SCHOOL OF ENGINEERING

ELECTRICAL AND COMPUTER SYSTEMS ENGINEERING

LABORATORY REPORT MARKING RUBRIC

ECE3051: ELECTRICAL ENERGY SYSTEMS

Experiment Number: 1

Title of Lab Sheet: SINGLE-PHASE AC NETWORKS

Group Number: 8

No.	Student ID	Name of Group Members	Total Marks
1	30720230	Loh Jia Quan	100/100
2	32194471	Tan Jin Chun	100/100
3	31106889	Agill Kumar Saravanan	100/100
4	30719305	Huan Meng Hui	100/100
5	32259417	Chong Yen Juin	100/100

MARKS BREAKDOWN

Section	Total Score	Actual Marks	Scoring Band	Criteria	Comment
Results	40		30-40	Clear and completely labelled figures of the experiment/simulation results with justifications and tables. A detailed caption is provided for each figure with an in-text figure reference. The x-axis and y-axis are labelled with the unit in the bracket. The legend is provided whenever it is deemed to be required. If there is more than one line, the lines should be clearly distinguishable with the visible difference such as dotted line, dashed line and solid line, even in black and white.	40
			20-30	Some of the figures of the experiment/simulation setup are not clear, do not have any labelling/ caption/ in-text caption reference/ distinguishable multiple lines and are blurry. The table and justification have mistakes or errors.	
			0-20	Insufficient amounts of figures and labelling of the experiment/simulation layout setup, which is not correct and/or unclear. The table is not filled.	
Discussion	40		30-40	Complete data collection and presentation using tables/figures/ graphs with appropriate labels. Discussion of the results with prudent judgment. Have a comparison of the measured results with theoretical values and in-text citations from the peer-reviewed references. The comprehensive comparison, evaluation and justification of the results are given with clear explanation to demonstrate the understanding of the laboratory.	40
			20-30	The discussion shows little understanding of what the experiment/simulation is all about. Brief comparison, evaluation and justification of the results, with unclear/ incorrect explanation on the theoretical and experimental/ simulation results.	
			0-20	Only restatement of the results without commenting on the expected key points. Incorrect judgment/ arguments were used. No comparison, evaluation and justification of the results, with an unsatisfactory explanation on	

				the theoretical and experimental/ simulation results.	
Conclusion, References and Appendix	20		15-20	Explained how the aims of the experiment have been achieved. The key features of the methods used, the most important results and the findings of the laboratory have been summarized. Complete references list to any book, articles and websites is provided with proper in-text citations in correct formatting. The appendix is provided in detail.	20
			10-15	A conclusion is drawn but is not supported by the experimental/ simulation evidence and a clear understanding of the findings. Incomplete references to the books or any other sources used in the report and the in-text citations are inappropriate or incorrect. The appendix is partially provided.	
			0-10	No sensible conclusion. The referencing is presented in the wrong format. No evidence, attachments, appendices are attached. Irrelevant referencing was used. Unclear understanding of the experiment without a summarized conclusion and the evidence of results. No appendix is provided.	
Total	100				100

Examiner/ Assessor of ECE3051: Electrical Energy Systems

Date: 7/5/2023

EXPERIMENT 1

SINGLE-PHASE AC NETWORKS

Single Element Loads

1. **Resistive Load**

ANALYSIS – Calculate the peak voltage and current from the measured rms values. Compare these values with the waveforms plotted using the CRO and hence determine the scaling factor.

Measure the time interval between zero crossings of the load voltage and the load current on the CRO and hence calculate the load phase angle. Note that 20ms = 360° on the X axis of the CRO. What is the power factor of this load? Compare the value with the reading from the V/A/W meter.

Calculate the resistance of the load-bank resistor. How does this value of resistance relate to the rating of 1500 W for the load-bank switch setting?

Analysis Answers:
(Please answer all analysis questions by including all relevant discussions, explanations, calculations, equations and figures as necessary) [6 Marks]

Calculate the peak voltage and current from the measured rms values.
from Figure 1

$I_{rms,V/A/W} = 12.17\,A$

$I_{peak,V/A/W} = I_{rms} * \sqrt{2} = 17.21A$

$V_{rms,V/A/W} = 124.4V$

$V_{peak,V/A/W} = V_{rms} * \sqrt{2} = 175.93V$

There is a difference between the calculated and the measured values. This could be due to the internal resistance of the resistor or the tolerance that exists within the resistor itself.

Compare these values with the waveforms plotted using the CRO and hence determine the scaling factor.
Channel 1

$V_{rms,CRO} = 125\,V$

$V_{peak,CRO} = V_{rms,CRO} * \sqrt{2} = 176.78\,V$

Scaling = $V_{peak,CRO} / V_{peak,V/A/W}$ = 1

Channel 2

$I_{rms,CRO}$ = 12.9

$I_{peak,CRO} = I_{rms,CRO} * \sqrt{2}$ = 18.24

Scaling = $I_{peak,CRO} / I_{peak,V/A/W}$ = 1.1

The scalings are close to 1, which is reasonable as we configured the probe and the CRO to have a scaling of one.

Measure the time interval between zero crossings of the load voltage and the load current on the CRO and hence calculate the load phase angle. Note that 20ms = 360° on the X axis of the CRO.

Time interval measured = delay of voltage - delay of current = 120us

Frequency = 50Hz

Load Phase angle, θ = f * 360 * time interval = 2.16 degree

What is the power factor of this load? Compare the value with the reading from the V/A/W meter.

