National Institute Of Technology Durgapur

ELECTRICAL MEASUREMENT LABORATORY

Group V

Experiment 1

MEASUREMENT OF POWER IN SINGLE-PHASE CIRCUIT BY THREE-VOLTMETER METHOD AND THREE-AMMETER METHOD

2nd June, 2021

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Experiment No: 1

Measurement Of Power in Single-Phase Circuit by Three-Voltmeter Method and Three-Ammeter Method

Objective:

- To measure the single-phase power in a single-phase A.C. circuit by using three voltmeters.
- To measure the single-phase power in a single-phase A.C. circuit by using three ammeters.

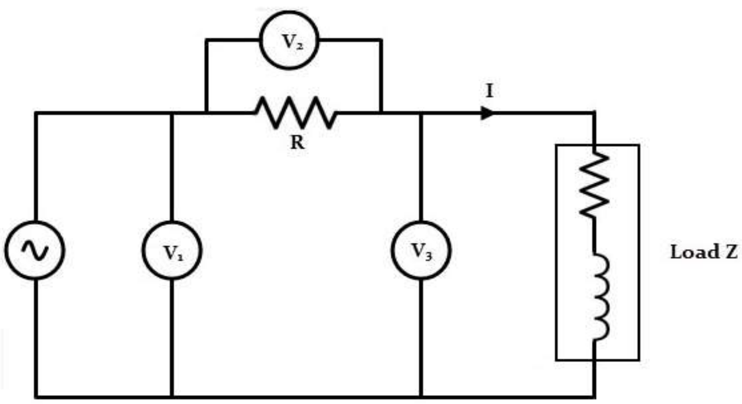
Apparatus Required:

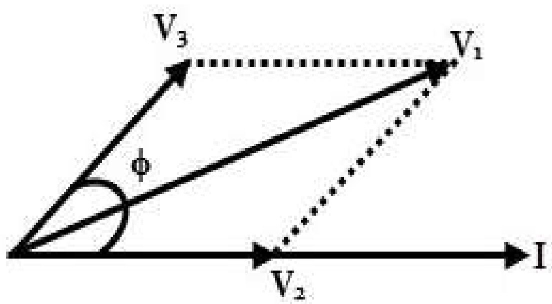
It consists of following instruments:

Sl. No.	Instrument Name	Specification	Quantity
1.	AC Voltage Supply	20V rms, 50 Hz	1
2.	Ammeter	0 - 35 A (AC)	3
3.	Voltmeter	0 - 50 V (AC)	3
4.	Resistors	1.7Ω, 1.8Ω, 1.9Ω, 2.0Ω	4
5.	RL load	R = 1 Ω, L = 3 mH	1
6.	Connecting Wires	-	-

Theory:

Power measurement in Single phase A.C. circuit by using three voltmeters:





From the phasor diagram,

$$\boxed{V_1^2 = V_2^2 + V_3^2 + 2V_2V_3\cos\varphi} \longrightarrow (1)$$

But,

$$\boxed{V_2 = IR}$$

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Therefore,

$$\boxed{V_1^2 = V_2^2 + V_3^2 + 2(IR)V_3 \cos\varphi} \Longrightarrow (2)$$

Now, power consumed by load $\Rightarrow \boxed{P = V_3 I \cos\varphi}$

Therefore, equation (2) gives,

$$V_1^2 = V_2^2 + V_3^2 + 2PR$$

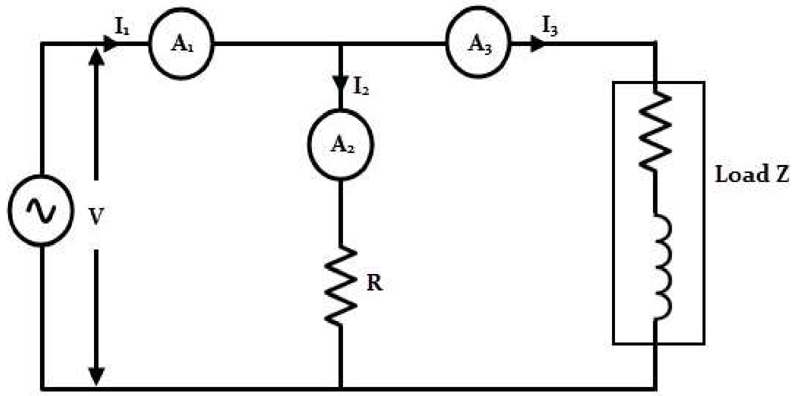
$$\Rightarrow \boxed{P = \frac{V_1^2 - V_2^2 - V_3^2}{2R}} \Longrightarrow (3)$$

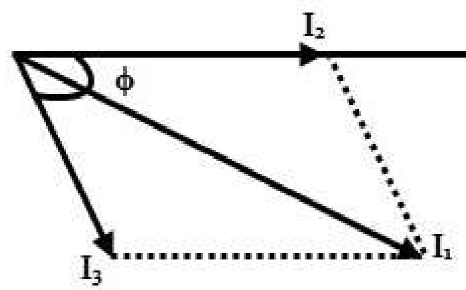
Now, simplifying equation (1),

$$\boxed{\cos\varphi = \frac{V_1^2 - V_2^2 - V_3^2}{2V_2V_3}} \Longrightarrow (4)$$

From equations (3) and (4), it can be observed that the power and power factor in an A.C. circuit can be measured by using three single-phase voltmeters, instead of a wattmeter.

Power measurement in Single phase A.C. circuit by using three ammeters:





From the phasor diagram,

$$\boxed{I_1^2 = I_2^2 + I_3^2 + 2I_2I_3 \cos\varphi} \Longrightarrow (1)$$

But,

$$\boxed{I_2 = \frac{V}{R}}$$

Therefore,

$$\boxed{I_1^2 = I_2^2 + I_3^2 + 2\left(\frac{V}{R}\right) I_3 \cos\varphi} \Longrightarrow (2)$$

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Now, power across load, $\boxed{P = VI_3 \cos\varphi}$

Therefore, equation (2) gives,

$$\boxed{I_1^2 = I_2^2 + I_3^2 + 2\left(\frac{P}{R}\right)}$$

$$\boxed{P = \left(\frac{I_1^2 - I_2^2 - I_3^2}{2}\right)R} \Longrightarrow (3)$$

Now, simplifying equation (1),

$$\boxed{\cos\varphi = \frac{I_1^2 - I_2^2 - I_3^2}{2I_2I_3}} \Longrightarrow (4)$$

From equations (3) and (4), it can be observed that the power and power factor in an A.C. circuit can be measured by using three single-phase ammeters, instead of a wattmeter.

