ELECTRICAL & ELECTRONICS Measurement Lab EES 351

Measurement of Power in Single Phase AC Circuit by three - Voltmeter and Three Ammeter Method

Experiment - I

Date : 2nd June, 2021

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EXPERIMENT NO.:- 1

→ AIM OF THE EXPERIMENT :-

Measurement of Power in Single-Phase circuit by three-voltmeter method and three-ammeter method.

→ OBJECTIVE :-

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

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

→ APPARATUS REQUIRED :-

- 3 voltmeters
- 3 ammeters
- Connecting wires
- Resistance
- load (comprising of inductance & resistance)

SL NO.	Instrument Name	Specification	Quantity
1	AC Voltage supply	20.0V(rms), 50Hz	1
2	Ammeter	0-35 A (AC)	3
3	Voltmeter	0-50V (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.	—	—

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→ THEORY :

→ Three Voltmeter Method :

From the phasor diagram,

$$V_1^2 = V_2^2 + V_3^2 + 2V_2V_3\cos\phi \quad \text{——— (1)}$$

but $V_2 = IR$

$$\Rightarrow V_1^2 = V_2^2 + V_3^2 + 2(IR)V_3\cos\phi \quad \text{——— (2)}$$

Now power consumed by load, $P = V_3 I \cos\phi$

Therefore, equation (2) gives,

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

$$\Rightarrow P = \frac{V_1^2 - V_2^2 - V_3^2}{2R} \quad \text{——— (3)}$$

Now, simplifying equation (1),

$$\cos\phi = \frac{V_1^2 - V_2^2 - V_3^2}{2V_2V_3} \quad \text{——— (4)}.$$

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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 3 single-phase voltmeters, instead of a wattmeter.

→ Three Ammeter Method :-

From the phasor diagram,

$$I_1^2 = I_2^2 + I_3^2 + 2 I_3 I_2 \cos\phi \quad \text{—— (1)}$$

But $I_2 = V/R$

Therefore, $I_1^2 = I_2^2 + I_3^2 + 2(V/R) I_3 \cos\phi$ —— (2)

Now, power across load, $P = V I_3 \cos\phi$

Therefore equation (2) gives,

$$I_1^2 = I_2^2 + I_3^2 + 2(P/R)$$

$$\Rightarrow P = \left(I_1^2 + I_2^2 + I_3^2 / 2\right) R \quad \text{—— (3)}$$

Now, simplifying equation (1),

$$\cos\phi = \frac{I_1^2 + I_2^2 - I_3^2}{2 I_1 I_3} \quad \text{—— (4)}$$

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.

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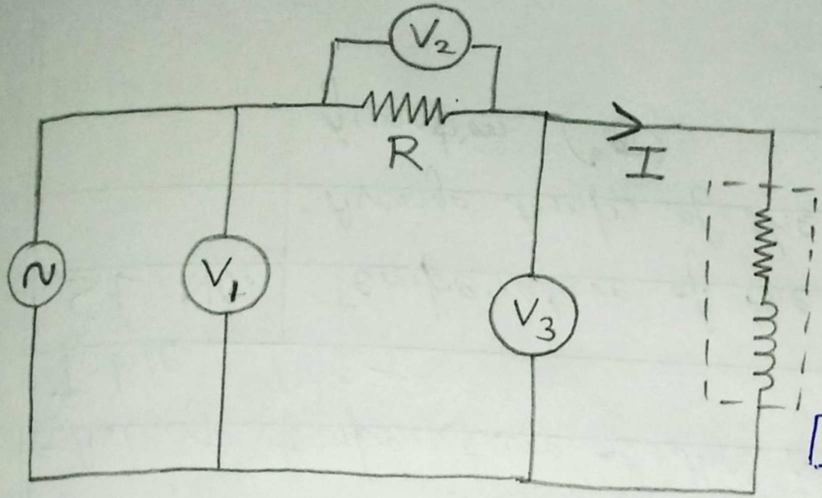
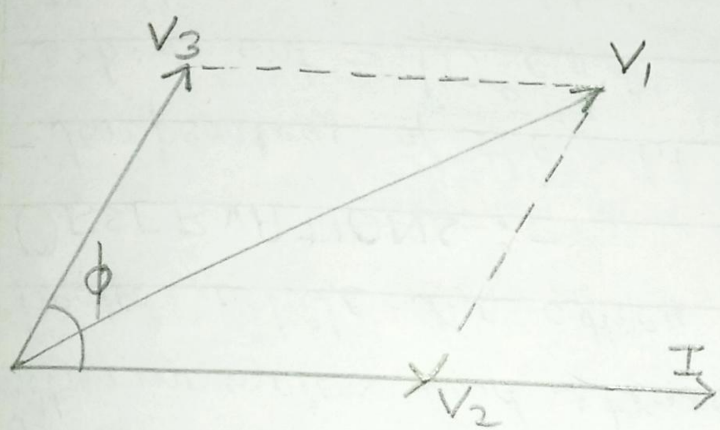


