$= (49.8)^2 \times (\cancel{37}.68)$

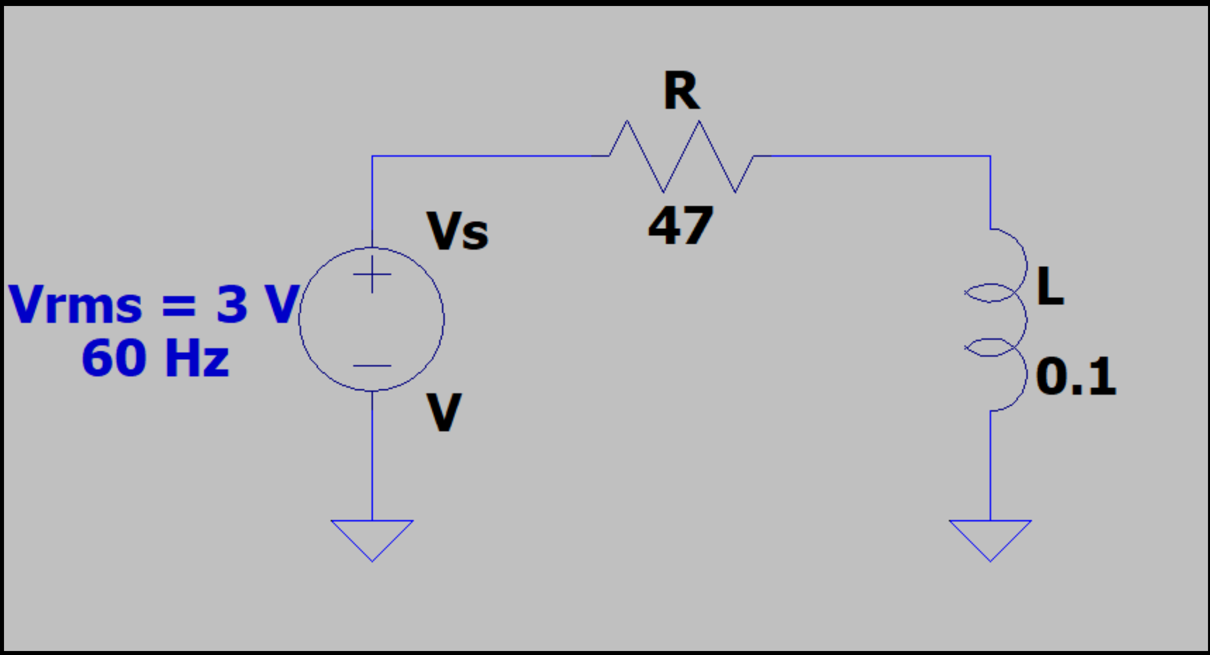
~~= 149.42 mVAR~~

$= 93.45\ mVAR$

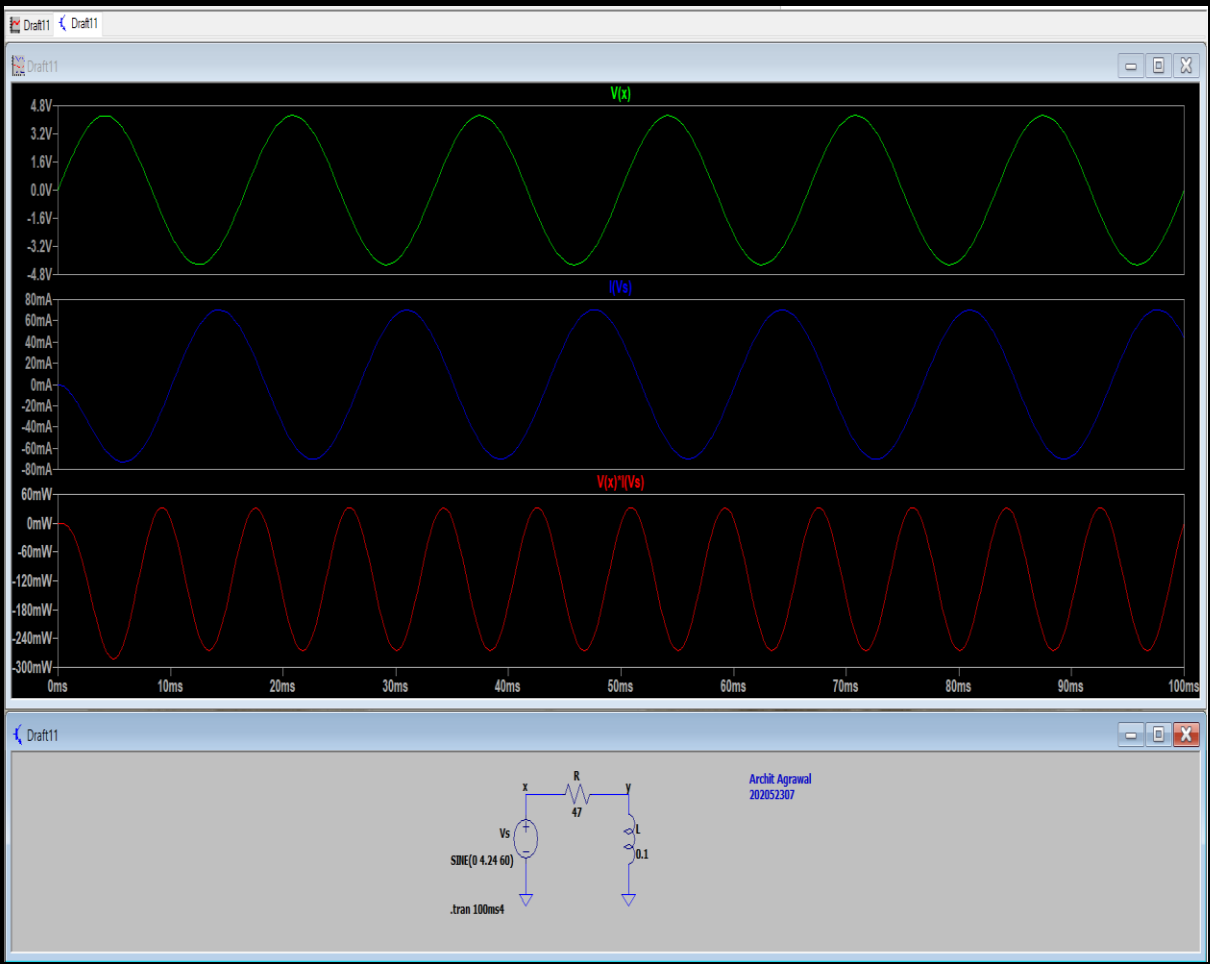
Apparent Power (S) = $I_{rms}^2 Z$

$= 149.4\ mVA$

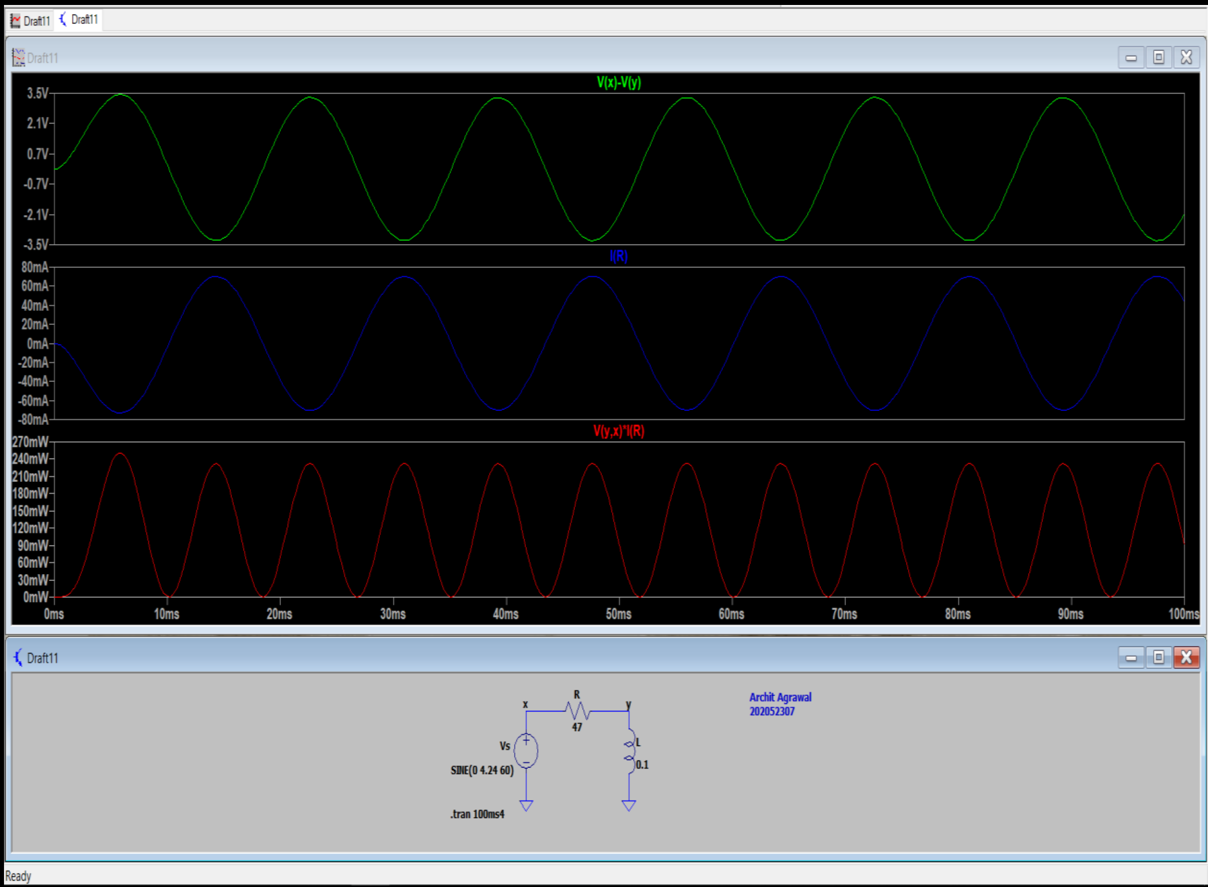
CIRCUIT



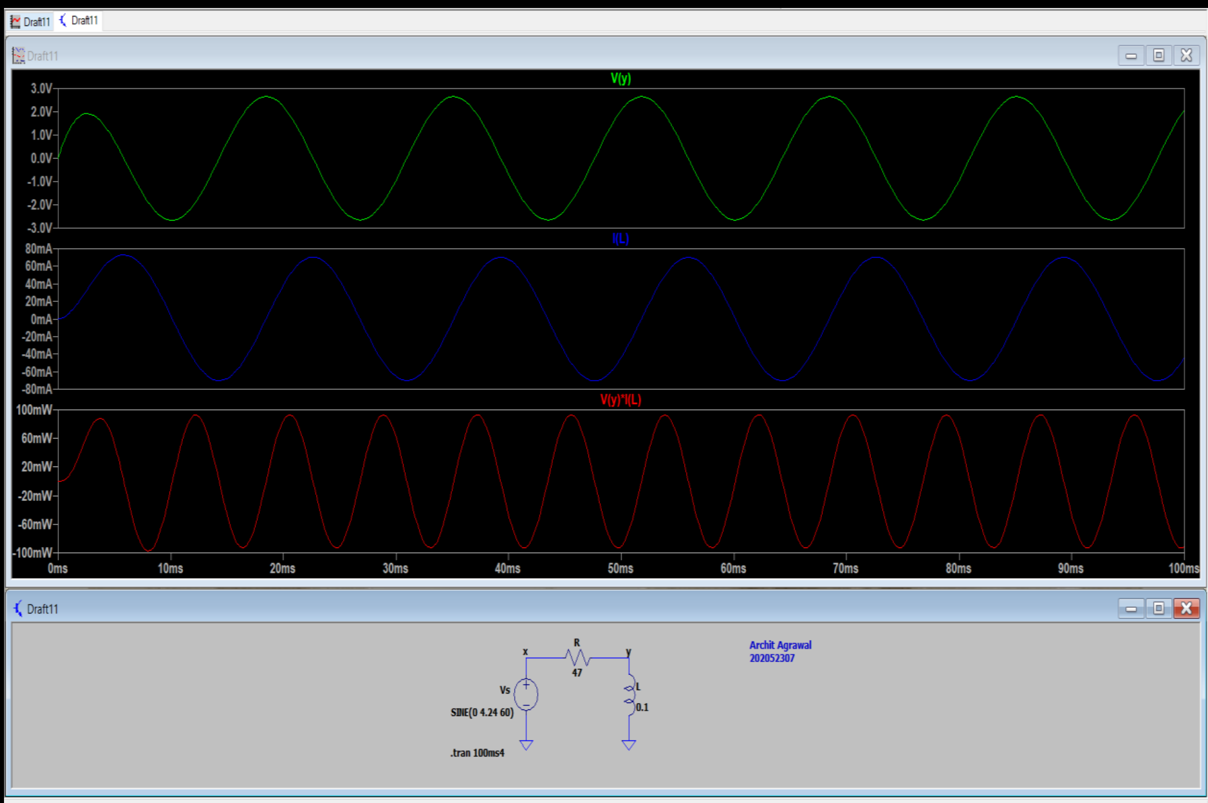
Source Voltage, total current and total power



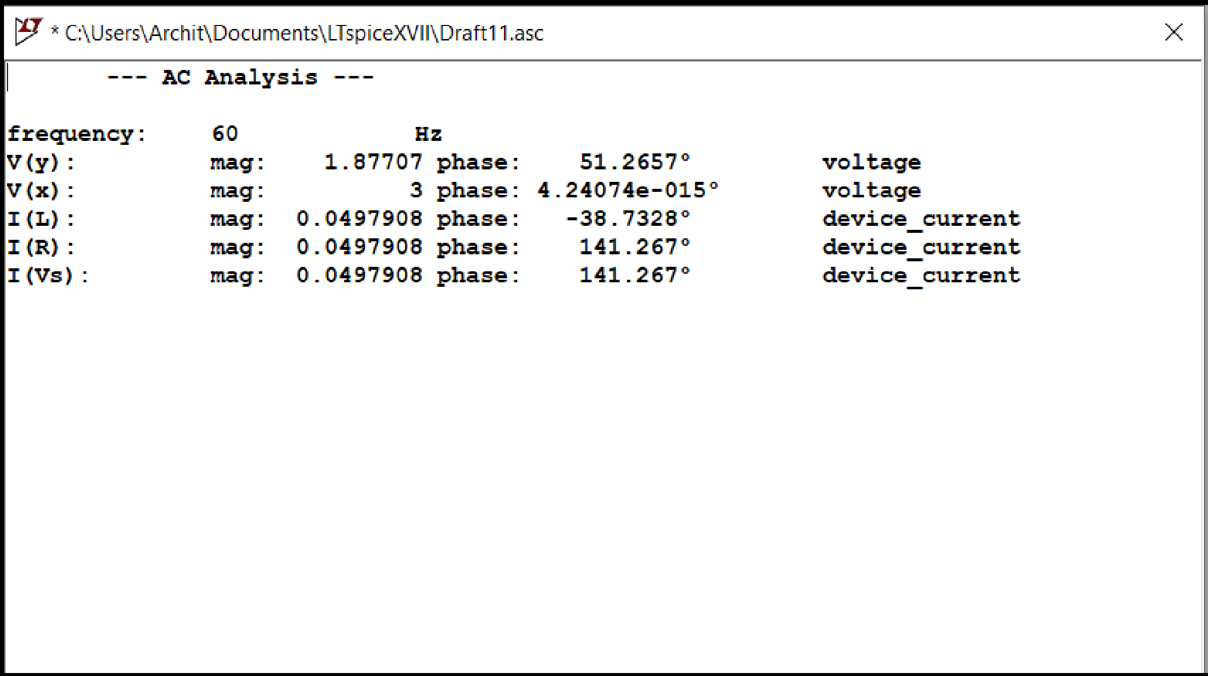
Voltage, Current and Power across Resistor



Voltage, Current and Power across Inductor



AC Analysis



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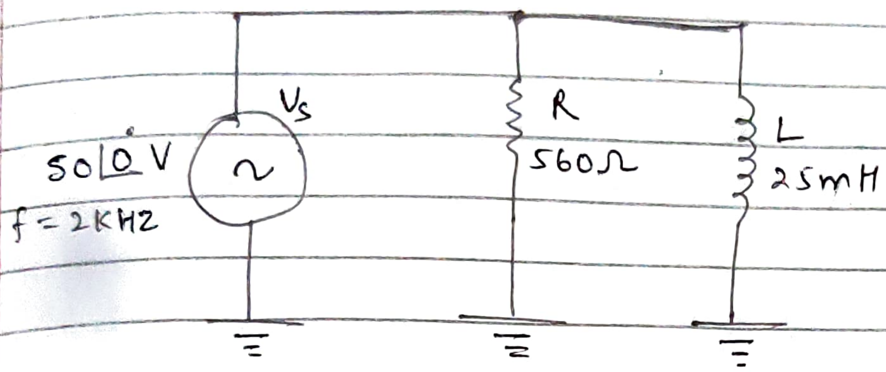
```
       --- AC Analysis ---

frequency:     60             Hz
V(y):          mag:    1.87707 phase:     51.2657°         voltage
V(x):          mag:          3 phase: 4.24074e-015°        voltage
I(L):          mag:  0.0497908 phase:    -38.7328°         device_current