Schematic Circuit Diagram:

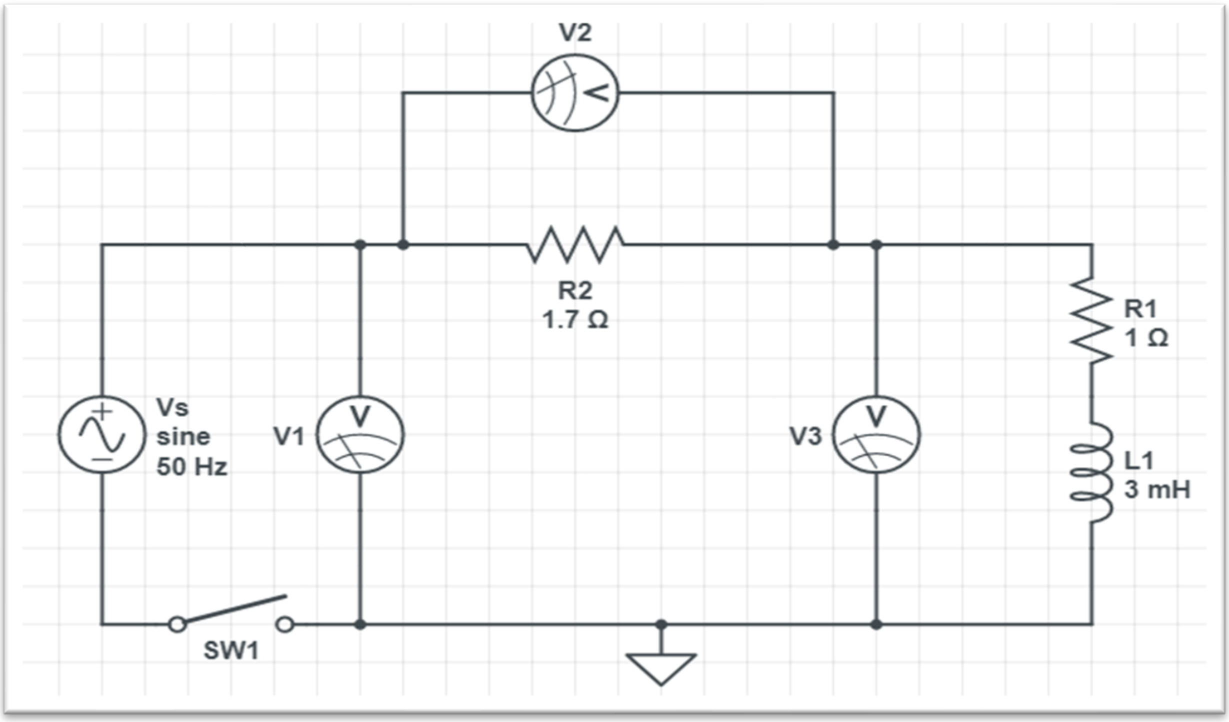

Figure 1 : Circuit Diagram for Three Voltmeter Method when R = 1.7 Ω

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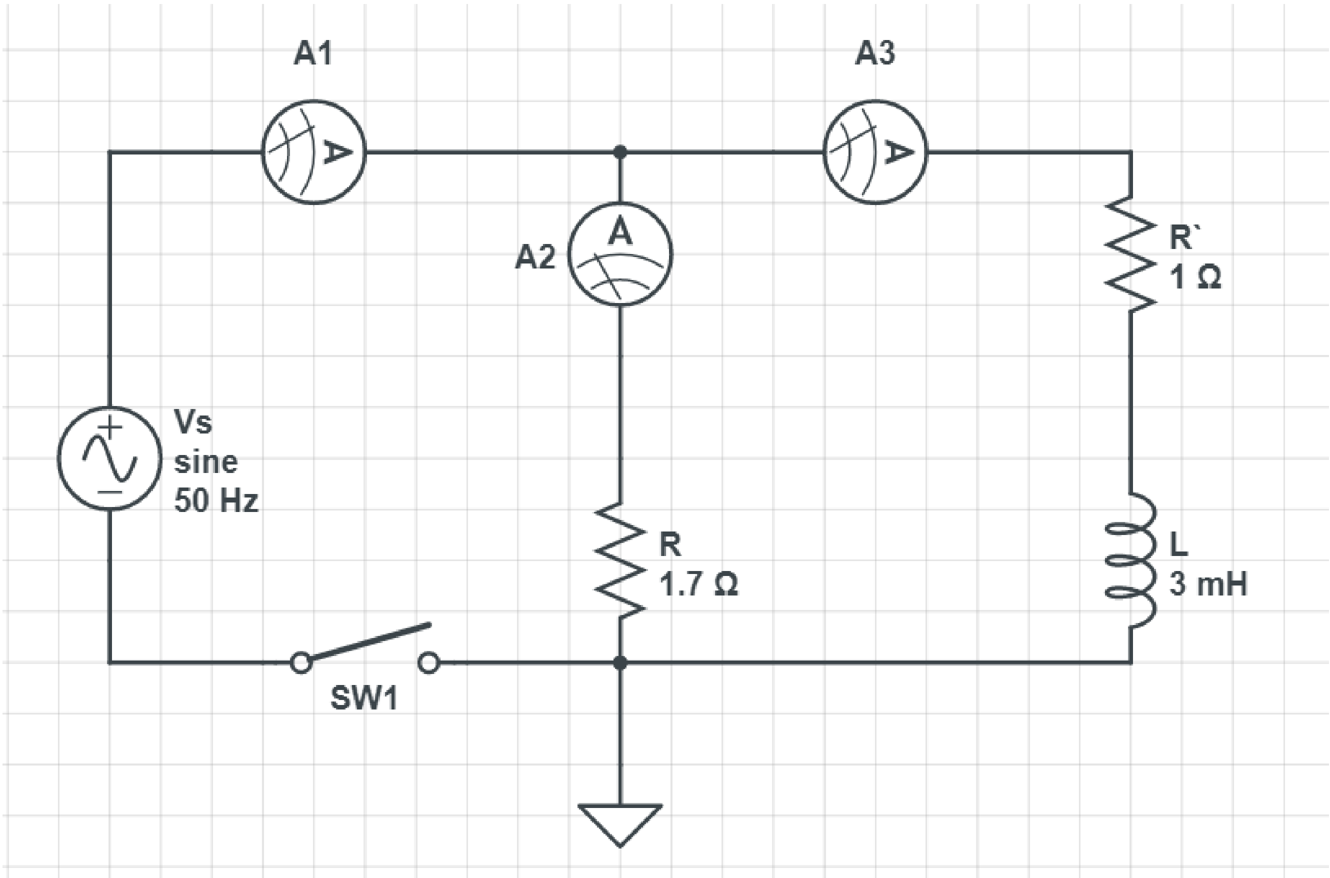