1.1 Diagram for 3 voltmeter method.



1.2 Phasor diagram.

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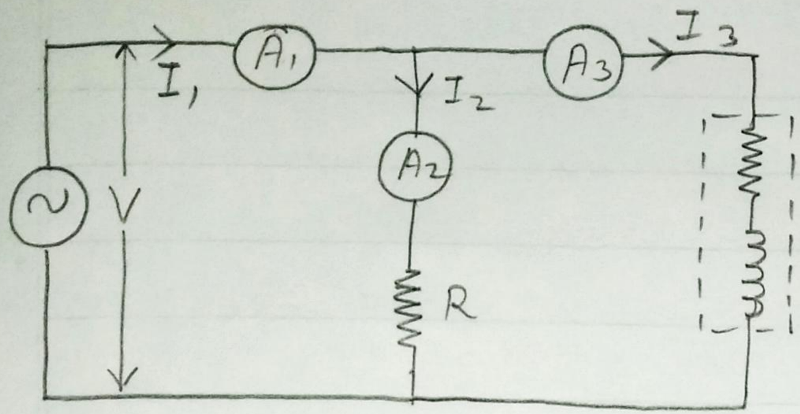
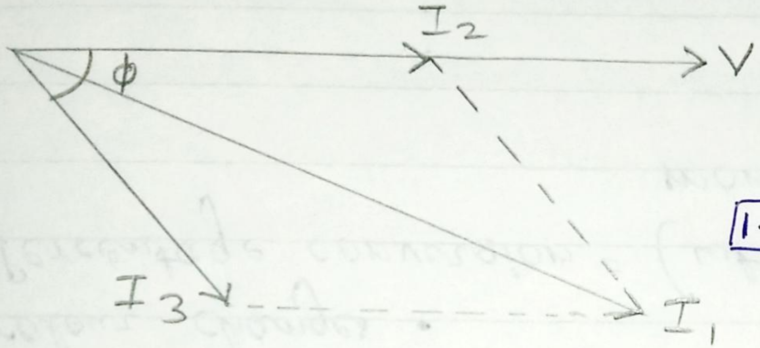


Load Z.

$\boxed{1.3}$ → diagram for 3 Ammeter Method.



$\boxed{1.4}$ Phasor diagram.

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EXPERIMENTAL RESULTS :

Table 1 : Three-Voltmeter Method.

SL No.	R (Ω)	V_1 (Volt)	V_2 (volt)	V_3 (Volt)	Power (Watt)	Power factor (P.f.)	Mean Power (Watt)	Mean Power factor (P.f)
1	1.7	20	11.8690	9.6097	48.9133	0.7277	Mean P = 44.5551	Mean p.f. = 0.7278
2	1.8	20	12.1853	9.3020	45.8309	0.7278		
3	1.9	20	12.4618	9.0124	43.0211	0.7278		
4	2.0	20	12.7202	8.7393	40.4553	0.7278		

Table 2 : Three-Voltmeter Method

SL No.	R (Ω)	I_1 (amp)	I_2 (amp)	I_3 (amp)	Power (Watt)	Power factor (P.f.)	Mean Power	Mean Power factor
1	1.7	24.4845	11.7647	14.5551	211.8468	0.7277	Mean Power = 211.8448 W	Mean Power factor = 0.7277
2	1.8	23.8891	11.1110	14.5551	211.8454	0.7278		
3	1.9	23.3591	10.5263	14.5551	211.8493	0.7277		
4	2.0	20.5925	10.0000	14.5551	211.8448	0.7277		

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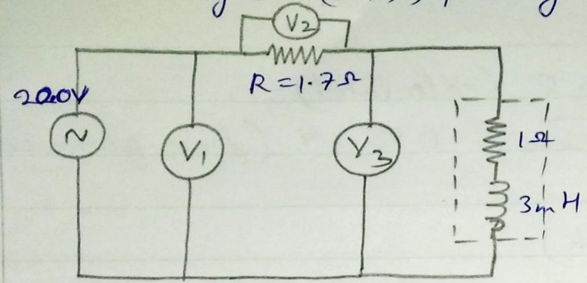
→ CALCULATIONS :– (for 3 Voltmeter method)

From diagram (1.1), putting the values of R & load, (given)



load.

• $\boxed{R = 1.7}$

Hence, $V_1 = 220V \angle 0°$

So, load $= 1 + j[2\pi \times 50 \times 0.003]$

$\Rightarrow$ load $= 1 + j(0.9424)$

$Z = (1+1.7) + j(0.9424)$ { (R + load)

$\Rightarrow Z = 2.7 + j(0.9424)$

$\Rightarrow Z = 2.8597 \angle 19.24°$.

So, $I_{total} = \dfrac{20}{2.7 + 0.9424j}$ } $\left[I_{total} = \dfrac{V}{R + load} \right]$ $(I = \frac{V}{Z})$.

$= (6.6029 - 2.3046j)$ A.

Now, $V_2 = I_{Total} \times R$.

$= (6.6029 - 2.3046j) \times 1.7$

$= 11.2249 - 3.9178j$ V

$\Rightarrow V_2 = 11.8890 \angle -19.24°$ V.

Now, $V_3 = I_{total} \times load$

$= (6.6029 - 2.3046j) \times (1 + 0.9424j)$

$= 8.7747 + 3.9179j$ V

$\Rightarrow V_3 = 9.6097 \angle 24.06°$ V

We know Power $(P) = \dfrac{V_1^2 - V_2^2 - V_3^2}{2R}$.

by putting the values of V_1, V_2, V_3 & R

we get $P = \dfrac{166.3053}{2 \times 1.7}$ W. $\Rightarrow$ P = 48.9133W.