I(R):          mag:  0.0497908 phase:     141.267°         device_current
I(Vs):         mag:  0.0497908 phase:     141.267°         device_current
```

Name : Archit Agrawal
Student ID : 202052307

CIRCUIT 4 :



$$X_L = \omega L = 2\pi(2K)(25m)$$
$$= 314.2\ \Omega$$

$$Z_R = 560\angle 0^\circ\ \Omega = 560 + j(0)\ \Omega$$

$$Z_L = 314.2\angle 90^\circ\ \Omega = 0 + j(314.2)\ \Omega$$

$$Z = Z_R \parallel Z_L$$

$$= \frac{Z_R \cdot Z_L}{Z_R + Z_L} = \frac{560\angle 0^\circ \times 314.2\angle 90^\circ}{560 + j(314.2)}$$

$$Z = \frac{175952\angle 90^\circ}{642.12\angle 29.29^\circ}$$

$$\bar{Z} = 274\angle 60.71^\circ\ \Omega$$

$$\bar{V}_R = \bar{V}_L = \bar{V}_s = 50\angle 0^\circ\ V$$

$$I_s = \frac{\bar{V}_s}{\bar{Z}} = \frac{50\angle 0^\circ}{274\angle 60.71^\circ} = 0.182\angle -60.71^\circ\ A$$