Calculated power factor = cos (2.16) = 0.999

Measured power factor = 0.999

Our measured and calculated power factor are very close to each other

Calculate the resistance of the load-bank resistor. How does this value of resistance relate to the rating of 1500 W for the load-bank switch setting?

checked

$R_{LCR} = 10.497\ \Omega$

$Calculated\ power = V^2/R = 124.4^2 / 10.497 = 1474.27\ W$

$I_{rms,V/A/W} = 12.17\ A$

$V_{rms,V/A/W} = 124.4V$

$R_{V/A/W} = V_{rms,V/A/W}/I_{rms,\ V/A/W} = 10.22\Omega$

$Calculated\ power = V^2/R = 124.4^2 / 10.41 = 1486.59W$

$I_{rms,CRO} = 12.9\ A$

$V_{rms,\ CRO} = 125\ V$

$R_{CRO} = V_{rms,CRO}/I_{rms,\ CRO} = 9.69\ \Omega$

$Calculated\ power = V^2/R = 125^2 /9.69 = 1612\ W$

All of the power obtained from the different resistance measured using LCR meters, calculations from WAV meters and CROs are close to the 1500W rating of the load bank switch. The deviations in power ratings could be attributed to the power lost across the internal resistance in the equipment.

$P = \frac{V^2}{R}$

Resistance is inversely proportional to the power rating for the load-bank switch setting.

RESULT- Show the complete workings for the calculation. Include all of the relevant calculation steps and equations. (Ensure your answer is provided with proper units) [5 Marks]

Parameter	Measured Value (Unit)	Calculated Value (Unit)	Differences
Real Power	1513 W	1500 W	13W
Reactive Power	55 VAR	0 VAR	55 VAR
Apparent Power	1514 VA	1500 VA	14 VA
V_{RMS}	124.4 V_{RMS} (V/A/W meter) 125.0 V_{RMS} (CRO)	130 V_{RMS}	5.6 V_{RMS} (V/A/W meter) 5.0 V_{RMS} (CRO)
I_{RMS}	12.17 A_{RMS} (V/A/W meter) 12.90 A_{RMS} (CRO)	11.54 A_{RMS}	0.63 A_{RMS} (V/A/W meter) 1.36 A_{RMS} (CRO)
Power Factor	0.999 (V/A/W meter) 0.999 (CRO time interval)	1	0.001 (V/A/W meter)

checked

	0.999 (CRO phase)		0.001 (CRO time interval) 0.001 (CRO phase)
Peak Voltage, V_{MAX}	175.93 V (V/A/W meter) 184.00 V (CRO)	183.847 V	7.917 V (V/A/W meter) 0.153 V (CRO)
V_{MIN}	-175.93 V (V/A/W meter) -176.00 V (CRO)	-183.847 V	7.917 V (V/A/W meter) 7.847 V (CRO)
Peak Current, I_{MAX}	17.21 A (V/A/W meter) 19.20 A (CRO)	16.32 A	0.89 A (V/A/W meter) 2.88 A (CRO)
I_{MIN}	-17.21 A (V/A/W meter) -18.02 A (CRO)	-16.32 A	0.89 A (V/A/W meter) 1.70 A (CRO)
Resistance of the load-bank resistor	10.497 Ω (LCR Meter) 10.200 Ω (V/A/W Meter) 9.690 Ω (CRO)	11.266 Ω	0.769 Ω (LCR Meter) 1.066 Ω (V/A/W Meter) 1.576 Ω (CRO)
Time interval between zero crossing	0.14 ms (V/A/W meter) 0.12 ms (CRO time interval) 0.16 ms (CRO phase)	0	0.14 ms (V/A/W meter) 0.12 ms (CRO time interval) 0.16 ms (CRO phase)
Load Phase Angle	2.56 lagging (V/A/W meter) 2.16 lagging (CRO time interval) 2.89 lagging (CRO phase)	0	2.56 lagging (V/A/W meter) 2.16 lagging (CRO time interval) 2.89 lagging (CRO phase)

Show the complete working steps to calculate all of the required parameters. [4 Marks]
Difference = |Measured - Calculated|
Real Power
Measured: 1513 W
Calculated: 1500 W (Required by labsheet)
Difference = 13 W

Reactive Power
Measured: 55 VAR
Calculated: 0 VAR

checked

As load is pure resistive, Reactive Power is 0 VAR

Difference = 55 VAR

Apparent Power

Measured: 1514 VA

Calculated: 1500 VA

$$|S_m| = \sqrt{{P_m}^2 + {Q_m}^2}$$

$$|S_m| = \sqrt{1500^2 + 0^2}$$

$$S_m = 1500 \text{ VA}$$

Difference = 14 VA

VRMS

Measured: 124.4 V (V/A/W meter), 125 V (CRO)

Calculated: 130 V (Required by labsheet)

Difference = 5.6 V (V/A/W meter), 5.0 V(CRO)

IRMS

Measured: 12.17 A (V/A/W meter), 12.9 A(CRO)

Calculated: 11.54 A

$$Apparent\ Power/VRMS = 1500/130 = 11.54\, A$$

Difference = 0.63 A (V/A/W meter), 1.36 A (CRO)

Peak Voltage, VMAX

Measured: 175.93 V (V/A/W meter), 184 V(CRO)

For V/A/W meter

$$\text{VRMS}*\sqrt{2} = 124.4*\sqrt{2} = 175.93 \text{ V}$$

Calculated: 183.847 V

$$\text{VRMS}*\sqrt{2} = 130*\sqrt{2} = 183.847 \text{ V}$$

Difference = 7.917 V (V/A/W meter), 0.152 V (CRO)

VMIN

Measured: -175.93 V (V/A/W meter), -176 V(CRO)

Calculated: -183.847 V

Difference = 7.917 (V/A/W meter), 7.847(CRO)

Peak Current, IMAX

Measured: 17.21 A (V/A/W meter), 19.2 A(CRO)

For V/A/W meter

$$\text{IRMS}*\sqrt{2} = 12.17*\sqrt{2} = 17.21 \text{ V}$$

Calculated: 16.32A

$$\text{IRMS}*\sqrt{2} = 11.54*\sqrt{2} = 16.32\text{A}$$

Difference = 0.89 A (V/A/W meter), 2.88 A (CRO)

IMIN

Measured: -17.21 A (V/A/W meter), -18.02A(CRO)

Calculated: -16.32A

Difference = 0.89 A (V/A/W meter), 1.70 A (CRO)

checked

Resistance of the load-bank resistor
Measured: 10.497Ω (LCR Meter), 10.20 Ω(V/A/W Meter), 9.69 Ω(CRO)
For V/A/W meter