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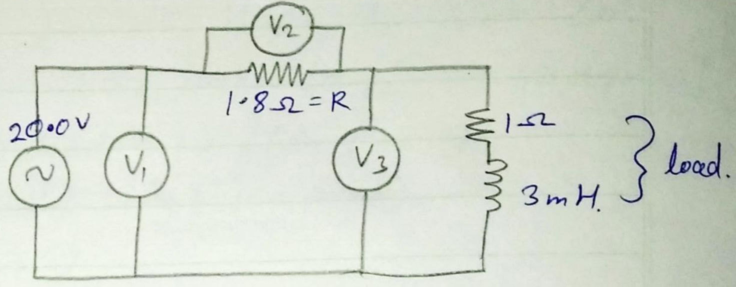
$\cos\phi = \dfrac{V_1^2 - V_2^2 - V_3^2}{2 V_2 V_3}$ { known formula, (derived earlier) }

by putting the values of V_1, V_2 & V_3.

$\cos\phi = \dfrac{166 \cdot 3053}{2 \times 11 \cdot 8890 \times 9 \cdot 6097}$

$\Rightarrow \cos\phi = 0 \cdot 7277$

• $\boxed{\text{for } R = 1 \cdot 8\,\Omega}$



putting the respective values.

$V_1 = 20V \angle 0°$.

$load = 1 + j(2\pi \times 50 \times 0 \cdot 003)$

$= 1 + j(0 \cdot 9424)$

$\therefore Z = (1 \cdot 8 + 1) + j(0 \cdot 9424) = 2 \cdot 8 + 0 \cdot 9424 j$

So, $I_{total} = \dfrac{20\angle 0°}{2 \cdot 8 + 0 \cdot 9424 j}$ $\left\{ I = \dfrac{V}{R + load} = \dfrac{V}{Z} \right\}$, By KVL

$= 6 \cdot 4160 - 2 \cdot 1594 j$ A.

So, $V_2 = I_{total} \times R = (6 \cdot 4160 - 2 \cdot 1594 j) \times 1 \cdot 8$

$= 11 \cdot 5488 - 3 \cdot 8869$ V

$\Rightarrow V_2 = 12 \cdot 1853 \angle 18 \cdot 60°$ V.

Now $V_3 = I_{total} \times load$

$= (6 \cdot 4160 - 2 \cdot 1594) \times (1 + 0 \cdot 9424 j)$

$= 8 \cdot 4510 + 3 \cdot 8870 j$ V

$\Rightarrow V_3 = 9 \cdot 3020 \angle 24 \cdot 69°$ V

We know, Power $P = \dfrac{V_1^2 - V_2^2 - V_3^2}{2R}$

putting the values of V_1, V_2, V_3 & R.

$\Rightarrow P = \dfrac{164 \cdot 9912}{2 \times 1 \cdot 8}$ W. $= 45 \cdot 8309$ W.

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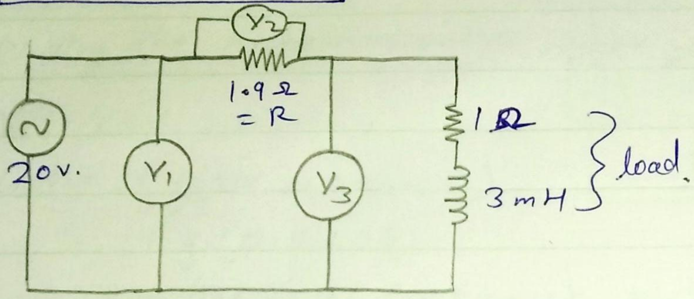
$$\cos\phi = \frac{V_1^2 - V_2^2 - V_3^2}{2V_2V_3}$$

putting the respective values,

$$\cos\phi = \frac{164.9912}{2\times 12.1853 \times 9.3020} = 0.7278$$

$$\Rightarrow \cos\phi = 0.7278$$

- $\boxed{\text{for } R = 1.9\,\Omega}$



$V_1 = 20\text{ V} \angle 0°.$

load $= 1 + j(0.9424.)$

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

$\Rightarrow Z = 2.9 + j0.9424.$

Applying KCL, KVL. we get

$I_{total} \times Z = V_1 \quad \Rightarrow I_{total} = \frac{V_1}{Z}$

$$\Rightarrow I_{total} = \frac{20\angle 0°}{2.9 + j(0.9424)} = 6.2378 - 2.0270j\text{ A.}$$

Now, $V_2 = I_{total} \times R$

$= (6.2378 - 2.0270j) \times 1.9\text{ V}$

$= 11.8518 - 3.8513j\text{ V} \quad \Rightarrow V_2 = 12.4618 \angle{-18.00°}\text{ V}$

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$V_3 = I_{total} \times load.$

$\Rightarrow V_3 = (6.2378 - 2.0270\,j) \times (1 + j0.9424)\ V.$

$= 8.1480 + 3.8515j\ V$

$\Rightarrow V_3 = 9.0124 \angle 25.18°\ V.$

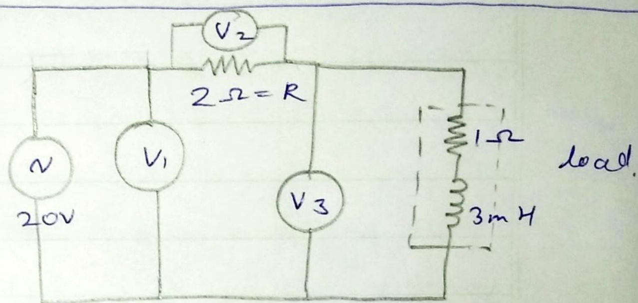
We, know Power $P = \dfrac{V_1^2 - V_2^2 - V_3^2}{2R}$

putting the values of V_1, V_2, V_3 and R.