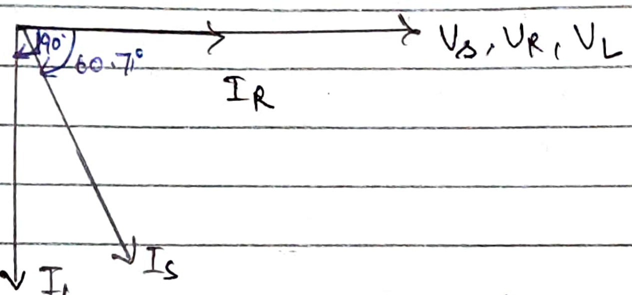
Name: Aachit Agrawal
Student ID: 202052307

$$I_R = \frac{\overline{V_R}}{\overline{Z_R}} = \frac{50\angle 0^\circ}{560\angle 0^\circ} = 0.09\angle 0^\circ \text{ A}$$

$$I_L = \frac{\overline{V_L}}{\overline{Z_L}} = \frac{50\angle 0^\circ}{314.2\angle 90^\circ} = 0.159\angle -90^\circ \text{ A}$$

Phasor Diagram

⇒ I_s lags V_s by 60.71°.
⇒ V_R is in phase with I_R.
⇒ I_L lags V_s by 90°.



$$Z = 134.04 + j(238.9)\ \Omega$$

True power $(P) = I_{rms}^2 Z_R$
$= (0.182)^2 \times 134.04$
$= 4.39$ W

Reactive power $(Q) = I_{rms}^2 Z_{X_L}$
$= (0.182)^2 \times (238.9)$
$= 7.826$ W

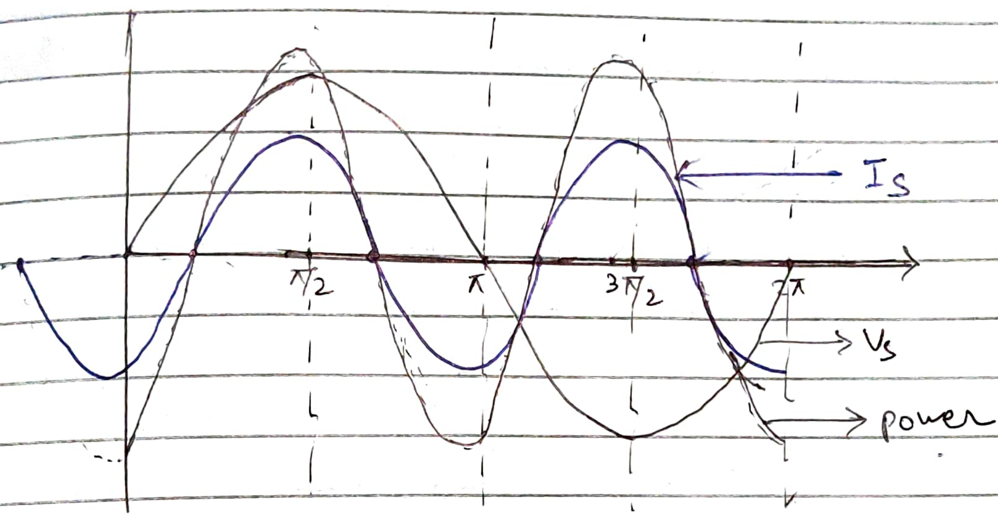
Apparent Power $(S) = I_{rms}^2 Z$
$= (0.182)^2 \times 274$
$= 8.976$ W

Name: Ankit Agrawal
Student ID : 202052307

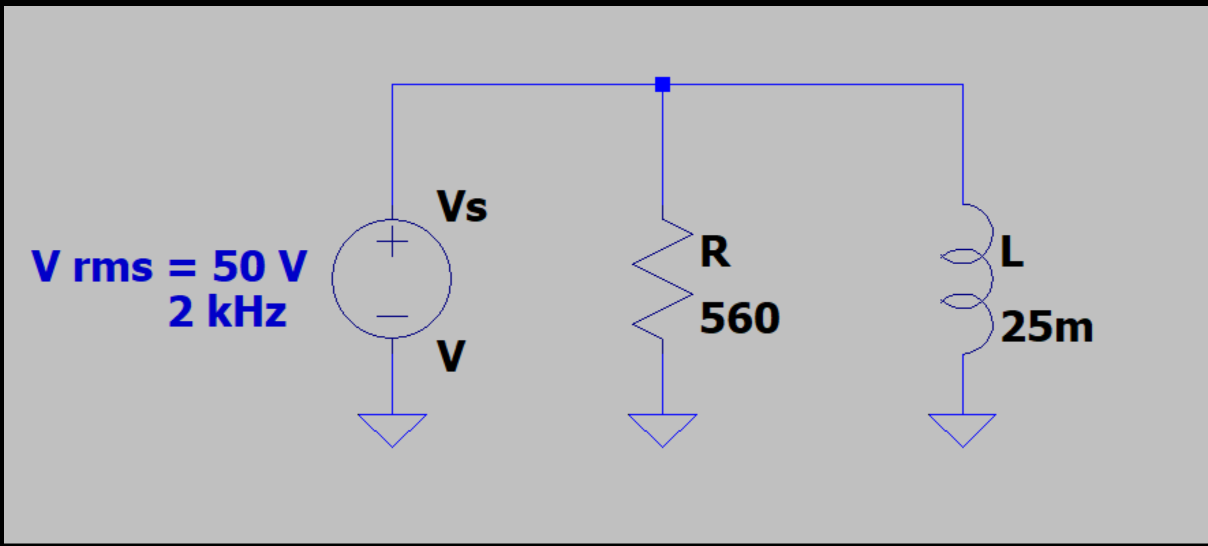
Date:
Page: 11

Time Domain

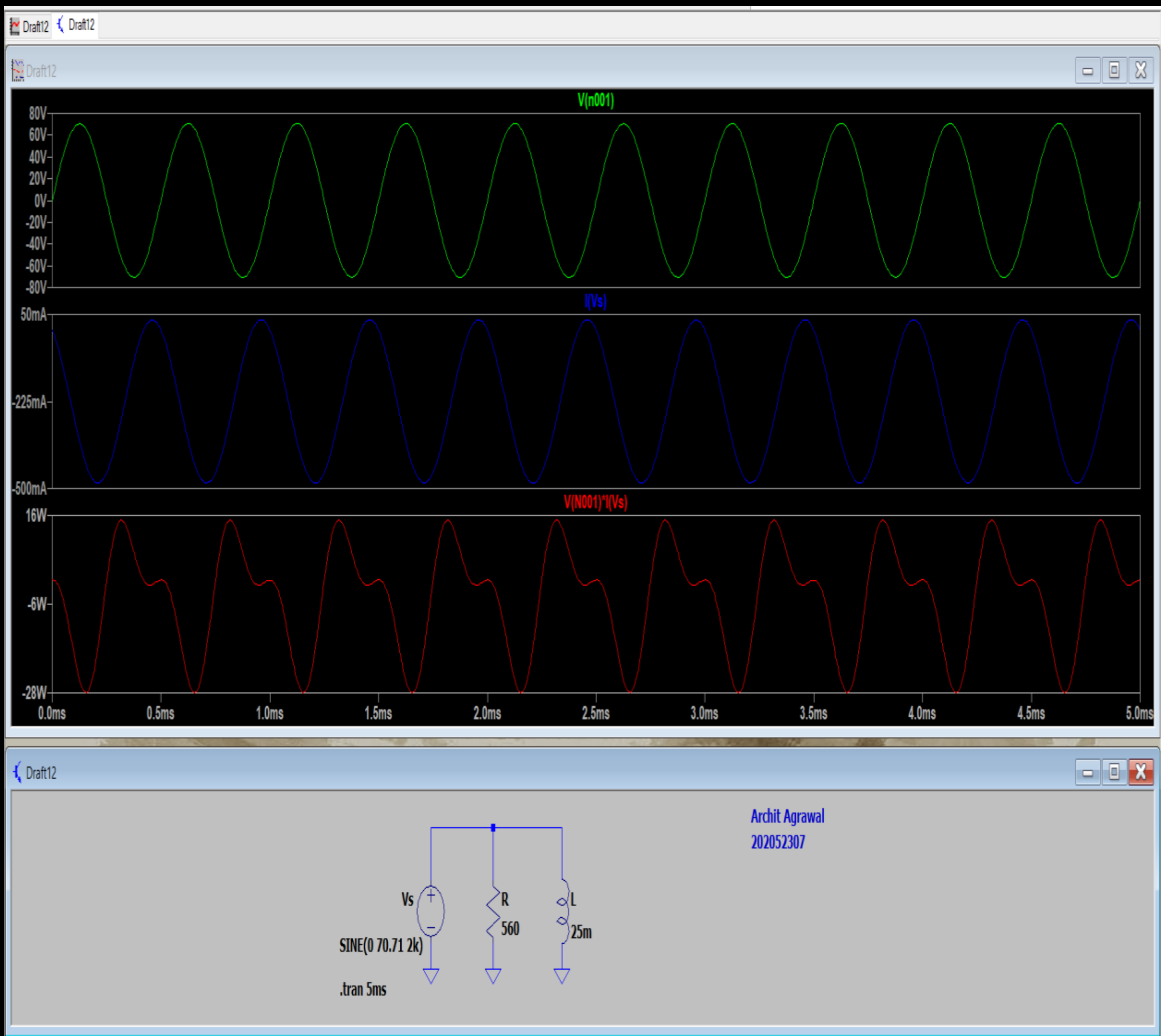
$$V_s = 50\sqrt{2}\sin(\omega t + 0^\circ) \quad V$$
$$I_s = 0.182\sqrt{2}\sin(\omega t - 60.7^\circ) \quad A$$
$$I_R = 0.09\sqrt{2}\sin(\omega t + 0^\circ) \quad A$$
$$I_L = 0.159\sqrt{2}\sin(\omega t - 90^\circ) \quad A$$