VRMS/IRMS = 124.1/12.17 = 10.20 Ω

For CRO

VRMS/IRMS =125/12.9 = 9.69 Ω

Calculated: 11.265Ω

VRMS/IRMS = 130/11.54 = 11.265 Ω

Difference: 0.768 Ω (LCR Meter), 1.065 Ω(V/A/W Meter), 1.575 Ω(CRO)

Time interval between zero crossing
Measured: 0.14ms (V/A/W meter), 120us (CRO time interval), 0.16ms(CRO phase)
Using V/A/W meter

$$load\ phase\ angle\ =\ 2.56$$

time interval = load phase angle/(frequency*360) = 0.14ms

Using CRO's phase

time interval = load phase angle/(frequency*360) = 0.16ms

Calculated: 0 (Theoretical due to pure resistive circuit)
Difference = 0

Load Phase Angle
Measured: 2.56 (V/A/W meter), 2.16(CRO time interval),2.89 lagging(CRO phase)
Using V/A/W meter

$$load\ phase\ angle\ =\ cos^{-1}(PF_{VAW})$$

$$load\ phase\ angle\ =\ cos^{-1}(0.999)\text{=2.56}$$

Using CRO's time interval

$$load\ phase\ angle\ =\ 120us\ *\ (frequency\ *\ 360) = 2.16$$

Calculated: 0

0 due to pure resistive load

Difference = 0

Power Factor
Measured: = 0.999 lagging (V/A/W meter), 0.999 (CRO time interval), 0.999 (CRO phase)
For CRO Time Interval

$$PF_{CRO\ Time\ Interval}\ =\ cos(2.16)\ =\ 0.999$$

For CRO Phase

$$PF_{CRO\ Phase}\ =\ cos(2.89)\ =\ 0.999$$

Calculated: 1

$$cos(load\ phase\ angle)\ =\ cos(0)\ =\ 1$$

Difference = 0.001

checked

Insert the snapshot (picture) of:

1. *Fluke clamp meter readings for resistive load showing active power, apparent power, reactive power, V_{RMS}, I_{RMS} and p.f.*
2. *CRO waveform of load current and load voltage with proper indication, label and scale. Note: Clearly label the voltage and current waveform.* [4 Marks]

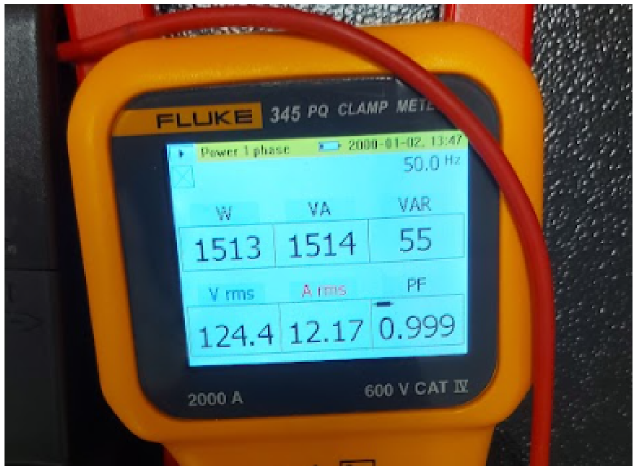
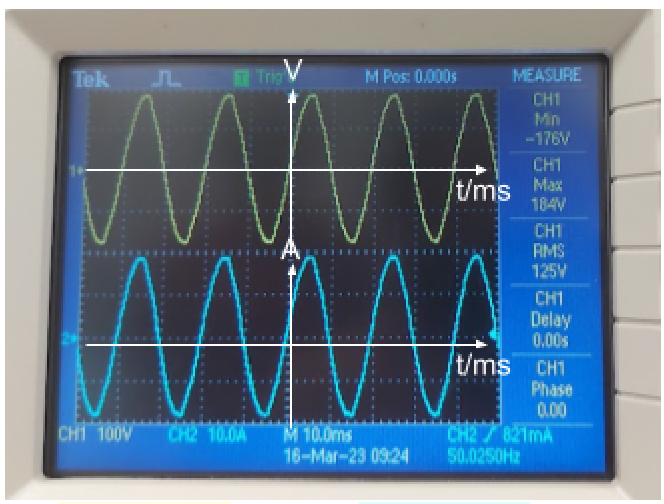


Fig. 1. V/A/W Meter Showing Power Consumed, Load Voltage and Current, and Power Factor for purely resistive load



Load Voltage	Load Current
x-scale = 1 : 10ms	x-scale = 1 : 10ms
y-scale = 1 : 100V	y-scale = 1 : 10A

Fig. 2. Voltage (Yellow) waveform along with min, max, RMS, delay, and phase measurements on the CRO for purely resistive load

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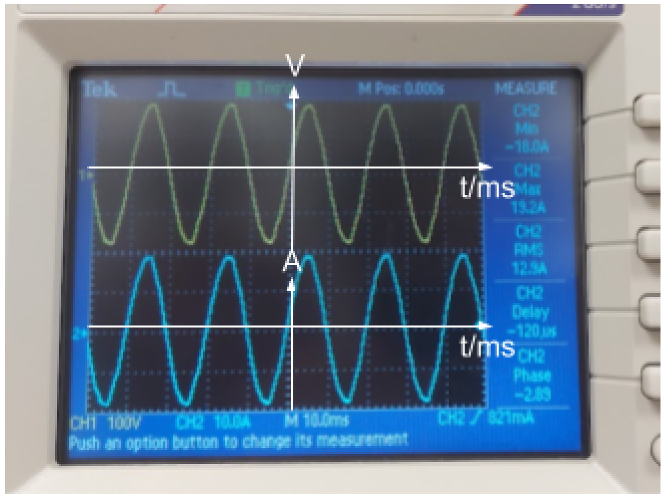

Load Voltage
x-scale = 1 : 10ms
y-scale = 1 : 100V

Load Current
x-scale = 1 : 10ms
y-scale = 1 : 10A

Fig. 3. Current (Blue) waveform along with min, max, RMS, delay, and phase measurements on the CRO for purely resistive load

Fig. 4. LCR meter showing resistance of the load to achieve 1500W power consumption

checked

2. **Inductive Load**

Adjust the inductor value to a value close to 80mH by changing the switching position [**Hint:** connect two phases of the load in parallel]. Use an LCR meter for measurement.