$\Rightarrow P = \dfrac{163.4801}{2 \times 1.9}\ W. \Rightarrow P = 43.0211\ W.$

$\cos\phi = \dfrac{V_1^2 - V_2^2 - V_3^2}{2V_2V_3} = 0.7278.$

$\boxed{\text{for } R = 2\,\Omega}$



Here $V_1 = 20V \angle 0°$

$Load = 1 + j(2\pi \times 50 \times 0.003)$

$load = 1 + j(0.9424)$

$\therefore Z_{total} = (2+1) + j(0.9424)$

$= 3 + j(0.9424.)$

Applying KVL, $V_1 = I_{total} \times Z$

$\Rightarrow I_{total} = V_1/Z = \dfrac{20\angle 0°}{3 + j(0.9424)}$

$\Rightarrow I_{total} = 6.0678 - 1.9061\,j\ A$

Voltage across $R = V_2 = I_{total} \times R.$

$\Rightarrow V_2 = (6.0678 - 1.9061\,j) \times 2 := 12.1356 - 3.8122j.$

$\Rightarrow V_2 = 12.7202852 \angle -17.4393°.$

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$V_3 = I_{total} \times load.$

$= (6.6078 - 1.9061j) \times (1 + 0.9424j)$

$= (7.8641 + 3.8121j)\,V = 8.7393 \angle 25.86^\circ\ V.$

We know, Power $(P) = \dfrac{V_1^2 - V_2^2 - V_3^2}{2R}$

& $\cos\phi = \dfrac{V_1^2 - V_2^2 - V_3^2}{2 V_2 V_3}$.

putting the values of V_1, V_2, V_3 & R, we get

$P = 40.4553\,W$ & $\cos\phi = 0.7278$

Hence, mean Power $P = \dfrac{48.9133 + 45.8309 + 43.0211 + 40.4553}{4}$

$\Rightarrow P_{avg.} = 44.5551\ W$

& average power factor (p.f.)

$= \dfrac{0.7278 + 0.7277 + 0.7278 + 0.7278}{4}$

$\Rightarrow (P.f.)_{avg} = 0.7278$

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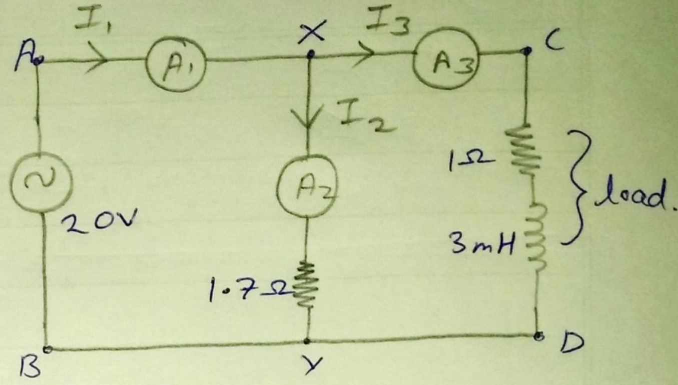
(3- Ammeter Method):-

$\boxed{\text{for } R = 1.7\,\Omega}$



putting respective values of R, load of the diagram 1.3.

Applying KCL at node 'X'

$\Rightarrow I_1 = I_2 + I_3$ — (i)

Now considering loop AXYB.

$I_2 = \frac{V}{R} = \frac{20}{1.7}$ A

$\Rightarrow I_2 = 11.7647 \angle 0°$.

Voltage across XY = 20V.

$\Rightarrow I_3 = V/(r + j\omega L) = \frac{20}{1 + j(2\pi \times 50 \times 0.003)}$

$= 10.5925 - 9.9824j$ A.

$\Rightarrow |I_3| = 14.5551 \angle -43.30°$ A.

from (i) $I_1 = I_2 + I_3 = (11.7647 + 10.5925) - (j9.9824)$

$= 22.3572 - 9.9824j$ A.

So, $I_1 = 24.4845A \angle -24.06°$.

We know Power (P) $= \frac{(I_1^2 - I_2^2 - I_3^2)R}{2}$.

by putting respective values, P = 211.8468 W.

& $\cos\phi = \frac{I_1^2 - I_2^2 - I_3^2}{2 I_1 I_3}$ $\Rightarrow \cos\phi = 0.7277$.