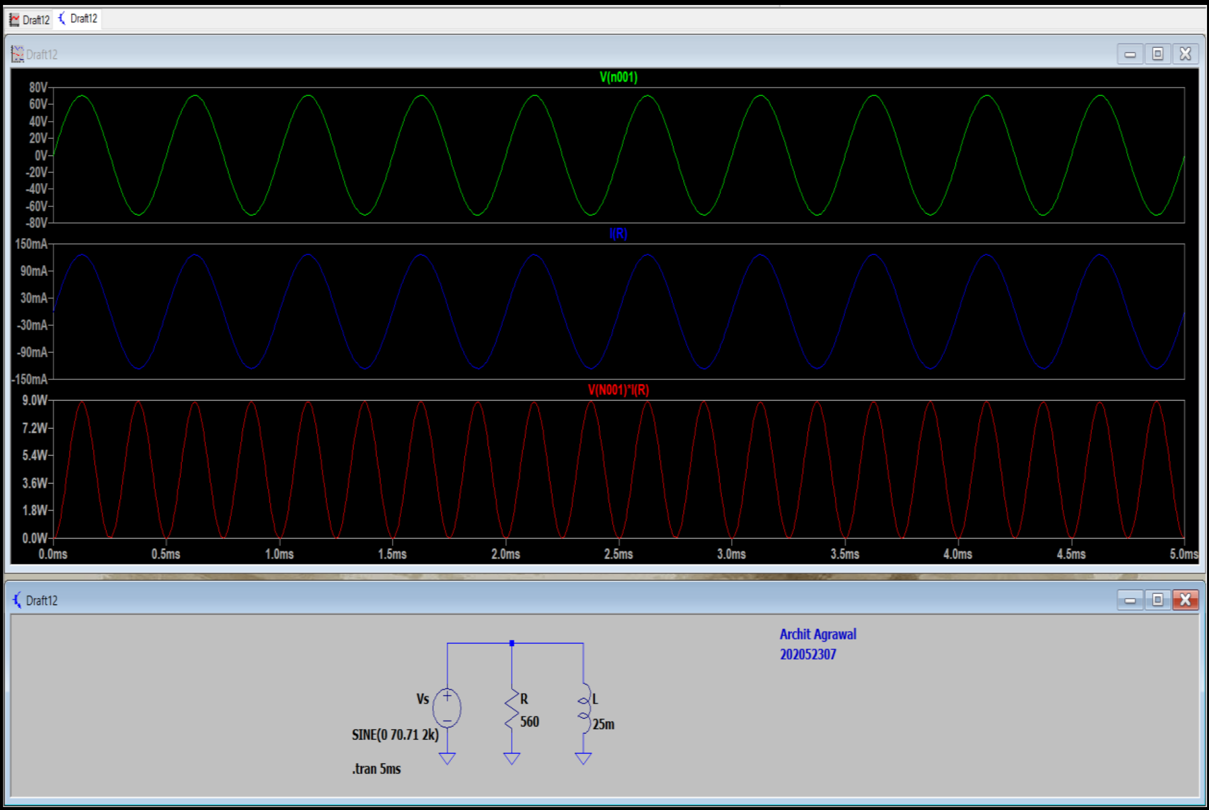
CIRCUIT



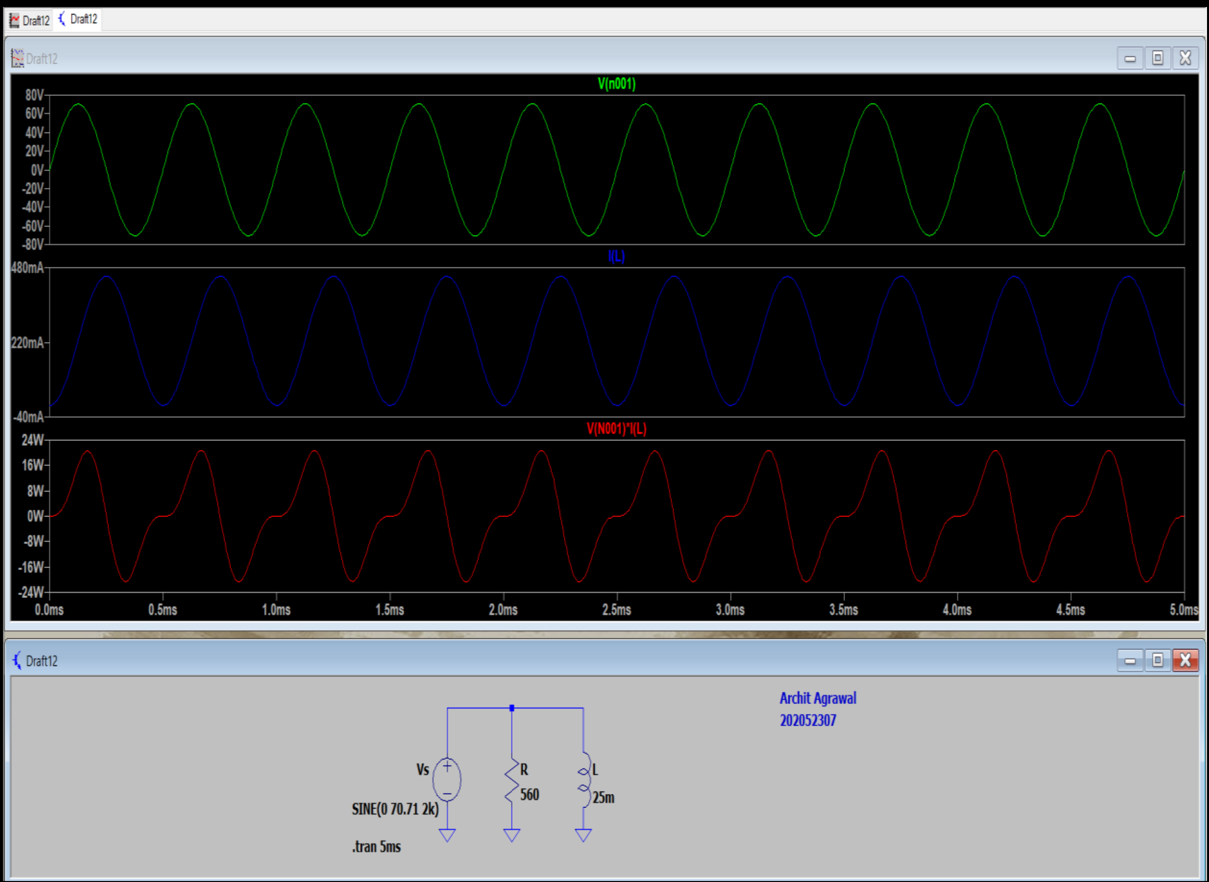
Source Voltage, total current and total power



Voltage, Current and Power across Resistor



Voltage, Current and Power across Inductor



AC Analysis

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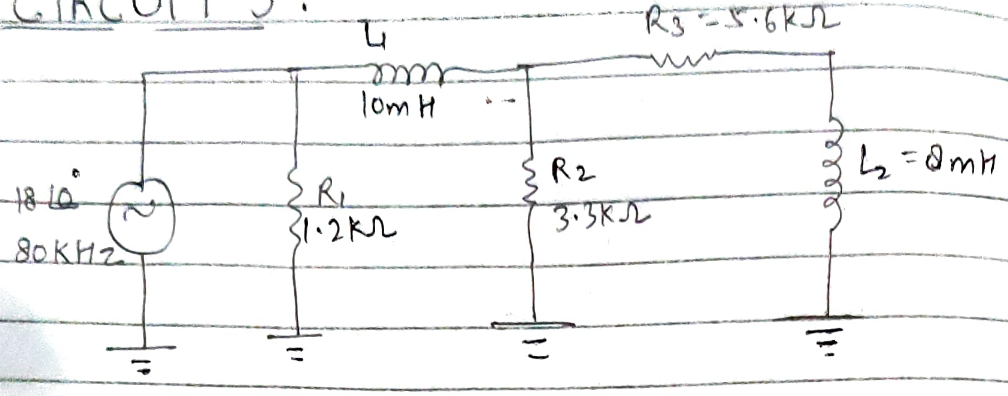
```
       --- AC Analysis ---

frequency:    2000           Hz
V(n001):      mag:         50 phase:           0°         voltage
I(L):         mag:   0.159155 phase:    -89.9998°         device_current
I(R):         mag:  0.0892857 phase:           0°         device_current
I(Vs):        mag:   0.182489 phase:     119.293°         device_current
```