Record the value and remove the LCR meter.

Adjust the voltage to 100 V. Measure the current, voltage and power across the

inductor. Using the CRO, plot the waveforms of load voltage and load current.

ANALYSIS – Measure the time interval between zero crossings of the load voltage and the load current on the CRO and hence calculate the load phase angle.

Is this angle exactly 90 degrees lagging? If not, why not, and what is the power factor of the inductor? Compare the value with the reading from the V/A/W meter.

Calculate the resistance and inductance value of the inductor. How does the inductance value compare with the nominal 80mH nameplate value?

Analysis Answers:
(Please answer all analysis questions by including all relevant discussions, explanations, calculations, equations and figures as necessary) [7 Marks]

Measure the time interval between zero crossings of the load voltage and the load current on the CRO and hence calculate the load phase angle.

Time interval measured = delay of voltage - delay of current = 5.56ms

Frequency = 50Hz

Load Phase angle, θ = f*360*time interval = 100.08 degree

Is this angle exactly 90 degrees lagging? If not, why not, and what is the power factor of the inductor? Compare the value with the reading from the V/A/W meter.
No, it is not exactly 90 degrees lagging, as shown by the time interval and phase measurements. This could be attributed to the presence of internal resistance that produced quite a significant active power that disrupted the 90 degree loading.

Theoretical power factor = cos (θ) = cos (90) = 0

Measured power factor (V/A/W meter) = 0.108

Measured power factor (CRO Phase) = cos(100.08) = 0.18

Measured power factor (CRO Time Interval) = cos(99.89) = 0.16

Calculate the resistance and inductance value of the inductor. How does the inductance value compare with the nominal 80mH nameplate value?

We can calculate the resistance and inductance value from the Real Power and Irms over the load, and the inductance from

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the Reactive Power and Irms. We assume the load only have resistance and inductance, with no capacitance

$P = I^2 R$

$67 = (5.75^2)R$

$R = 2.03\Omega$

$Q = I^2 X_m$

$572 = (5.75^2)X_l$

$X_m = 17.3j\,\Omega$

Using Xm, we can further calculate the inductance by disregarding capacitance

$X_l = \omega L$

$17.3 = 2\pi \times 50 * L$

$L = 55.07mH$

The inductance value deviates from the 80mH by 31%, which could be caused by stray capacitance in the inductor load that reduced the total reactance of the load.

RESULT- Show the complete workings for the calculation. Include all the relevant calculation steps and equations. (Ensure your answer is provided with proper units) [5 Marks]

Parameter	Measured Value (Unit)	Calculated Value (Unit)	Differences
Real Power	67 W	0 W	67 W
Reactive Power	576 VAR	397.84 VAR	178.16 VAR
Apparent Power	572 VA	397.84 VA	174.16 VA
V_{RMS}	100.3 V_{RMS} (V/A/W meter) 101.0 V_{RMS} (CRO)	100 V_{RMS}	0.3 V_{RMS} (V/A/W meter) 1.0 V_{RMS} (CRO)
I_{RMS}	5.75 A_{RMS} (V/A/W meter) 6.12 A_{RMS} (CRO)	3.98 A_{RMS}	1.77 A_{RMS} (V/A/W meter) 2.14 A_{RMS} (CRO)
Power Factor	0.116 (V/A/W meter) 0.18 (CRO time interval) 0.18 (CRO phase)	0	0.116 (V/A/W meter) 0.18 (CRO time interval)

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			0.18 (CRO phase)
Peak Voltage, V_{MAX}	141.84 V (V/A/W meter) 148 V(CRO)	141.42V	0.42 V_{MAX} (V/A/W meter) 6.58 V_{MAX} (CRO)
V_{MIN}	-141.84 V (V/A/W meter) -144 V(CRO)	-141.42V	0.42 V_{MIN} (V/A/W meter) 2.58 V_{MIN} (CRO)
Peak Current, I_{MAX}	8.13 A (V/A/W meter) 9.6 A(CRO)	5.614A	2.516 A (V/A/W meter) 3.986 A (CRO)
I_{MIN}	-8.13 A (V/A/W meter) -8.8 A (CRO)	-5.614A	2.516 A (V/A/W meter) 3.186 A (CRO)
Inductance from LCR meter	78.01mH (LCR Meter) 55. 06mH (V/A/W Meter)	80mH	1.99 mH (LCR Meter) 24.94 mH (V/A/W Meter)
Time interval between zero crossing	4.63ms (V/A/W meter) 5.56ms (CRO time interval) 5.55ms (CRO phase)	5 ms	0.37 ms 0.56 ms 0.55 ms
Load Phase Angle	83.34 lagging (V/A/W meter) 100.08 lagging (CRO time interval) 99.89 lagging (CRO phase)	90° lagging	6.66° 10.08 ° 9.89 °

Show the complete working steps to calculate all of the required parameters. [4 Marks]

Difference = |Measured - Calculated|
Real Power
Measured: 67 W
Calculated: 0 W (Assumed Pure Inductive)
Difference = 67 W

checked

Reactive Power
Measured: 572 VAR
Calculated: $397.84\,VAR$

$$V = 100V$$
$$L = 80mH$$
(Assume Pure Inductor)
$$Z = 2 * \pi i * f * L = 2 * \pi * 50 * 80mH = 25.13j$$
$$I = V/Z_m = 100/25.13 = 3.98A$$
$$Q_m = I^2 Z_m = 3.98^2 * 25.13 = 397.84\,VAR$$

Difference = VAR

Apparent Power
Measured: 576 VA
Calculated: 397.84VA

$$|S_m| = \sqrt{P_m^{\ 2} + Q_m^{\ 2}}$$
$$S_m = \sqrt{0^2 + 397.84^2}$$
$$S_m = 397.84\,VA$$