Figure 2: Circuit Diagram for Three Ammeter Method when R = 1.7 Ω

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Experimental Results:

Table 1: Three-Voltmeter Method

<table>
<tr><th rowspan="2">Sl. No.</th><th rowspan="2">R (ohm)</th><th rowspan="2">V1 (Volt)</th><th rowspan="2">V2 (Volt)</th><th rowspan="2">V3 (Volt)</th><th rowspan="2">Power (Watt)</th><th rowspan="2">Power factor(pf)</th><th colspan="2">Mean</th></tr>
<tr><th>Power</th><th>Power Factor(pf)</th></tr>
<tr><td>1.</td><td>1.7</td><td>20</td><td>11.8690</td><td>9.6097</td><td>48.9133</td><td>0.7277</td><td rowspan="4">Mean P = 44.5551 W</td><td rowspan="4">Mean pf = 0.7278</td></tr>
<tr><td>2.</td><td>1.8</td><td>20</td><td>12.1853</td><td>9.3020</td><td>45.8309</td><td>0.7278</td></tr>
<tr><td>3.</td><td>1.9</td><td>20</td><td>12.4618</td><td>9.0124</td><td>43.0211</td><td>0.7278</td></tr>
<tr><td>4.</td><td>2.0</td><td>20</td><td>12.7202</td><td>8.7393</td><td>40.4553</td><td>0.7278</td></tr>
</table>

Table 2: Three-Ammeter Method

<table>
<tr><th rowspan="2">Sl. No</th><th rowspan="2">R (ohm)</th><th rowspan="2">I_1 (A)</th><th rowspan="2">I_2 (A)</th><th rowspan="2">I_3 (A)</th><th rowspan="2">Power (Watt)</th><th rowspan="2">Power factor(pf)</th><th colspan="2">Mean</th></tr>
<tr><th>Power</th><th>Power Factor(pf)</th></tr>
<tr><td>1.</td><td>1.7</td><td>24.4845</td><td>11.7647</td><td>14.5551</td><td>211.8468</td><td>0.7277</td><td rowspan="4">Mean P = 211.8448 W</td><td rowspan="4">Mean pf = 0.7277</td></tr>
<tr><td>2.</td><td>1.8</td><td>23.8891</td><td>11.1110</td><td>14.5551</td><td>211.8454</td><td>0.7278</td></tr>
<tr><td>3.</td><td>1.9</td><td>23.3591</td><td>10.5263</td><td>14.5551</td><td>211.8493</td><td>0.7277</td></tr>
<tr><td>4.</td><td>2.0</td><td>20.5925</td><td>10.0000</td><td>14.5551</td><td>211.8448</td><td>0.7277</td></tr>
</table>

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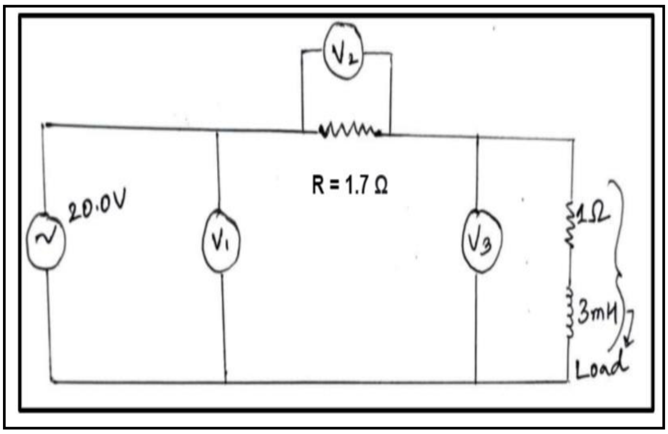
Calculations:

Three-Voltmeter Method:

For R = 1.7 Ω



Here, $V_1 = 20V\angle 0°$

So, Load = 1 + j [2π*50*0.003]

⇨ Load = 1 + j (0.9424)

Z = (1+1.7) + j (0.9424)

⇨ Z = 2.7+0.9424i

⇨ $Z = 2.8597\angle 19.24°$

According to KVL,

$V_1 = I_{total}\,[R + \text{Load}]$

So, I_{total} = 20/(2.7+0.9424i)

⇨ I_{total} =(6.6029-2.3046j) A

$V_2 = I_{total} * R$

= (6.6029 – 2.3046j) * 1.7

So, V_2 = 11.2249 – 3.9178j V

or, $V_2 = 11.8890\angle -19.24°$ V

$V_3 = I_{total}$ * Load

= (6.6029 – 2.3046j) * (1+0.9424j)

V_3 = (8.7747 + 3.9179j) V

or, $V_3 = 9.6097\angle 24.06°$ V

So, Power $P = (V_1^2 - V_2^2 - V_3^2)/2R$

⇨ P = (166.3053) / (2*1.7) W

⇨ P = 48.9133 W

$\cos \Phi = (V_1^2 - V_2^2 - V_3^2) / 2(V_2 * V_3)$

⇨ cos Φ = 166.3053 / (2*11.8890*9.6097)

⇨ cos Φ = 0.7277

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For $R = 1.8\ \Omega$

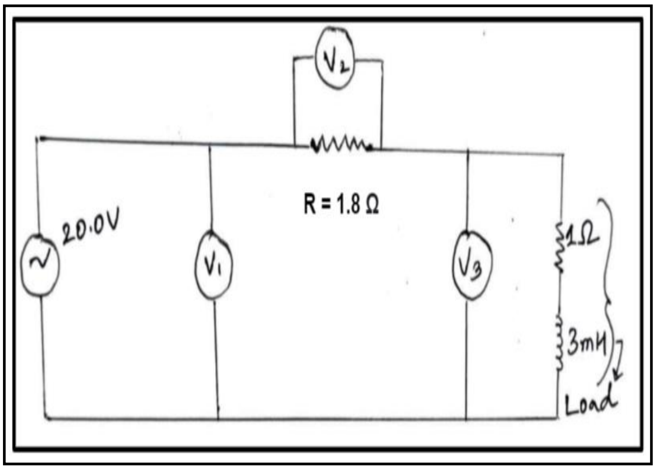
Here, $\underline{V_1 = 20V\angle 0°}$

So, Load = 1 + j [2π*50*0.003]

- ⇨ Load = 1 + j (0.9424)

Z = (1+1.8) + j (0.9424)