Name: Archit Agrawal
Student ID: 202052307

Date:
Page: 12

CIRCUIT 5:



$$X_{L_1} = \omega L_1 = 2\pi f L_1 = 2\pi (80k)(10m) = 5.026 k\Omega$$

$$X_{L_2} = \omega L_2 = 2\pi(80k)(8m) = 4.021 k\Omega$$

$$Z_1 = Z_{L_2} + Z_{R_3}$$

$$= 5.6K + j(4.021K) \ \Omega$$

$$= 6.894 \angle 35.68° \ k\Omega$$

$$Z_2 = Z_{R_2} \parallel Z_1$$

$$= \frac{Z_{R_2} \cdot Z_1}{Z_1 + Z_{R_2}}$$

$$= \frac{3.3K\angle 0° \times 6.894K\angle 35.68°}{(5.6k + j(4.021K)) + (3.3k)}$$

$$= \frac{22.75 \times 10^6 \angle 35.68°}{9.766 K \angle 24.31°}$$

$$= 2.33K \angle 11.37° \ \Omega$$

$$Z_2 = 2.284K + j(0.46K) \ \Omega$$

Name: Archit Agrawal
Student ID: 202052307

$$Z_3 = Z_2 + Z_{XL_4}$$
$$= 2.284K + j(0.46K) + j(5.026K)$$
$$= 2.284K + j(5.486K)$$
$$= 5.942K \angle 67.4^\circ \ \Omega$$

$$Z = Z_{R_1} \parallel Z_3$$

$$= \frac{Z_{R_1} \cdot Z_3}{Z_{R_1} + Z_3}$$

$$= \frac{1.2K \angle 0^\circ \times 5.942K \angle 67.4^\circ}{2.284K + j(5.486K) + 1.2K}$$

$$= \frac{7.13 \angle 67.4^\circ \times 10^6}{6.5 \angle 57.6^\circ \times 10^3}$$

$$Z = 1.096K \angle 9.8^\circ \ \Omega$$

$$Z = 1.08K + j(0.187K) \ \Omega$$

$$\therefore \bar{I_s} = \frac{\bar{V_s}}{Z} = \frac{18 \angle 0^\circ}{1.096K \angle 9.8^\circ} = 16.42 \angle -9.8^\circ \ mA$$

$$\bar{I_s} = 16.18 - j(2.794) \ mA$$

From the circuit we know, $V_{R_1} = V_s$

$$\therefore \bar{I_{R_1}} = \frac{\bar{V_s}}{\bar{Z_{R_1}}} = \frac{18 \angle 0^\circ}{1.2K \angle 0^\circ} = 15 \angle 0^\circ \ mA$$

Name: Archit Agrawal
Student ID: 202052307

$$\overline{I_{L_1}} = \overline{I_S} - \overline{I_{R_1}}$$

$$= 16.18 - j(2.794) - 15$$
$$= 1.18 - j(2.794) \text{ mA}$$
$$= 3.032 \angle -67.10^\circ \text{ mA}$$

$$\therefore \overline{V_{L_1}} = \overline{I_{L_1}} \times \overline{Z_{L_1}}$$
$$\cancel{= 15.18}$$
$$= 3.032 \angle -67.10^\circ \text{ mA} \times 5.026\text{K} \angle 90^\circ$$
$$= 15.18 \angle 22.6^\circ \text{ V}$$

$$V_{L_1} = 14.01 + j(5.83) \text{ V}$$

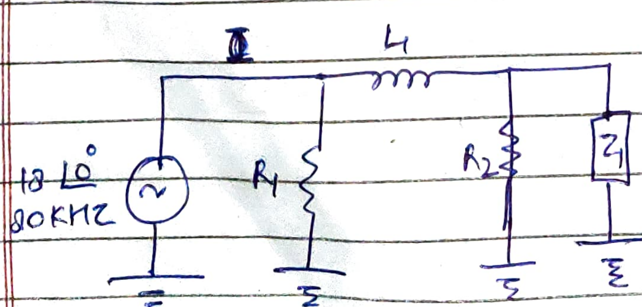
$$\overline{V_{R_2}} = \overline{V_S} - \overline{V_{L_1}}$$

$$V_{R_2} = 18 - (14.01 + j(5.83))$$
$$= 3.99 - j(5.83) \text{ V}$$

$$\overline{V_{R2}} = 7.07 \angle -55.6^\circ \text{ V}$$

$$\overline{I_{R2}} = \frac{\overline{V_{R2}}}{Z_{R2}} = \frac{7.07 \angle -55.6^\circ}{3.3\text{K} \angle 0^\circ}$$

$$\overline{I_{R2}} = 2.142 \angle -55.6^\circ \text{ mA}$$



Name: Archit Agrawal
Student ID: 202052307

Date:
Page: 15

$$\bar{I}_{Z_1} = \frac{\bar{V}_{Z_1}}{Z_1} = \frac{7.07 \angle -55.6^\circ}{6.894K \angle 35.68^\circ} \qquad (\because \bar{V}_{Z_1} = \bar{V}_S - \bar{V}_{L_1})$$

$$\bar{I}_{Z_1} = 1.025 \angle -91.28^\circ \text{ mA}$$

$$\bar{I}_{R_3} = \bar{I}_{L_2} = \bar{I}_{Z_1} = 1.025 \angle -91.28^\circ \text{ mA}$$

$$\bar{V}_{R_3} = \bar{I}_{R_3} \times Z_{R_3}$$

$$= 1.025 \angle -91.28^\circ \text{ mA} \times 5.6K \angle 0^\circ$$

$$\bar{V}_{R_3} = 5.734 \angle -91.28^\circ \text{ V}$$

and, $\bar{V}_{L_2} = \bar{I}_{L_2} \times Z_{X_{L_2}}$

$$= 1.025 \angle -91.28^\circ \text{ mA} \times 4.021K \angle 90^\circ$$

$$= 4.117 \angle -1.25^\circ \text{ V}$$

The values calculated are

$\bar{V}_S = 18 \angle 0^\circ$ V

$\bar{I}_S = 16.42 \angle -9.8^\circ$ mA

$\bar{V}_{R_1} = V_S = 18 \angle 0^\circ$ V

$\bar{I}_{R_1} = 15 \angle 0^\circ$ mA

$\bar{V}_{L_1} = 15.18 \angle 22.6^\circ$ V

$\bar{I}_{L_1} = 3.032 \angle -67.10^\circ$ mA

$\bar{V}_{R_2} = 7.07 \angle -55.6^\circ$ V

$\bar{I}_{R_2} = 2.142 \angle -55.6^\circ$ mA

Name: Archit Agrawal
Student ID: 202052307

Page: 16

$\overline{V_{R_3}} = 5.734 \angle -91.28^\circ$ V
$\overline{I_{R_3}} = 1.025 \angle -91.28$ mA

$\overline{V_{L_2}} = 4.117 \angle -1.25^\circ$ V
$\overline{I_{L_2}} = 1.025 \angle -91.28$ mA

Now,
$V_s = 18 \angle 0^\circ$ V
$I_s = 16.42 \angle -9.8^\circ$ mA

phase difference (ϕ) $= 9.8^\circ$
∴ power factor ($\cos\phi$) $= \cos(9.8^\circ) = 0.985$

Apparent Power (S) $= I_{rms} \cdot V_{rms}$
$= 16.42 \times 18$
$= 0.295$ W

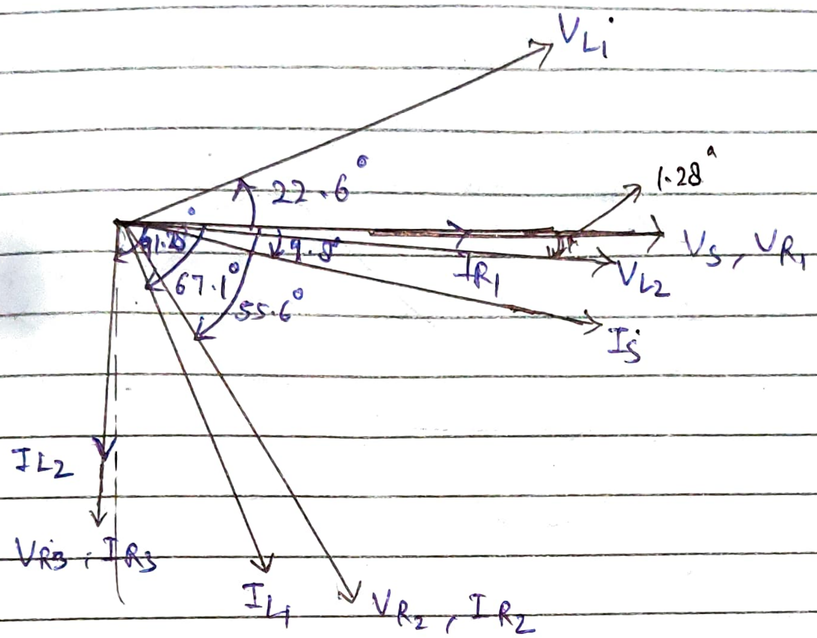
True Power (P) $= S \times \cos\phi$
$= 0.295 \times 0.985$
$= 0.291$ W