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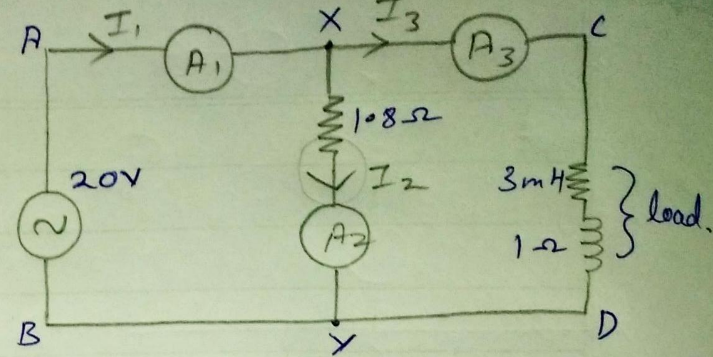
• $\boxed{\text{for } R = 1.8\ \Omega}$



putting the respective values,

applying KCL at node X

$I_1 = I_2 + I_3$ —— (iii)

Now considering loop AXYB

$I_2 = V/R = \frac{20}{1.8}$

$\Rightarrow I_2 = 11.111\ A\ \angle 0°.$

$I_3 = \frac{V_{xy}}{Z_{(xCDY)}} = \frac{V}{\text{load}} = \frac{20}{1+j(2\pi \times 50 \times 0.003)}$

$\Rightarrow I_3 = 10.5925 - 9.982j = 14.5551\ A\ \angle -43.30°$

now from (iii) we get $I_1 = (11.111 + 10.5925) - j(9.982)$

$\Rightarrow I_1 = 21.7035 - 9.9824j\ A = 23.8891\ A\ \angle -24.6997°.$

We know power $(P) = \frac{(I_1^2 - I_2^2 - I_3^2)}{2} \times R$

by putting respective values, we get

$P = 211.8454\ W.$

$\cos\phi = \frac{I_1^2 - I_2^2 - I_3^2}{2 I_2 I_3} = 0.7278$ (after puting the respective values of I_1, I_2, I_3).

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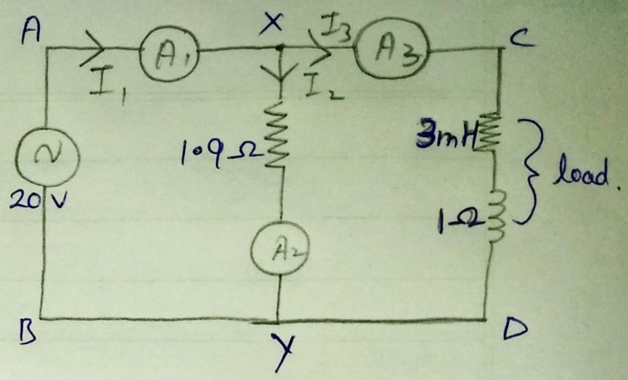
$\boxed{\text{for } R = 1.9\,\Omega}$

putting respective values,

Considering loop AXYB,



$V_{xy} = 20\,V \Rightarrow I_2 = \dfrac{V_{xy}}{R}$

$\Rightarrow I_2 = \dfrac{20}{1.9} = 10.5263\,A \angle 0°.$

Now in loop XCDY,

$I_3 = \dfrac{V_{xy}}{\text{load}} = \dfrac{20}{1 + j(100\pi \times 0.003)} = 10.5925 - j9.9824\,A.$

$\Rightarrow I_3 = 14.5551\,A \angle{-43.30°}.$

Applying KCL at node X $\Rightarrow I_1 = I_2 + I_3.$

putting the values of I_2 & I_3

$\Rightarrow I_1 = (10.5263 + 10.5925) - j\,9.9824$

$= (21.1188 - 9.9824\,j)\,A. = 23.3591 \angle{-28.30°}\,A.$

Using formula:-

$P = \dfrac{(I_1^2 - I_2^2 - I_3^2)R}{2}$ & $\cos\phi = \dfrac{(I_1^2 - I_2^2 - I_3^2)}{2 I_2 I_3}.$

putting respective values of I_1, I_2, I_3 & R we get,

$P = 211.8439\,W$ & $\cos\phi = 0.7277.$

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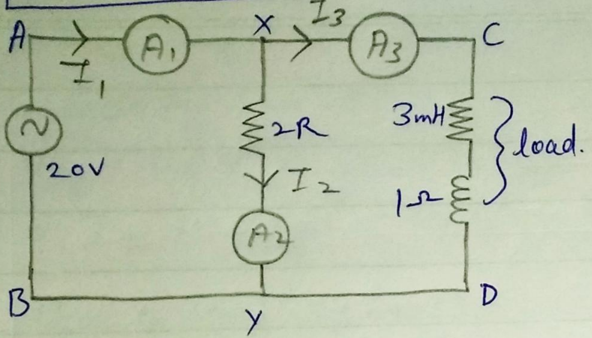
$\boxed{\text{for } R = 2\,\Omega}$



Considering loop AXYB, applying KVL

$V_{AB} = I_2 \times R$

$\Rightarrow I_2 = \frac{20}{R} = 20/2 = 10\,A\,\angle 0°.$

Now, at loop XCDY,

$I_3 = \frac{V_{xy}}{load} = \frac{20}{1+j(100\pi \times 0.003)}$

$\Rightarrow I_3 = 10.5925 - 9.9824j = 14.5551\,\angle -43.30° A$

Applying KCL at node X

$\Rightarrow I_1 = I_2 + I_3$. $\Rightarrow I_1 = (10 + 10.5925) - j(9.9824)$

$\Rightarrow I_1 = 22.8874\,\angle -25.86°\,A.$

We know, $P = \frac{(I_1^2 - I_2^2 - I_3^2)R}{2}$ & $\cos\phi = \frac{I_1^2 - I_2^2 - I_3^2}{2 I_2 I_3}$.

putting respective values of I_1, I_2, I_3 & R,

we get, $P = 211.8448\,W$

& $\cos\phi = 0.7277$.