- ⇨ Z = 2.8+0.9424i



According to KVL,

$V_1 = I_{total}\ [R + Load]$

So, I_{total} = 20/(2.8+0.9424i)

- ⇨ I_{total} =(6.4160-2.1594j) A

$V_2 = I_{total} * R$

= (6.4160-2.1594j) * 1.8

So, V_2 = 11. 5488 – 3.8869j V

or, $\underline{V_2 = 12.1853\angle -18.60°\ V}$

$V_3 = I_{total}$ * Load

= (6.4160-2.1594j) * (1+0.9424j)

V_3 = (8.4510 + 3.8870j) V

or, $\underline{V_3 = 9.3020\angle 24.69°\ V}$

So, Power $P = (V_1^2 - V_2^2 - V_3^2)/2R$

- ⇨ P = (164.9912) / (2*1.8) W
- ⇨ $\underline{P = 45.8309\ W}$

$\cos\Phi = (V_1^2 - V_2^2 - V_3^2) / 2(V_2 * V_3)$

- ⇨ cos Φ = 164.9912 / (2*12.1853*9.3020)
- ⇨ $\underline{\cos\Phi = 0.7278}$

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For R = 1.9 Ω

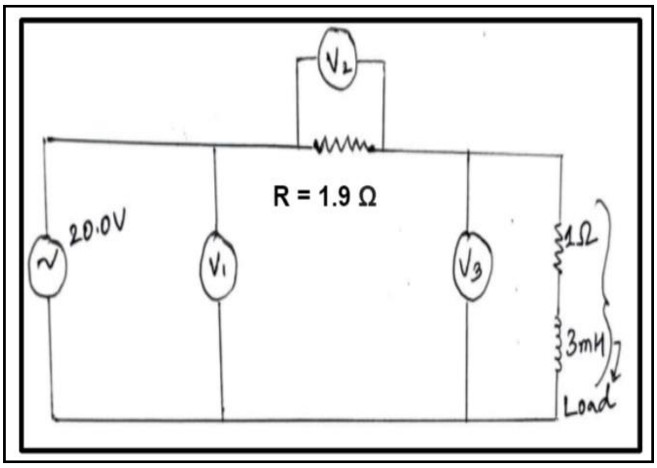
Here, $V_1 = 20V\angle 0°$

So, Load = 1 + j [2π*50*0.003]

- ⇨ Load = 1 + j (0.9424)

Z = (1+1.9) + j (0.9424)

- ⇨ Z = 2.9+0.9424i



According to KVL,

$V_1 = I_{total}\,[R + \text{Load}]$

So, $I_{total} = 20\angle 0°/(2.9+0.9424i)$

- ⇨ I_{total} =(6.2378-2.0270j) A

$V_2 = I_{total}$ * R

= (6.2378-2.0270j) * 1.9

So, V_2 = 11.8518 – 3.8513j V

or, $V_2 = 12.4618\angle -18.00°$ V

$V_3 = I_{total}$ * Load

= (6.2378-2.0270j) * (1+0.9424j)

V_3 = (8.1480 + 3.8515j) V

or, $V_3 = 9.0124\angle 24.29°$ V

So, Power $P = (V_1^2 - V_2^2 - V_3^2) / 2R$

- ⇨ P = (163.4801) / (2*1.9) W
- ⇨ P = 43.0211W

$\cos \Phi = (V_1^2 - V_2^2 - V_3^2) / 2(V_2 * V_3)$

- ⇨ cos Φ = 163.4801 / (2*12.4618*9.0124)
- ⇨ cos Φ = 0.7278

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$\boxed{\text{For } R = 2.0\ \Omega}$

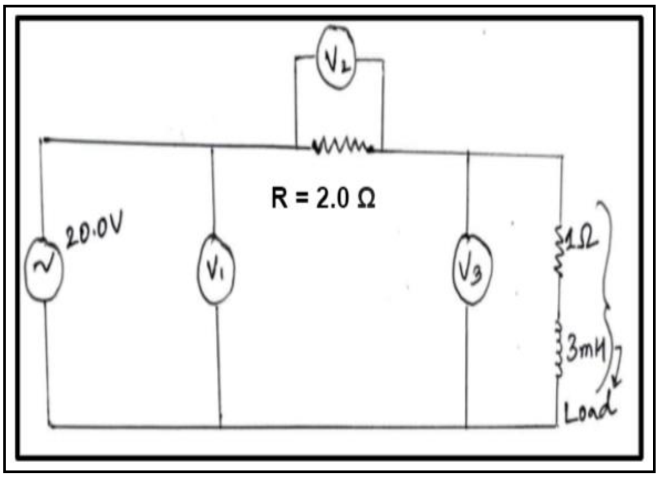
Here, $\underline{V_1 = 20V\angle 0°}$

So, Load = 1 + j [2π*50*0.003]

- ⇨ Load = 1 + j (0.9424)

Z = (1+2.0) + j (0.9424)

- ⇨ Z = 3.0+0.9424i



According to KVL,

$V_1 = I_{total}\,[R + \text{Load}]$

So, $I_{total} = 20\angle 0°/(3.0+0.9424i)$

- ⇨ I_{total} =(6.0678-1.9061j) A

$V_2 = I_{total} * R$

= (6.0678 -1.9061j) * 2.0

So, V_2 = 12.1356 – 3.8122j V

or, $\underline{V_2 = 12.7202\angle -17.4392°\ V}$

$V_3 = I_{total}$ * Load

= (6.0678-1.9061j) * (1+0.9424j)

V_3 = (7.8641 + 3.8121j) V

or, $\underline{V_3 = 8.7393\angle 25.86°\ V}$

So, Power $P = (V_1^2 - V_2^2 - V_3^2)/2R$

- ⇨ P = (161.8211) / (2*2.0) W
- ⇨ $\underline{P = 40.4553\ W}$

$\cos\Phi = (V_1^2 - V_2^2 - V_3^2) / 2(V_2 * V_3)$

- ⇨ cos Φ = 161.8211 / (2*12.7202*8.7393)
- ⇨ $\underline{\cos\Phi = 0.7278}$

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Three-Ammeter Method:

For R = 1.7 Ω

$I_2 = 20/1.7$ A

$I_2 = 11.7647\angle 0°$

$I_3 = 20/(1+jwL)$

$= 20 / (1+j\,(2\pi*50*0.003))$

$I_3 = (10.5925 - 9.8924j)$ A

$|I_3| = 14.5551\angle -43.30°$

According to KCL,

$I_1 = I_2 + I_3$

⇨ $I_1 = (22.3572 - 9.9824j)$ A

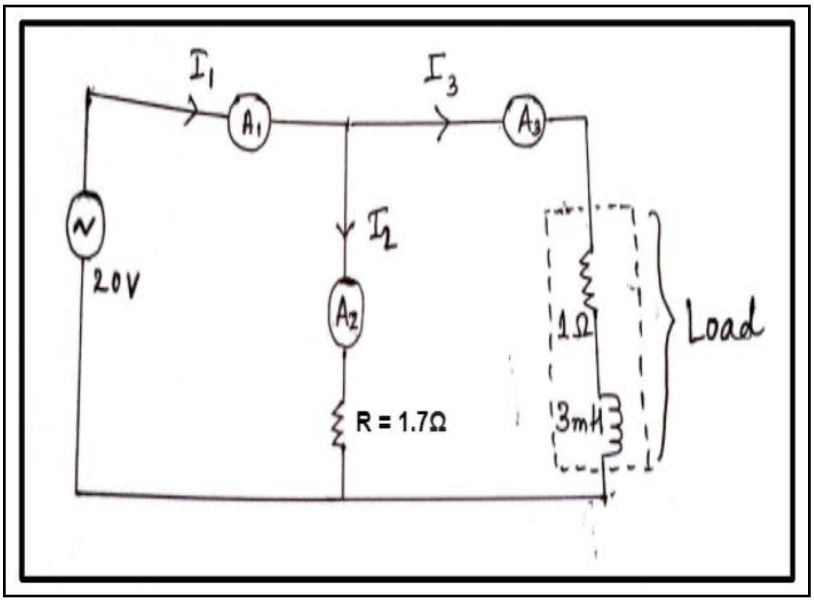
So, $I_1 = 24.4845\angle -24.06°$ A

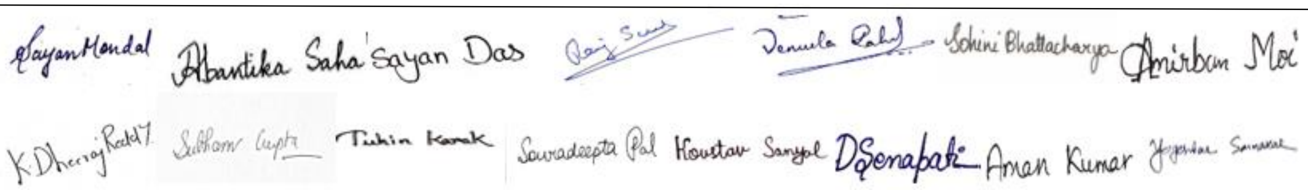
Therefore, Power, $P = (I_1{}^2 - I_2{}^2 - I_3{}^2)\,R/2$

⇨ $P = 211.8468W$

$\cos\Phi = (I_1{}^2 - I_2{}^2 - I_3{}^2)/2(I_2*I_3)$

⇨ $\cos\Phi = 0.7277$





For R = 1.8 Ω

$I_2 = 20/1.8$ A

$\underline{I_2 = 11.111\angle 0° \text{ A}}$

$I_3 = 20/(1+jwL)$

$= 20 / (1+j\,(2\pi*50*0.003))$

$I_3 = (10.5925 – 9.8924j)$ A

$\underline{|I_3| = 14.5551\angle -43.30°}$

According to KCL,

$I_1 = I_2 + I_3$

⇨ $I_1 = (21.7035 – 9.9824j)$ A

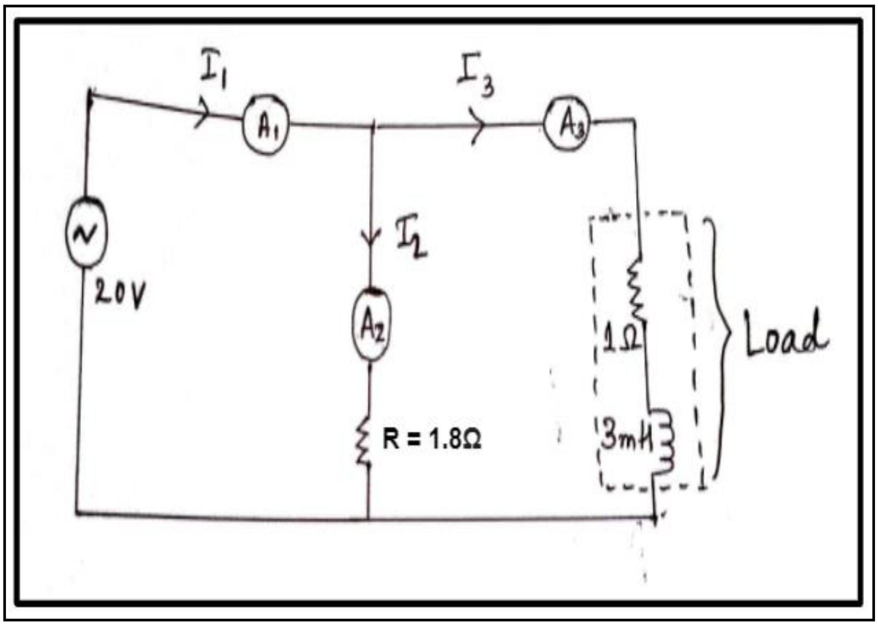
So, $\underline{I_1 = 23.8891\angle -24.6997° \text{ A}}$

Therefore, Power, $P = (I_1{}^2 - I_2{}^2 - I_3{}^2)\, R/2$

⇨ $\underline{P = 211.8454W}$

$\cos \Phi = (I_1{}^2 - I_2{}^2 - I_3{}^2)/2(I_2*I_3)$

⇨ $\underline{\cos \Phi = 0.7278}$



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$\boxed{\text{For } R = 1.9\ \Omega}$