Reactive power (Q) $= S \times \sin\phi$
$= 0.295 \times \sin(9.8)$
$= 0.0503$ W

Name: Arihit Agrawal
Student ID: 2020052307

Page: 17

Phasor Diagram



Time Domain

$V_s = 18\sqrt{2}\sin(\omega t)$ V
$I_s = 16.42\sqrt{2}\sin(\omega t - 9.8^\circ)$ mA

$V_{R_1} = 18\sqrt{2}\sin(\omega t)$ V
$I_{R_1} = 15\sqrt{2}\sin(\omega t)$ mA

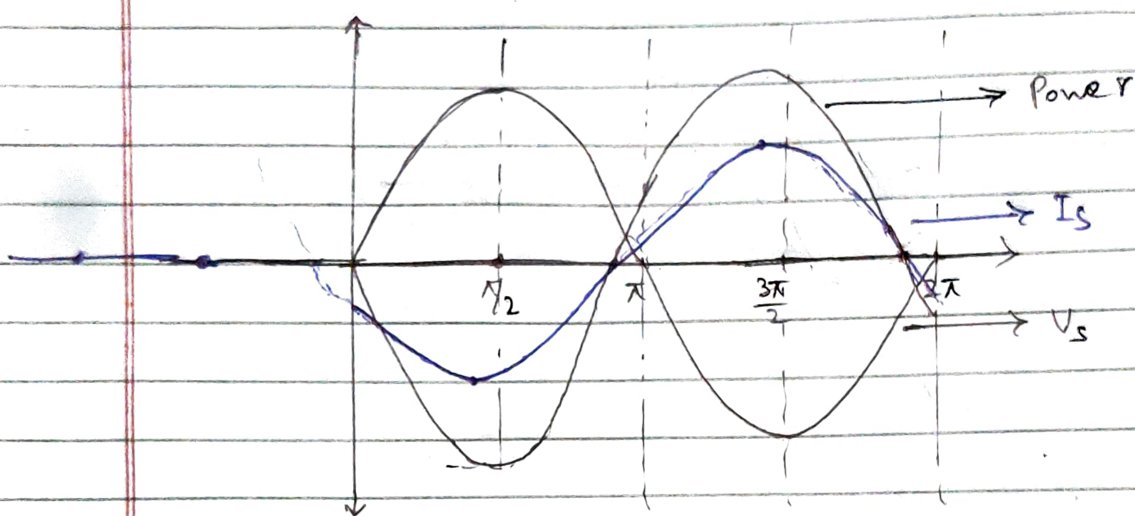
$V_{R_2} = 7.07\sqrt{2}\sin(\omega t - 55.6^\circ)$ V
$I_{R_2} = 2.142\sqrt{2}\sin(\omega t - 55.6^\circ)$ V

$V_{R_3} = 5.734\sqrt{2}\sin(\omega t - 91.28^\circ)$ V
$I_{R_3} = 1.025\sqrt{2}\sin(\omega t - 91.28^\circ)$ mA

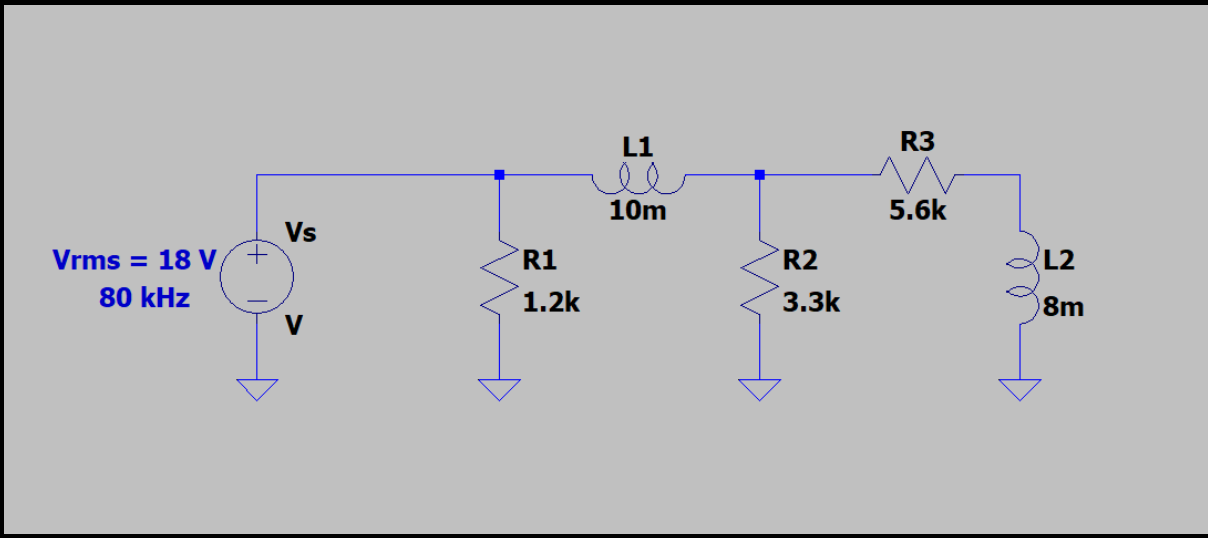
Name: Archit Agrawal
Student ID: 202051307

$V_{L_1} = 15.18\sqrt{2}\ \sin(\omega t + 22.6^\circ)\ V$
$I_{L_1} = 3.032\sqrt{2}\ \sin(\omega t - 67.4^\circ)\ mA$

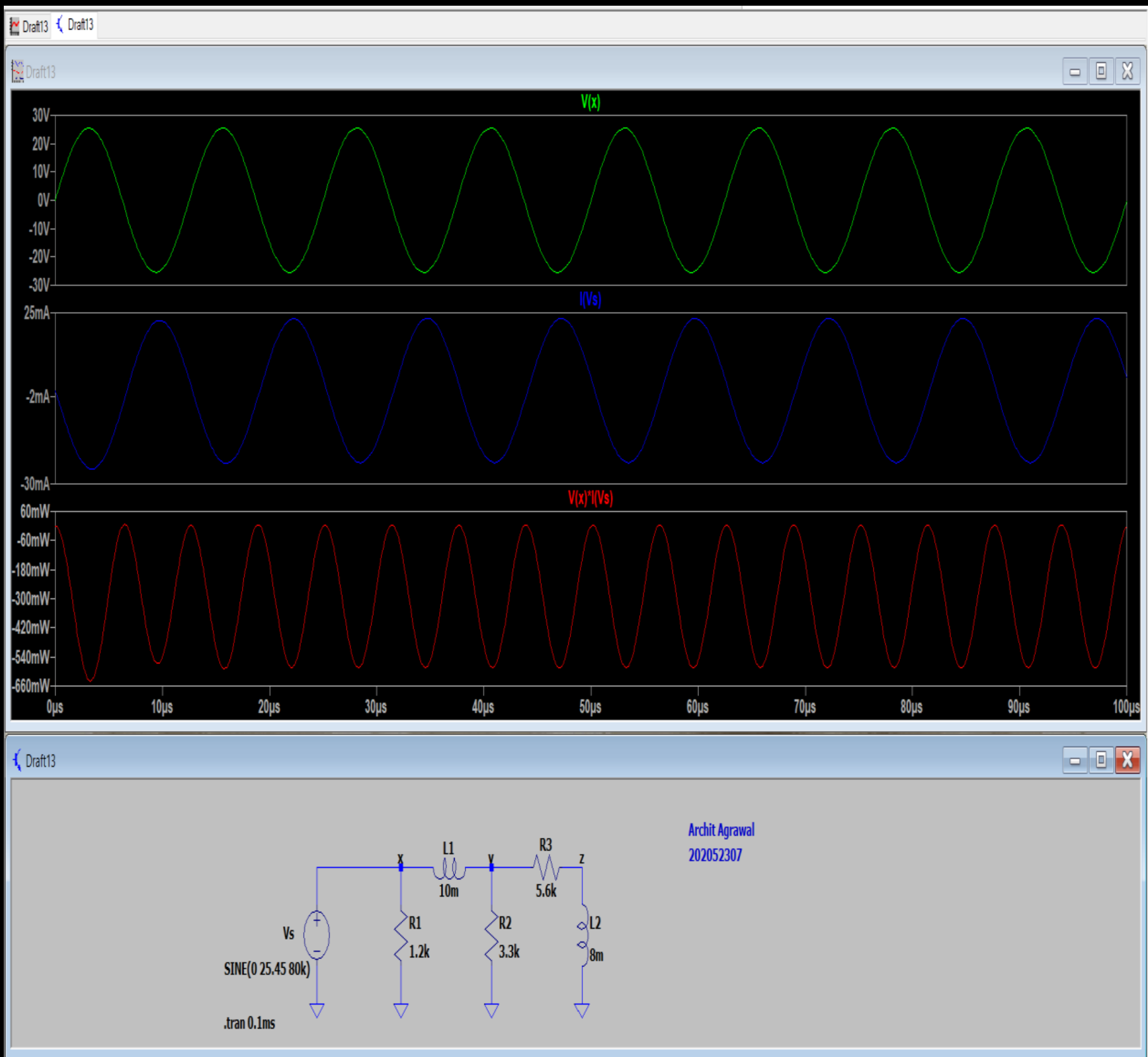
$V_{L_2} = 4.117\sqrt{2}\ \sin(\omega t - 1.25^\circ)\ V$
$I_{L_2} = 1.025\sqrt{2}\ \sin(\omega t - 91.25^\circ)\ mA$