Difference = 178.16 VA

VRMS
Measured: 100.3 V (V/A/W meter), 101 V (CRO)
Calculated: 100 V (Required by labsheet)
Difference = 0.3 V (V/A/W meter), 1.0 V (CRO)

IRMS
Measured: 5.75 A (V/A/W meter), 6.12 A (CRO)
Calculated: 3.98 A

Apparent Power/VRMS = 397.93/100 = 3.98 A

Difference = 1.77 A (V/A/W meter), 2.14 A (CRO)

Peak Voltage, VMAX
Measured: 141.84 V (V/A/W meter), 148 V (CRO)
For V/A/W meter

VRMS*$\sqrt{2}$ = 100.3*$\sqrt{2}$= 141.84 V

Calculated: 141.42 V

VRMS*$\sqrt{2}$ = 100*$\sqrt{2}$= 141.42 V

Difference = 0.42 V(V/A/W meter), 6.58 V (CRO)

VMIN
Measured: -141.84 V (V/A/W meter), -144 V (CRO)
Calculated: -141.42 V
Difference = 0.42 V (V/A/W meter), 2.58 V (CRO)

checked

Peak Current, IMAX
Measured: 8.13 A (V/A/W meter), 9.6 A(CRO)

$$IRMS*\sqrt{2} = 5.75*\sqrt{2} = 8.13\ A$$

Calculated: 5.61 A

$$IRMS*\sqrt{2} = 3.97*\sqrt{2} = 5.61A$$

Difference = 2.52 A (V/A/W meter), 3.99 A (CRO)

IMIN
Measured: -8.13 A (V/A/W meter), -8.8 A(CRO)
Calculated: -5.61A
Difference = 2.52 A (V/A/W meter), 3.19 A(CRO)

Inductance from LCR meter

Measured: 79.93mH (LCR Meter)

Calculated: 80mH (as required by labsheet)

Difference = 0.07 mH

Time interval between zero crossing
Measured: 4.63ms (V/A/W meter), 5.56ms (CRO time interval), 5.55ms (CRO phase)
Using V/A/W meter

$$load\ phase\ angle\ = 83.34$$

time interval = load phase angle/(frequency*360) = 4.63ms

Using CRO's phase

time interval = load phase angle/(frequency*360) = 5.55ms

Calculated: 5ms (Theoretical)

pure inductive circuit will have a 90 degree load phase angle

frequency = 50Hz

frequency*360*time interval = load phase angle

time interval = 90/(360*50)=5ms

Difference = 0

Load Phase Angle
Measured: 83.34 (V/A/W meter), 100.08(CRO time interval), 99.89(CRO phase)
Using V/A/W meter

$$load\ phase\ angle\ = cos^{-1}(PF_{VAW})$$

$$load\ phase\ angle\ = cos^{-1}(0.108) = 83.34$$

Using CRO's time interval

$$load\ phase\ angle\ = time\ interval\ *\ (frequency\ *\ 360)$$

Calculated: 90 lagging

90 lagging due to purely inductive load

checked

Difference = 0

Power Factor
Measured: = 0.116 lagging (V/A/W meter), 0.18 lagging(CRO time interval), 0.17 lagging(CRO phase)
For CRO Time Interval

$$PF_{CRO\ Time\ Interval} = cos(load\ phase\ angle) = 0.18$$

For CRO Phase

$$PF_{CRO\ Phase} = cos(load\ phase\ angle) = 0.17$$

Calculated: cos(load phase angle measured) = cos(90) = 0
0 lagging due to purely inductive load

Difference = 0.116 lagging (V/A/W meter), 0.18 lagging(CRO time interval), 0.17 lagging(CRO phase)

Insert the snapshot (picture) of:

3. *Fluke clamp meter readings for resistive load showing active power, apparent power, reactive power, $V_{RMS,}$ I_{RMS} and p.f.*
4. *CRO waveform of load current and load voltage with proper indication, label and scale. Note: Clearly label the voltage and current waveform.* [4 Marks]

Picture of V/A/W Meter

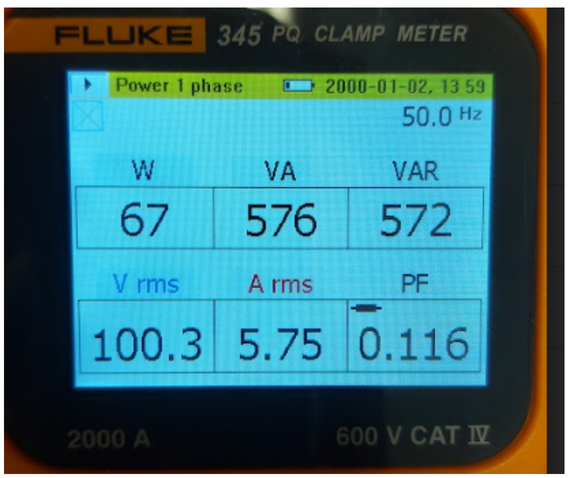

Fig. 5. V/A/W Meter Showing Power Consumed, Load Voltage and Current, and Power Factor for purely inductive load