Mean power $= \frac{\Sigma P}{n} = \frac{(2.118468 + 211.8454 + 211.8439 + 211.8448)}{4}$

hence $P_{avg.} = 211.8452\,W$

Mean power factor $(P.f.) = (\cos\phi)_{avg.} =$

$\frac{0.7277 + 0.7278 + 0.7277 + 0.7277}{4} = 0.7277$

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→ ERROR ANALYSIS :

• 3 Ammeter Method :-

% error = (Pcalculated − Wattmeter Reading)/Wattmeter Reading.

R (Ω)	i_3 (A)	Pcalculated (W)	Wattmeter Reading. $W = I_3^2 R$	Pcalculated − Wattmeter Reading.	% error.
1.7	14.5551	211.8468	211.850936	0.00413601	1.95232e−05
1.8	14.5551	211.8454	211.850936	0.00553601	2.61316e−05
1.9	14.5551	211.8493	211.850936	0.00163601	7.72246e−06
2	14.5551	211.8448	211.850936	0.00613601	2.89638e−05

• 3 Voltmeter Method :-

% error = (Pcalculated − Wattmeter Reading) / Wattmeter Reading.

R(Ω)	I_{real} (A)	$I_{(im)}$ (A)	$\lvert i \rvert = \sqrt{(I_{real})^2 + (I_{im})^2}$ (A)	Wattmeter Reading $W = I^2 R$	Pcalculated (W)	Pcalculated − W	% error.
1.7	6.6029	−2.3046	6.993530551	48.90946957	48.9133	0.00383043	7.8317e-05
1.8	6.416	−2.1594	6.769642853	45.82806436	45.8309	0.00283564	6.18756e-05
1.9	6.2378	−2.027	6.558877788	43.01887784	43.02111	0.00222216	5.1655e-05
2	6.0678	−1.96061	6.376691024	40.66218841	40.4553	−0.206888412	−0.00508798

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RESULTS: -

→ 3 - Voltmeter Method:

Mean Power $(P_{avg}) = 44.5551$ W

Mean Power Factor $(\cos\phi)$ avg. $= 0.7278$.

→ 3 - Ammeter Method:

Mean Power $(P_{avg.}) = 211.8448$ W.

Mean Power Factor $(\cos\phi)$avg. $= 0.7277$.

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→ CONCLUSION :

i) KCL and KVL are used to compute the readings of the 3 valtmeters and 3 ammeters in the respective methods. Furthermore, power consumed by the load and the power factor of the circuit are calculated by using the computed values of voltages and current in the working formulae.

(ii) The calculated values are observed to be in the expected range as seen in the simulations performed. in Simulink

(iii) It is observed that the power and powerfactor in an A.C. Circuit can be measured by using 3 single-phase valtmeters as well as ammeters successfully, instead of a wattmeter.

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Simulation

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

Three Voltmeter Method:

For R = 1.7 ohm

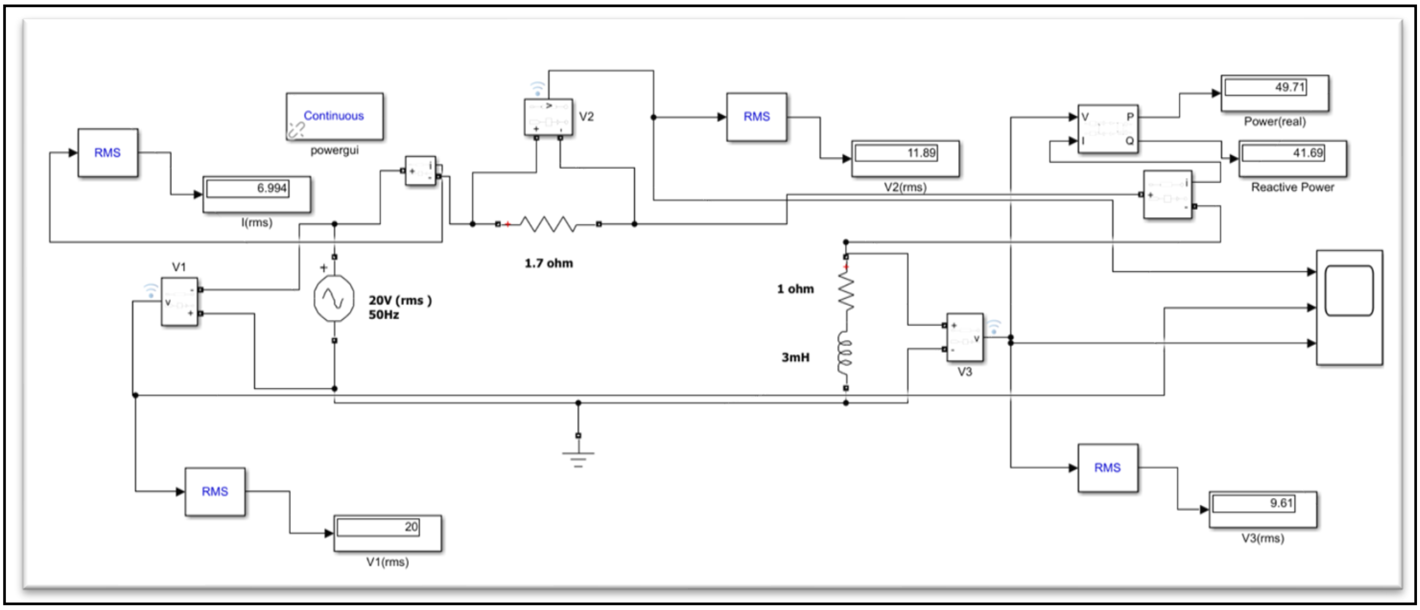
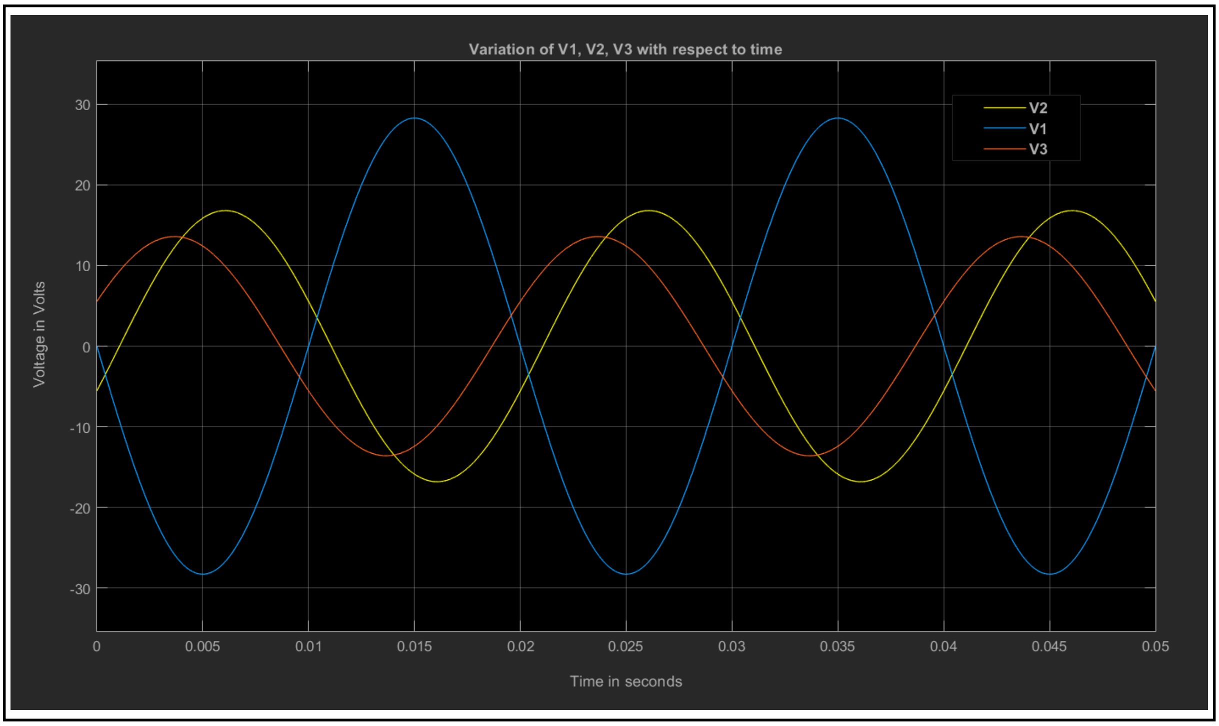


Figure: circuit at 1.7 ohms after running the simulation for 0.05s

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



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Three Ammeter Method:

For R = 1.7 ohms

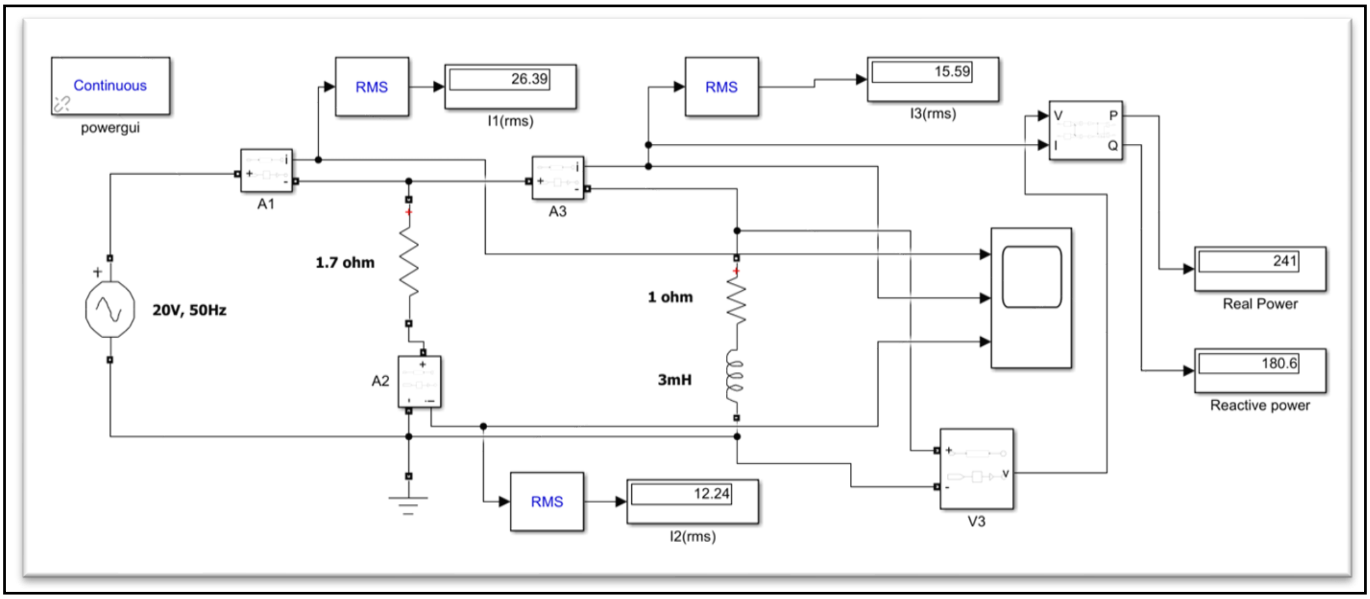
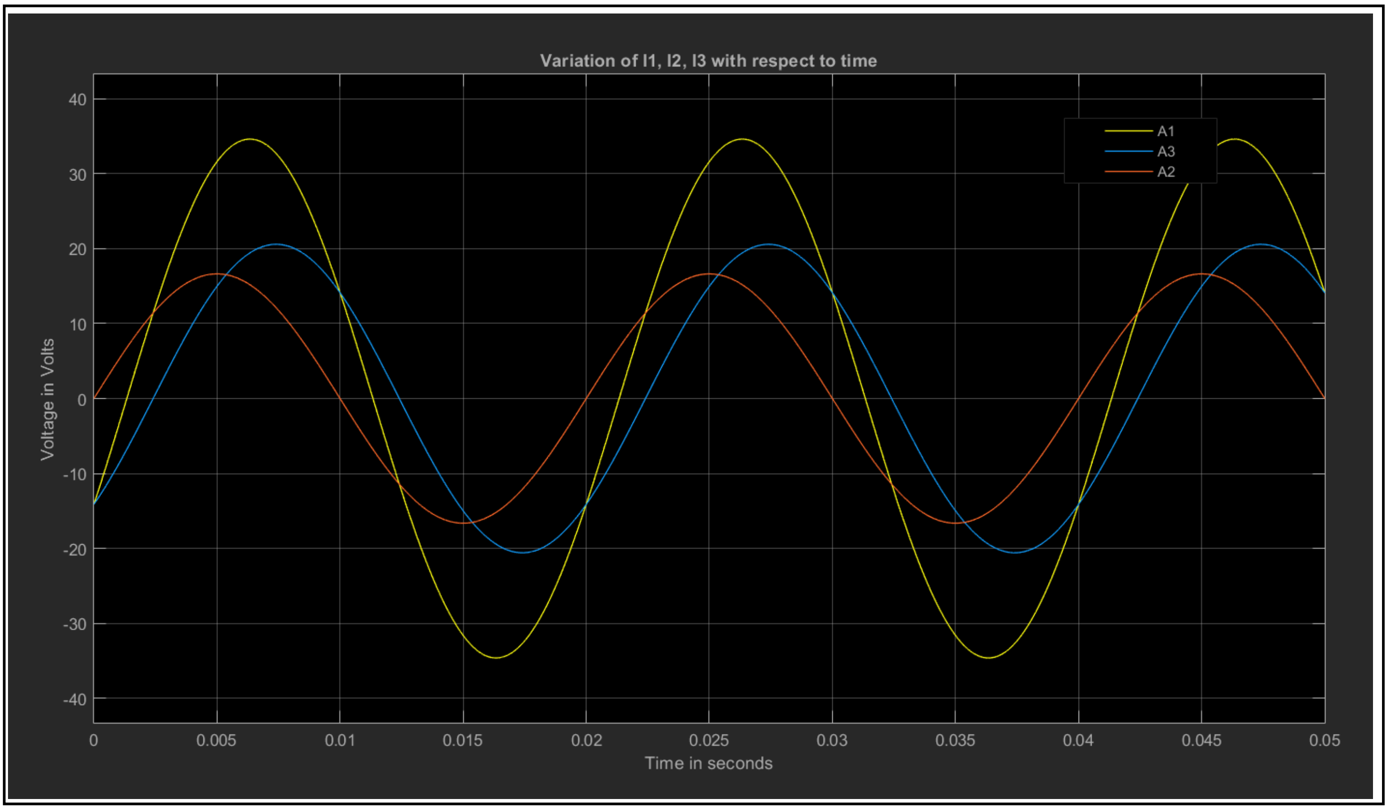


Figure: circuit at 1.7 ohms after running the simulation for 0.05s

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



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