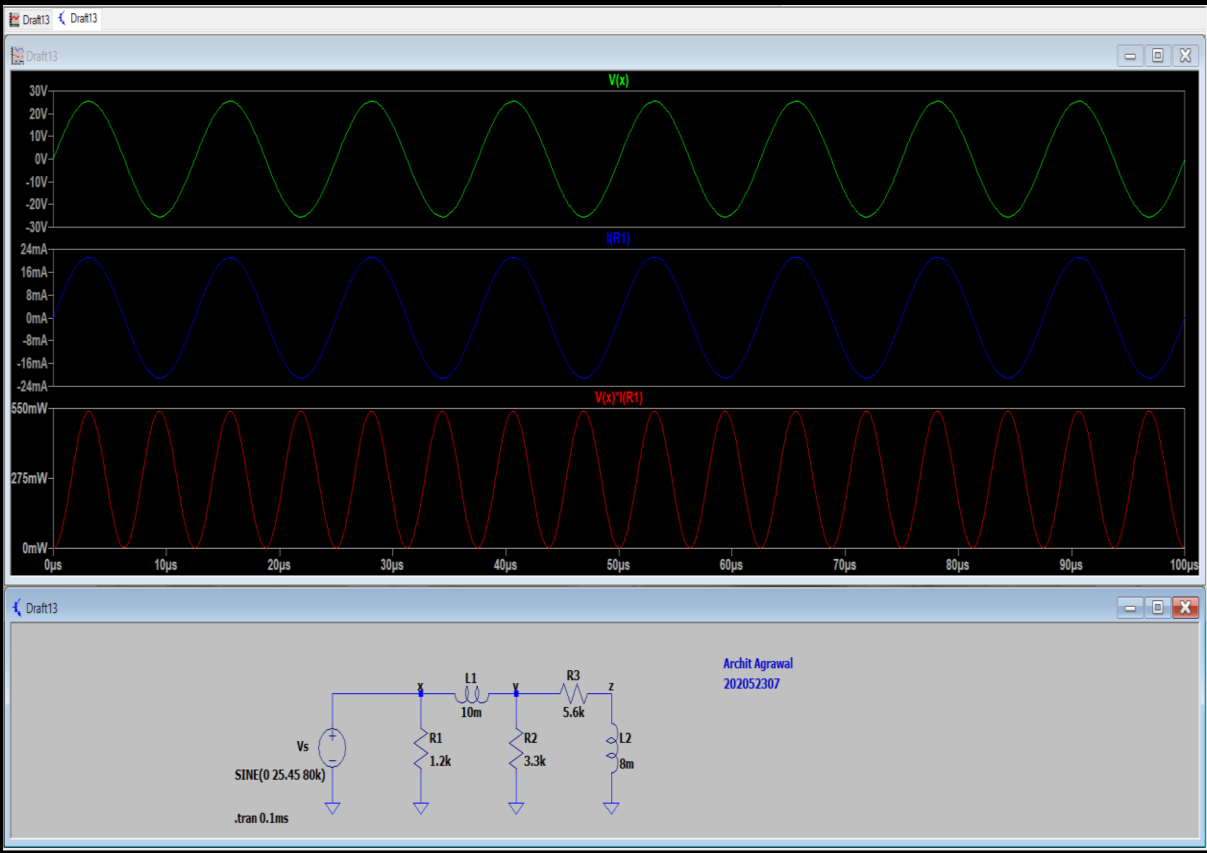
CIRCUIT



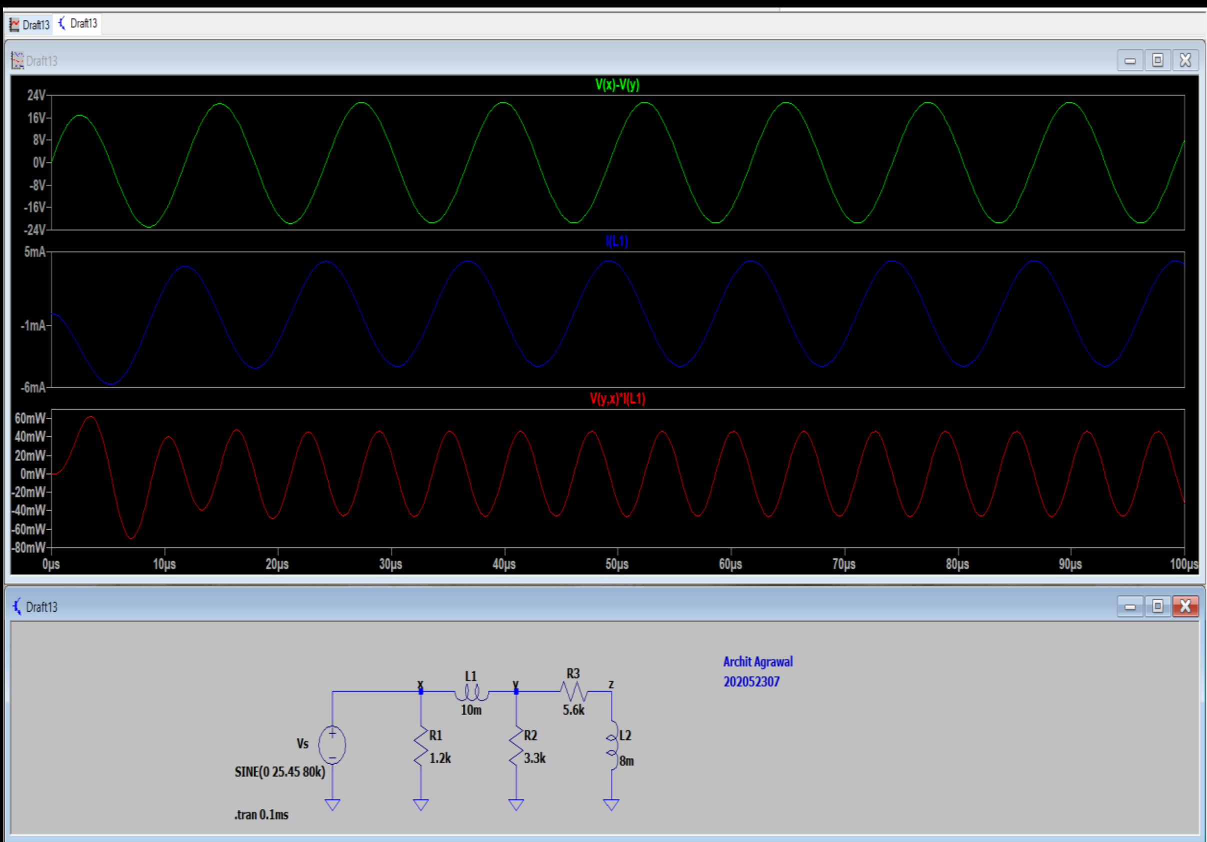
Source Voltage, total current and total power



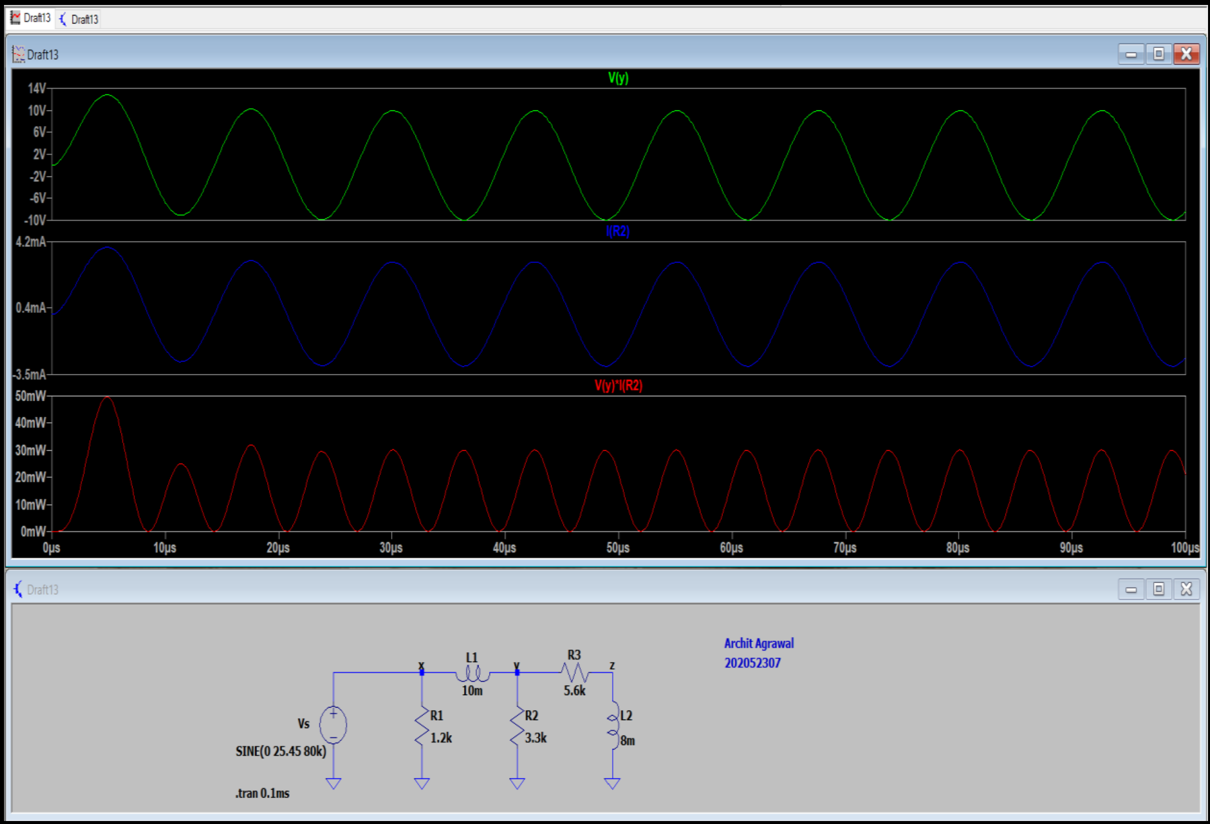
Voltage, Current and Power across Resistance R_1