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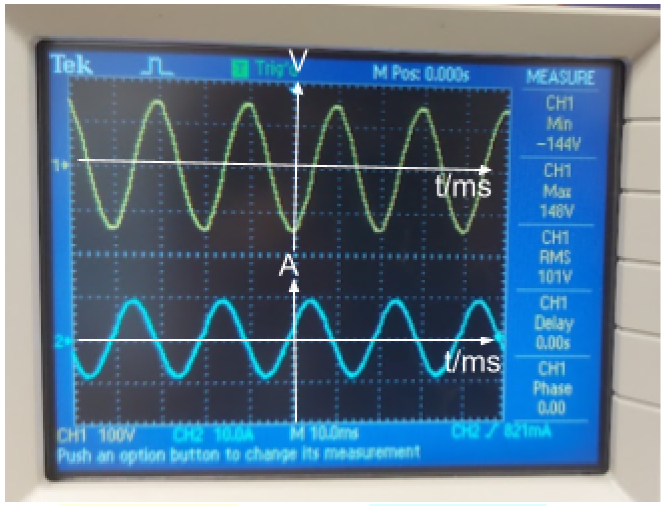
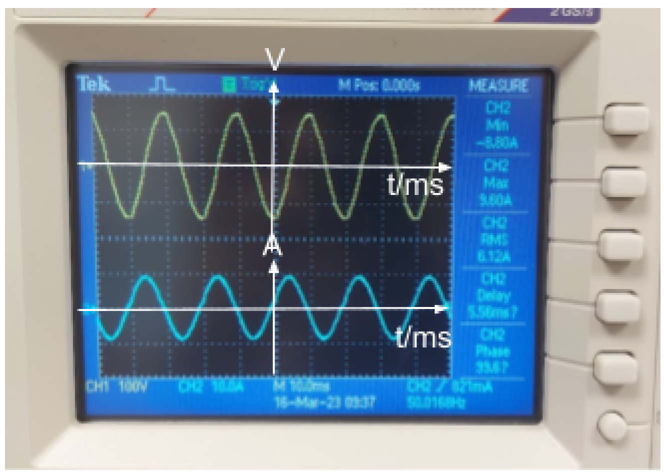


Load Voltage
x-scale = 1 : 10ms
y-scale = 1 : 100V

Load Current
x-scale = 1 : 10ms
y-scale = 1 : 10A

Fig. 6. Voltage (Yellow) waveform along with min, max, RMS, delay, and phase measurements on the CRO for purely inductive load



Load Voltage
x-scale = 1 : 10ms
y-scale = 1 : 100V

Load Current
x-scale = 1 : 10ms
y-scale = 1 : 10A

Fig. 7. Current (Blue) waveform along with min, max, RMS, delay, and phase measurements on the CRO for purely inductive load

Note:
For an inductive load the current graph should be lagging the voltage graph by 5ms. Due to the reversed polarities at the terminals during measurement, the measured graphs in figure (7) & (8) shows current leading voltage which is erroneous.

checked

Picture of LCR Meter

Fig. 8. LCR meter showing inductor bank's inductor value

3. **Capacitive Load**

Switch the capacitive load on (by taking the first switch to position '1') and adjust the capacitor value to a value close to 40 µF by changing the second switch [**Hint:** connect two phases of the load in parallel]. Use an LCR meter for measurement. Record the value and remove the LCR meter.

Adjust the voltage to 130 V. Measure the current, voltage and power across the

capacitor. Using the CRO, plot the waveforms of load voltage and load current.

ANALYSIS – Measure the time interval between zero crossings of the load voltage and the load current on the CRO and hence calculate the load phase angle.

Is this angle exactly 90 degrees leading? If not, why not? What is the power factor of the capacitor? Compare the value with the reading from the V/A/W meter.

Calculate the capacitance value of the capacitor. How does this value compare with the nominal 40 µF nameplate value?

Comment on the shape of the capacitor current – is it sinusoidal? If no, try and determine the dominant harmonic frequencies present from the ripple. Why is this effect more noticeable for capacitor load, compared to the resistive and inductive load?

WARNING: Discharge the capacitor bank (bring the first switch back to position '0').

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Measure the time interval between zero crossings of the load voltage and the load current on the CRO and hence calculate the load phase angle.

Time interval measured = delay of voltage - delay of current = 4.84ms

Frequency = 50Hz

Load Phase angle, θ = f*360*time interval = 87.12

Is this angle exactly 90 degrees leading? If not, why not? What is the power factor of the capacitor? Compare the value with the reading from the V/A/W meter.

No, it is not exactly 90 degrees leading, but it is approximately close, as shown by the time interval and phase measurements. It could be due to the internal resistance that produces active power that disrupted the 90 degree loading of the phasor.

Theoretical power factor = cos (θ) = cos (90) = 0

Measured power factor (V/A/W meter) = 0.027

Measured power factor (CRO Phase) = 0.05

Measured power factor (CRO Time Interval) = 0.05

The pf values obtained from the VAW and CRO readings are approximately close

Calculate the capacitance value of the capacitor. How does this value compare with the nominal 40 µF nameplate value?

We can calculate the resistance from the Real Power and Irms over the load, and the capacitance from the Reactive Power and Irms. We assume the load only have resistance and inductance, with no capacitance

$P = I^2R$

$6 = (1.68^2)R$

$R = 2.12\,\Omega$

$Q = I^2X_m$

$219 = (1.68^2)X_l$

$X_m = 77.59\,\Omega$

Using Xm, we can further calculate the inductance by disregarding capacitance

$X_l = 1/(wC)$

$77.59 = 1/(2\pi * 50 * C)$

$C = 41\,uF$

checked

The inductance value deviates from the uF by 2.56%, which could be caused by stray inductance in the inductor load that increases the total reactance of the load.

Comment on the shape of the capacitor current – is it sinusoidal? If no, try and determine the dominant harmonic frequencies present from the ripple. Why is this effect more noticeable for capacitor load, compared to the resistive and inductive load?
The shape of the capacitor current is sinusoidal with ripples in the waveform. We determine the dominant frequency to 50Hz which is the frequency of the source voltage. The frequency in the ripples could be caused by a high frequency noise.

This effect is not noticeable in the resistive load current as the impedance of the resistive load remains the same regardless of frequency of the source.

The effect is not noticeable in inductive load current as impedance of inductors increases as frequencies increases, thus high frequency noise in the source is attenuated by the impedance

The effect is most noticeable in capacitive loads due to its impedance being inversely proportional to the source frequency. The high frequency noise has lesser impedance, and thus is able to draw high frequency current from the source, thus creating the high frequency ripples in the waveform.