$I_2 = 20/1.9$ A

$\underline{I_2 = 10.5263\angle 0° \text{ A}}$

$I_3 = 20/(1+jwL)$

$= 20 / (1+j\,(2\pi*50*0.003))$

$I_3 = (10.5925 - 9.8924j)$ A

$\underline{|I_3| = 14.5551\angle -43.30° \text{ A}}$

According to KCL,

$I_1 = I_2 + I_3$

- ⇨ $\underline{I_1 = (21.1188 - 9.9824j) \text{ A}}$

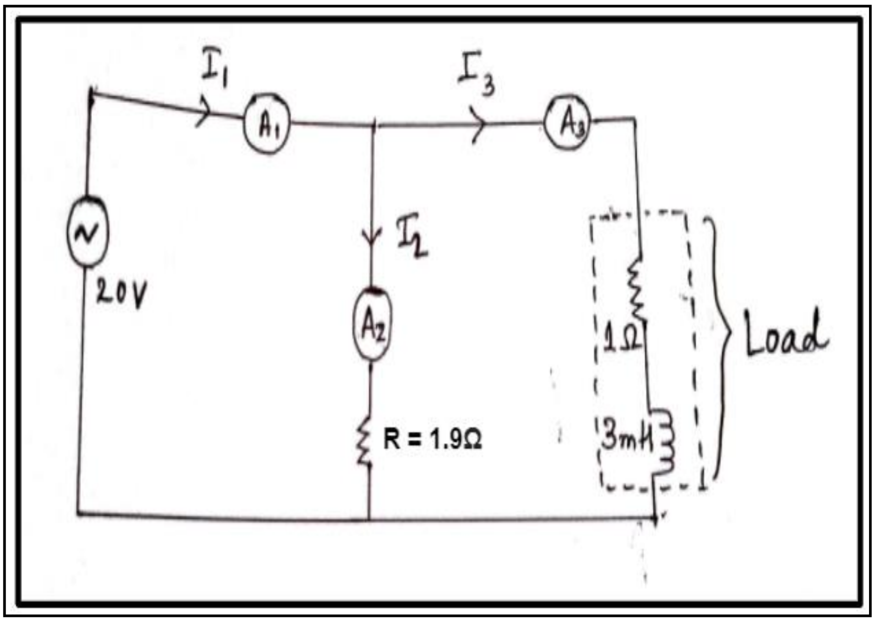
So, $I_1 = 23.3591\angle -25.30°$ A

Therefore, Power, $P = (I_1{}^2 - I_2{}^2 - I_3{}^2)\, R/2$

- ⇨ $\underline{P = 211.8439\text{W}}$

$\cos \Phi = (I_1{}^2 - I_2{}^2 - I_3{}^2)/2(I_2*I_3)$

- ⇨ $\underline{\cos \Phi = 0.7277}$



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$\boxed{\text{For } R = 2.0\ \Omega}$

$I_2 = 20/2.0$ A

$\underline{I_2 = 10\angle 0° \text{ A}}$

$I_3 = 20/(1+jwL)$

$= 20 / (1+j\,(2\pi*50*0.003))$

$I_3 = (10.5925 - 9.8924j)$ A

$\underline{|I_3| = 14.5551\angle{-43.30°}}$

According to KCL,

$I_1 = I_2 + I_3$

⇨ $I_1 = (20.5925 - 9.9824j)$ A

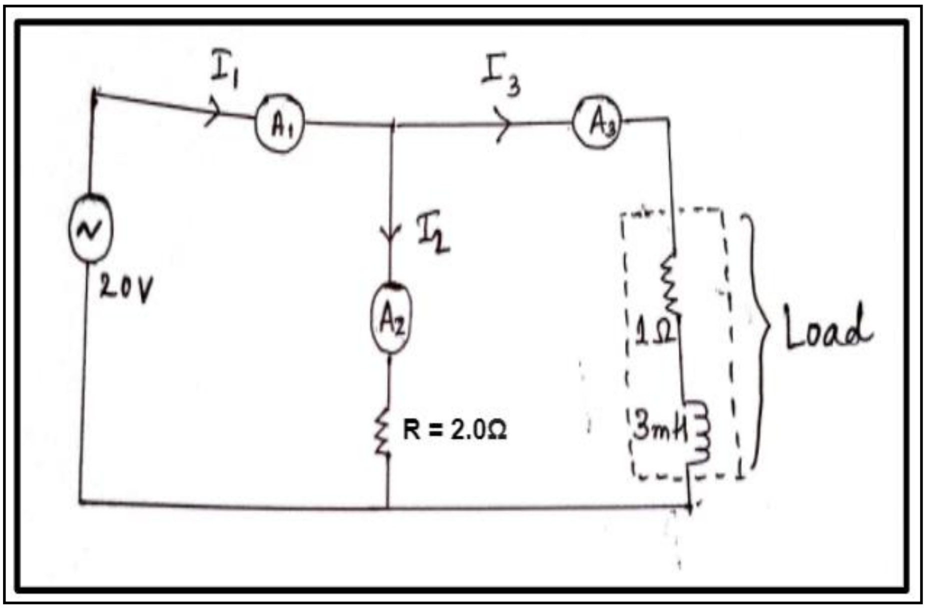
$\underline{\text{So, } I_1 = 22.8844\angle{-25.86°} \text{ A}}$

Therefore, Power, $P = (I_1{}^2 - I_2{}^2 - I_3{}^2)\,R/2$

⇨ $\underline{P = 211.8448\text{W}}$

$\cos\Phi = (I_1{}^2 - I_2{}^2 - I_3{}^2)/2(I_2*I_3)$

⇨ $\underline{\cos\Phi = 0.7277}$



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Error Analysis:

- Here Percentage (%) Error = $\frac{(Pcalculated - Wattmeter\ Reading)}{Wattmeter\ Reading}$
- R_{load} = 1Ω, $|I_3|$ = 14.5551 A (as evident from the calculations above)

1.) Three-Voltmeter Method:

Sl. No.	R(Ω)	I (A)	|I| (Magnitude of Current)	Wattmeter Reading (=$\|I\|^2 R_{load}$)	$P_{Calculated}$ (W)	$P_{calculated}$ - Wattmeter Reading	% Error
1.	1.7	6.6029-2.3046i	6.993530551	48.90946957	48.9133	0.00383043	7.83E-05
2.	1.8	6.4160-2.1594i	6.769642853	45.82806436	45.8309	0.00283564	6.19E-05
3.	1.9	6.2378-2.027i	6.558877788	43.01887784	43.0211	0.00222216	5.17E-05
4.	2	6.0678-1.96061i	6.376691024	40.66218841	40.4553	-0.206888412	-0.00508798

2.) Three-Ammeter Method:

Sl. No.	R (Ω)	$P_{calculated}$ (W)	Wattmeter Reading (= $(\|I_3\|^2)R_{load}$) (W)	$P_{calculated}$ - Wattmeter Reading	% Error
1.	1.7	211.8468	211.850936	0.00413601	1.95E-05
2.	1.8	211.8454	211.850936	0.00553601	2.61E-05
3.	1.9	211.8493	211.850936	0.00163601	7.72E-06
4.	2	211.8448	211.850936	0.00613601	2.90E-05

Sayan Mondal Abantika Saha Sayan Das [illegible] Jenula Paul Sohini Bhattacharya Anirban Moi

K.Dheeraj Reddy Subham Gupta Tuhin Karak Souradeepta Pal Koustav Sanyal D.Senapati Aman Kumar [illegible]

Result:

1) Three-Voltmeter Method:

Mean Power (Pavg) = 44.5551 W

Mean Power Factor (cos Φ)avg = 0.7278

2) Three-Ammeter Method:

Mean Power (Pavg) = 211.8448 W

Mean Power Factor (cos Φ)avg = 0.7277

Conclusion:

1) **KCL and KVL are used** to compute the readings of the three voltmeters and three ammeters in the respective methods. Furthermore, power consumed by the load and the power factor of the circuit is calculated by using the computed values of voltages and currents in the working formulae.