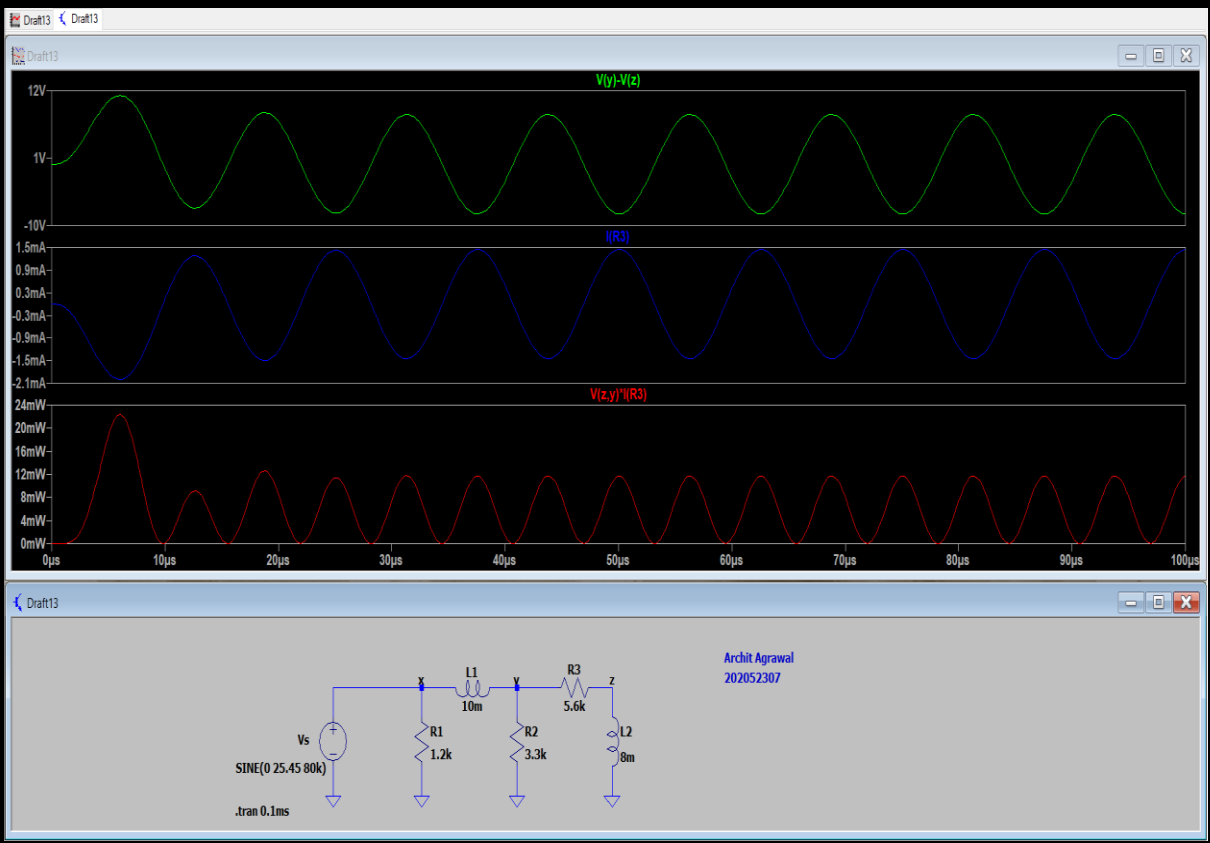
Voltage, Current and Power across Inductance L_1



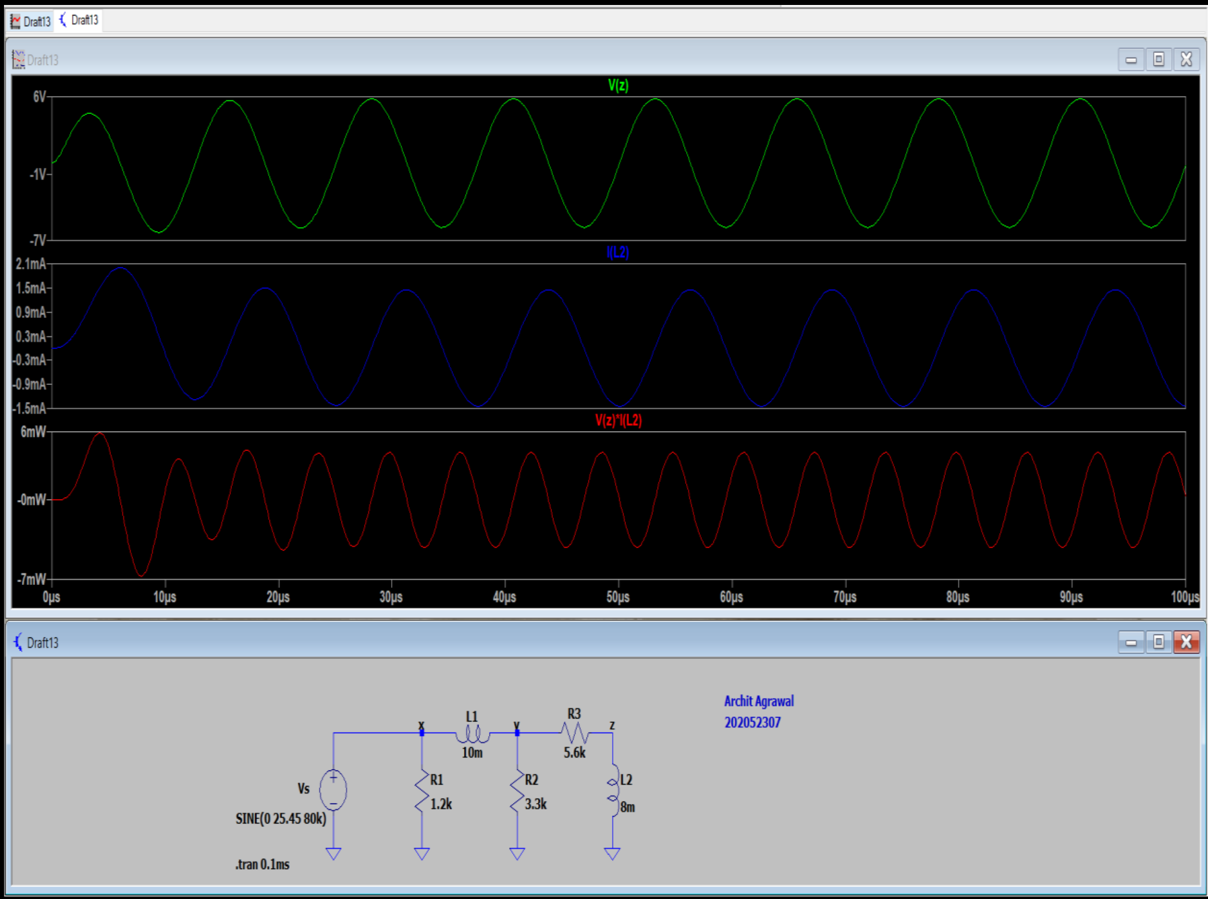
Voltage, Current and Power across Resistance R_2



Voltage, Current and Power across Resistance R_3



Voltage, Current and Power across Inductance L_2



AC Analysis

* C:\Users\Archit\Documents\LTspiceXVII\Draft13.asc

```
       --- AC Analysis ---

frequency:     80000          Hz
V(z):          mag:     4.11601 phase:    -1.71121°        voltage
V(x):          mag:          18 phase: 1.41358e-015°       voltage
V(y):          mag:     7.05672 phase:    -56.0299°        voltage
I(L1):         mag: 0.00302923 phase:     112.603°         device_current
I(L2):         mag: 0.00102357 phase:    -91.7112°         device_current
I(R3):         mag: 0.00102357 phase:     88.2888°         device_current
I(R2):         mag:  0.0021384 phase:    -56.0299°         device_current
I(R1):         mag:       0.015 phase: 1.41358e-015°       device_current
I(Vs):         mag:  0.0164044 phase:     170.185°         device_current
```

Name: Archit Agrawal
Student ID: 202052307

Date:
Page: 19

Observations and Conclusions

Performing the experiment we have drawn following conclusions :-

(i) the current through a resistor is in phase of the voltage across it.
(ii) the current through an inductor lags by the voltage across it by 90°.
(iii) the current through an capacitor leads by the voltage across it by 90°.

(iv) the phase angle is equal to the difference between phase of source voltage and total current.

(v) A resistor is a power-dissipating device while an inductor and capacitor only stores and release energy in an AC circuit.