RESULT- Show the complete workings for the calculation. Include all the relevant calculation steps and equations. (Ensure your answer is provided with proper units) [5 Marks] **(Note: the power was taken in reverse by accident)**

Parameter	Measured Value (Unit)	Calculated Value (Unit)	Differences
Real Power	6W	0W	6W
Reactive Power	219 VAR	212.38VAR	6.62VAR
Apparent Power	220 VA	212.38 VA	7.62VA
V_{RMS}	130.8 V (V/A/W meter) 131 V (CRO)	130 V	0.8V_{RMS} (V/A/W meter) 1.0V_{RMS} (CRO)
I_{RMS}	1.68 A (V/A/W meter) 1.86 A (CRO)	1.63A	0.05A (V/A/W meter) 0.23A (CRO)
Power Factor	0.027 (V/A/W meter) (CRO time interval) 0.05 (CRO phase)	0	0.027 (V/A/W meter) (CRO time interval) 0.05 (CRO phase)

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Peak Voltage, V_{MAX}	184.98 V (V/A/W meter) 192 V(CRO)	183.85V	1.13 V (V/A/W meter) 8.15 V(CRO)
V_{MIN}	-184.98 V (V/A/W meter) -185 V(CRO)	-183.85V	1.13 V (V/A/W meter) 1.15 V(CRO)
Peak Current, I_{MAX}	2.38 A (V/A/W meter) 3.6 A (CRO)	2.305A	0.075 A (V/A/W meter) 1.295 A(CRO)
I_{MIN}	-2.38 A (V/A/W meter) -2.64 A(CRO)	-2.305A	0.075 A (V/A/W meter) 0.335 A (CRO)
Capacitance from LCR meter	40.81 uF (LCR Meter) 41 uF (V/A/W Meter)	40uF	0.81 mH (LCR Meter) 1.00 mH (V/A/W Meter)
Time interval between zero crossing	4.91 ms (V/A/W meter) 4.84 ms (CRO time interval) 4.83 ms (CRO phase)	5 ms	0.09 ms (V/A/W meter) 0.16 ms (CRO time interval) 0.17 ms (CRO phase)
Load Phase Angle	88.45 leading(V/A/W meter) 87.12 leading (CRO time interval) 86.9 leading (CRO phase)	90° leading	1.55 leading(V/A/W meter) 2.88 leading (CRO time interval) 3.10 leading (CRO phase)

Show the complete working steps to calculate all of the required parameters. [4 Marks]
Difference = |Measured - Calculated|
Real Power
Measured: 6 W
Calculated: 0 W (Assumed Pure Inductive)
Difference = 6 W

Reactive Power

Measured: 219 VAR
Calculated: 212.38 VAR

$$V = 100V$$
$$L = 40uF$$
(Assume Pure Capacitor)
$$Z = 1/(2 * \pi i * f * L) = 1/(2 * \pi * 50 * 80mH) = 79.58j\,\Omega$$
$$I = V/Z_m = 130/79.58 = 1.63A$$
$$Q_m = I^2 Z_m = 1.63^2 * 79.58 = 212.38\,VAR$$

Difference = 6.62 VAR

Apparent Power
Measured: 220 VA
Calculated: 212.38VA

$$|S_m| = \sqrt{P_m^{\ 2} + Q_m^{\ 2}}$$
$$S_m = \sqrt{0^2 + 212.38^2}$$
$$S_m = 212.38\,VA$$

Difference = 7.62 VA

VRMS
Measured: 130.8 V (V/A/W meter), 131 V(CRO)
Calculated: 130 V (Required by labsheet)
Difference = 0.8 V (V/A/W meter), 1.0 V (CRO)

IRMS
Measured: 1.68 A (V/A/W meter), 1.86 A(CRO)
Calculated: 1.63 A

Apparent Power/VRMS = 212.38/130 = 1.63 A

Difference = 0.05 A (V/A/W meter), 0.23 A (CRO)

Peak Voltage, VMAX
Measured: 184.98 V (V/A/W meter), 192 V(CRO)
For V/A/W meter

VRMS*$\sqrt{2}$ = 130.8*$\sqrt{2}$= 184.98 V

Calculated: 183.85 V

VRMS*$\sqrt{2}$ = 130*$\sqrt{2}$= 183.85 V

Difference = 1.13 V (V/A/W meter), 8.15 V (CRO)

VMIN
Measured: -184.98V (V/A/W meter), -185 V(CRO)
Calculated: -183.85 V
Difference = 1.13 V (V/A/W meter), 1.15 V (CRO)

Peak Current, IMAX

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Measured: 2.38 A (V/A/W meter), 3.6 A(CRO)

$$IRMS*\sqrt{2} = 1.68*\sqrt{2} = 2.38A$$

Calculated: 2.305A

$$IRMS*\sqrt{2} = 1.63*\sqrt{2} = 2.305A$$

Difference = 0.075 A (V/A/W meter), 1.295 A (CRO)

IMIN

Measured: -2.38 A (V/A/W meter), -2.64 A (CRO)
Calculated: -2.305 A
Difference = 0.075 A (V/A/W meter), 0.335 A (CRO)

Capacitance from LCR Meter

Measured: 40.81uF (LCR Meter)

Calculated: 40uF (as required by labsheet)

Difference = 0.81uF

Time interval between zero crossing

Measured: 4.91ms (V/A/W meter), 4.84ms (CRO time interval),4.83ms (CRO phase)
Using V/A/W meter

time interval = load phase angle/(frequency*360) = 88.45/(50*360) = 4.91ms'

Using CRO's phase

time interval = load phase angle/(frequency*360) =86.9/(50*360) = 4.83ms

Calculated: 5ms (Theoretical)

pure capacitive circuit will have a 90 degree load phase angle

frequency = 50Hz

frequency*360*time interval = load phase angle

time interval = 90/(360*50)=5ms

Difference = 0.17ms

Load Phase Angle

Measured: 88.45 (V/A/W meter),87.12 (CRO time interval),86.9 (CRO phase)
Using V/A/W meter

$$load\ phase\ angle\ = cos^{-1}(0.027) = 88.45$$

Using CRO's time interval

$$load\ phase\ angle\ = time\ interval\ *\ (frequency\ *\ 360)\ =\ 4.84m\ *\ 50\ *\ 360\ =\ 87.12$$