2) The calculated values are observed to be in the expected range as seen in the simulations **performed in Simulink with the help of simscape electrical toolbox.**

3) It is observed that **the power and power factor in an A.C.** circuit can be measured by using **three single-phase voltmeters as well as ammeters successfully, instead of a wattmeter**.

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Simulation

All the graphs are obtained by running the simulations for 0.05s in Simulink.

Three Voltmeter Method:

For R = 1.7 ohm

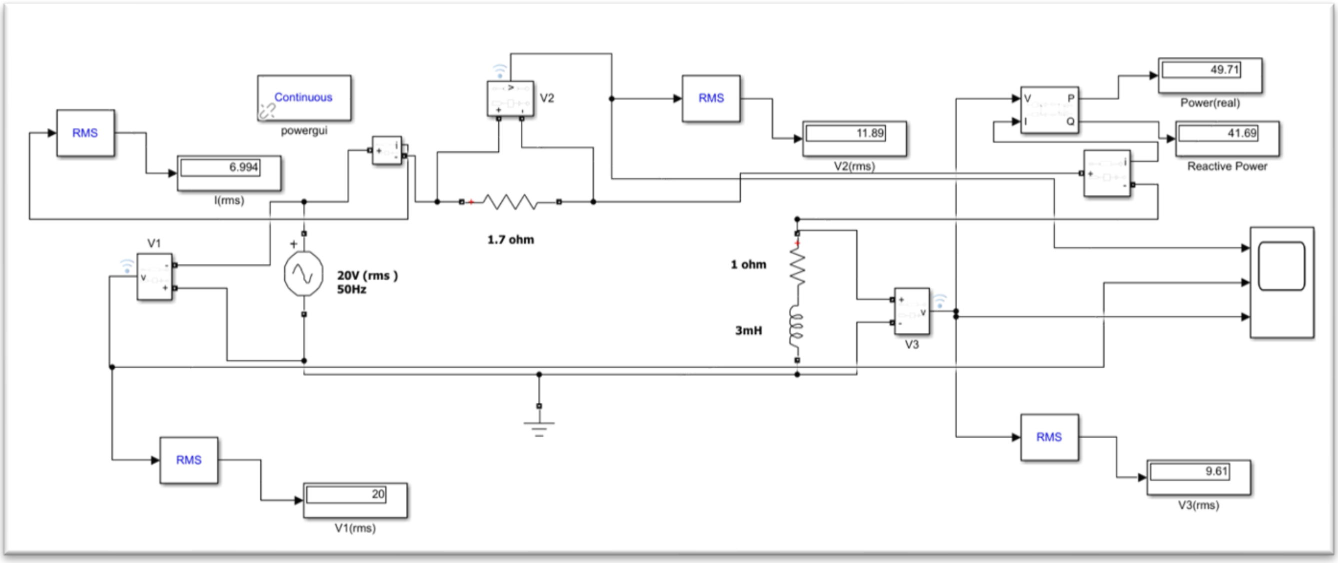

Figure: circuit at 1.7 ohms after running the simulation for 0.05s

Voltage waveforms of V_1, V_2 and V_3 for 0.05 seconds:

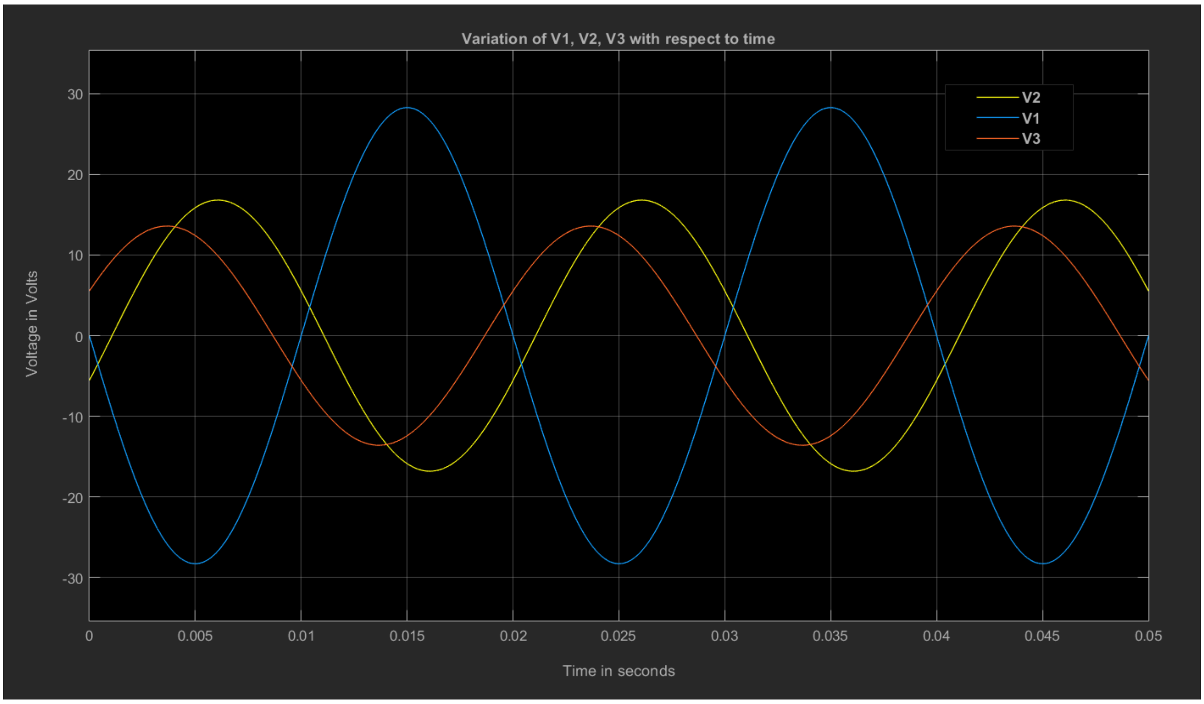

Figure 3: Simulation curves of voltages V1, V2, V3

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Aman Kumar

Three Ammeter Method:

For R = 1.7 ohms

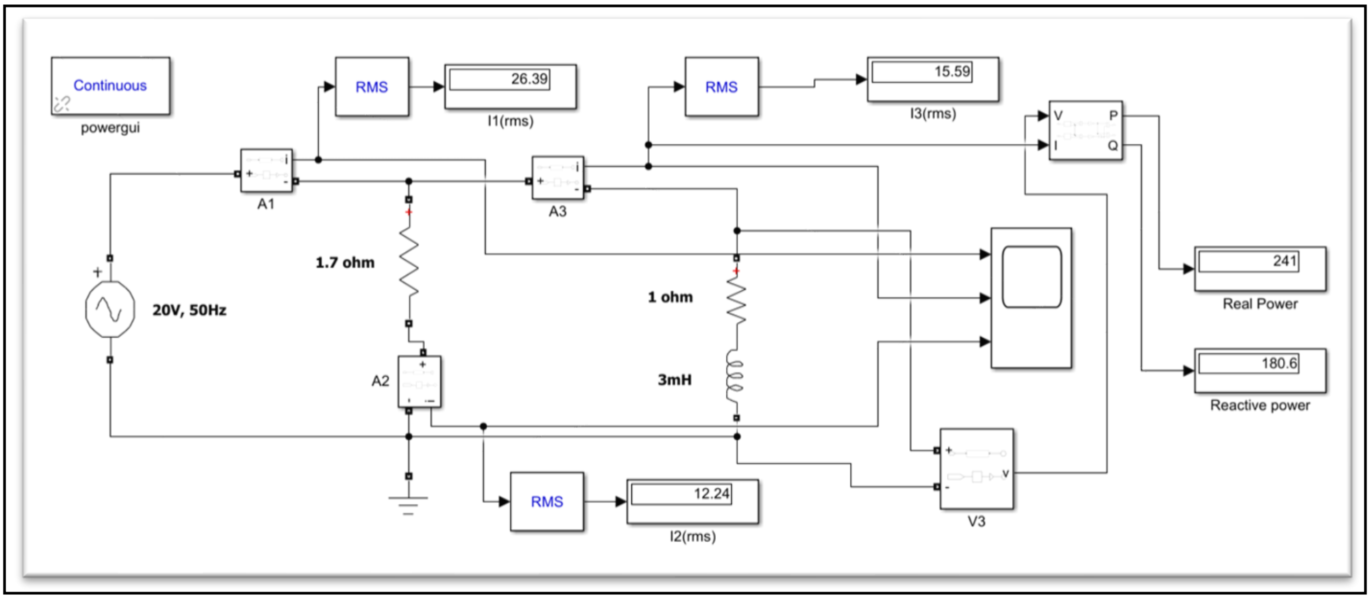

Figure: circuit at 1.7 ohms after running the simulation for 0.05s

Current waveforms of I_1, I_2 and I_3 for 0.05 seconds:

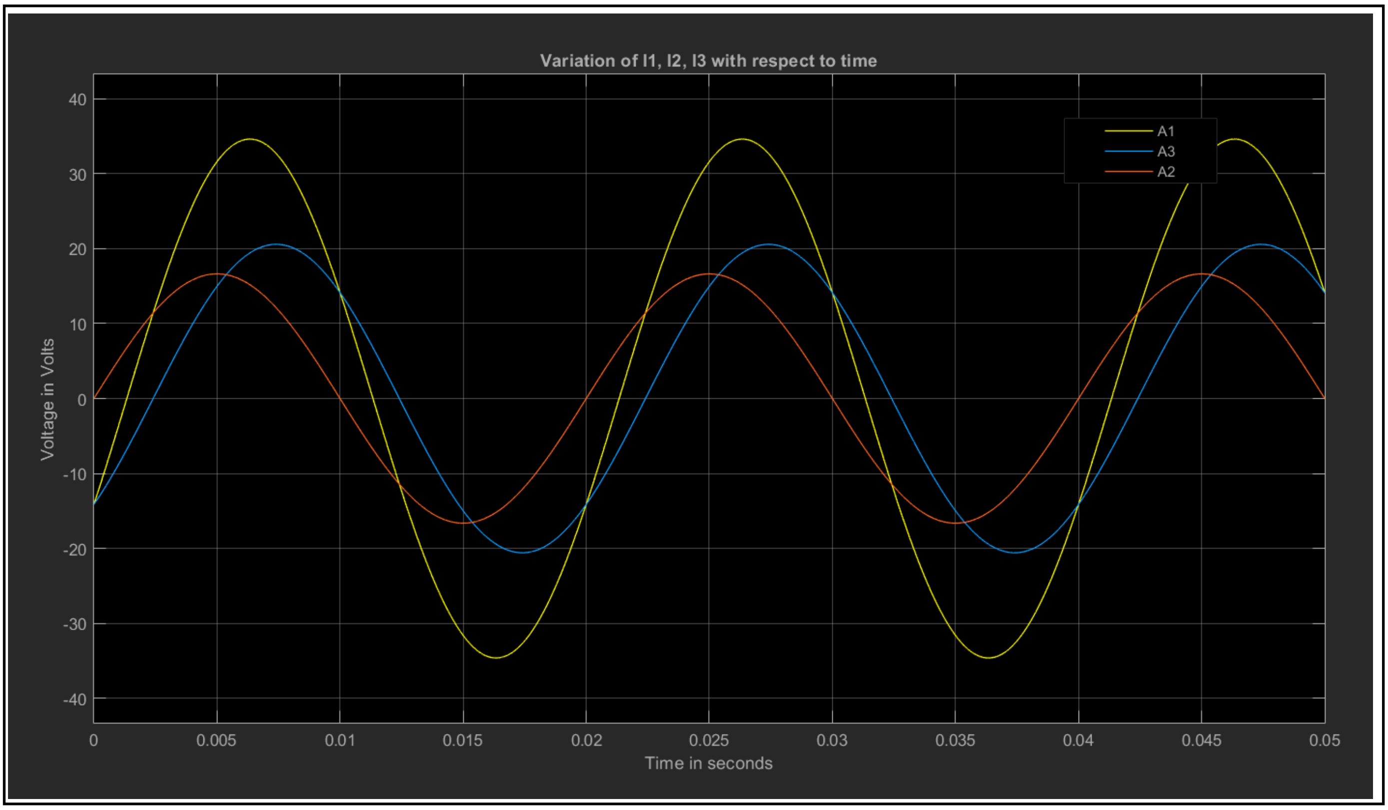

Figure 4: Simulation curve of currents, Here A1,A2, A3 refers to the instantaneous current reading of the ammeter

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