Calculated: 90 Leading

90 leading due to purely capacitive load

Difference = 1.55 (V/A/W meter), 2.88 (CRO time interval), 3.10 (CRO phase)

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Power Factor

Measured: = 0.027 leading(V/A/W meter), 0.05(CRO time interval),0.05 (CRO phase)

For CRO Time Interval

$$PF_{CRO\ Time\ Interval} = cos(87.12) = 0.05$$

For CRO Phase

$$PF_{CRO\ Phase} = cos(86.9) = 0.05$$

Calculated: cos(load phase angle measured) = cos(90) = 0

0 leading due to purely capacitive load

Difference: 0.027 leading(V/A/W meter), 0.05(CRO time interval),0.05 (CRO phase)

Insert the snapshot (picture) of:

5. *Fluke clamp meter readings for resistive load showing active power, apparent power, reactive power, V_{RMS}, I_{RMS} and p.f.*
6. *CRO waveform of load current and load voltage with proper indication, label and scale. Note: Clearly label the voltage and current waveform.* [4 Marks]

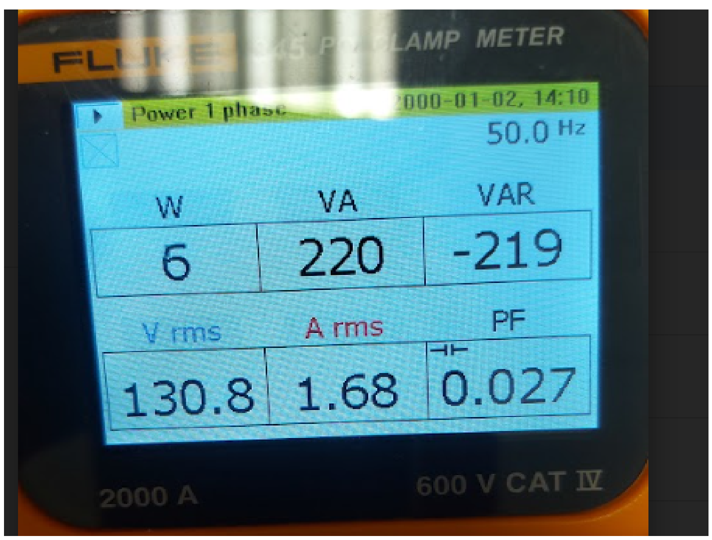
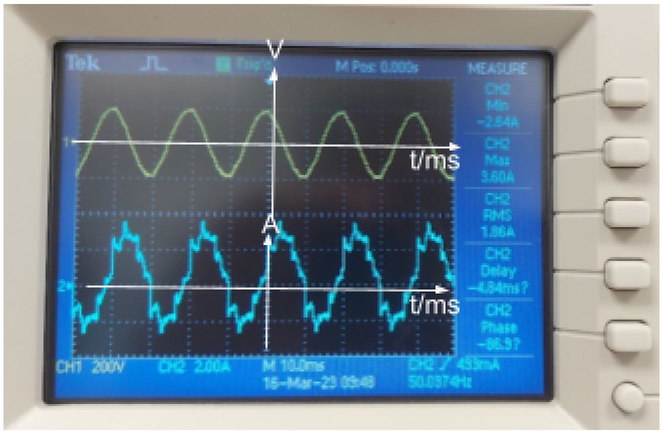


Fig. 9. V/A/W Meter Showing Power Consumed, Load Voltage and Current, and Power Factor for purely capacitive load

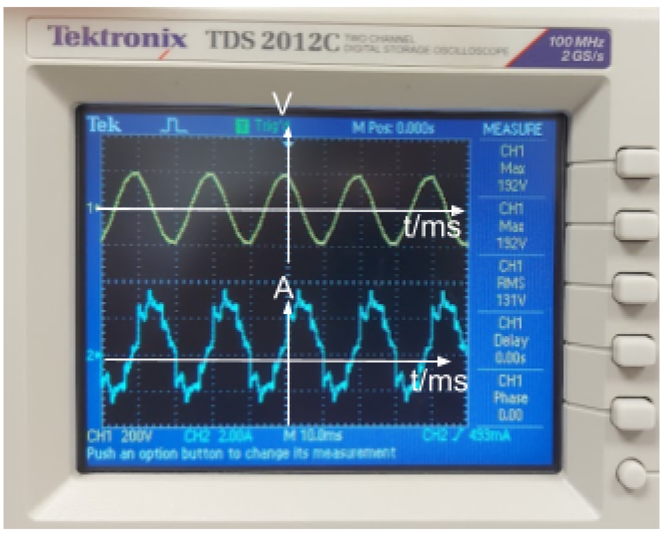
checked



Load Voltage
x-scale = 1 : 10ms
y-scale = 1 : 200V

Load Current
x-scale = 1 : 10ms
y-scale = 1 : 2A

Fig. 10. Voltage (Yellow) waveform along with min, max, RMS, delay, and phase measurements on the CRO for purely capacitive load



Load Voltage
x-scale = 1 : 10ms
y-scale = 1 : 200V

Load Current
x-scale = 1 : 10ms
y-scale = 1 : 2A

Fig. 11. Current (Blue) waveform along with min, max, RMS, delay, and phase measurements on the CRO for purely capacitive load

Note:
For a capacitive load the current graph should be leading the voltage graph by 5ms. Due to the reversed polarities at the terminals during measurement, the measured graphs in figure (10) & (11) shows current lagging voltage which is erroneous.

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Fig. 12. LCR meter showing the capacitor bank's value

Discussion

1. What are the differences in terms of power components for resistive, capacitive and inductive elements in an AC circuit? What is the definition of power factor and apparent power? How can the power factor be expressed in terms of circuit impedance and circuit power? [10 Marks]

What are the differences in terms of power components for resistive, capacitive and inductive elements in an AC circuit?

The power components for resistive elements is known as active power, measured in Watts, or also known as true power. This is the power that is used to do useful work in a system and powers the system. Resistive components, such as resistors, consume power in proportion to the square of current flowing through, and dissipates in the form of heat energy

The power components for capacitive and inductive elements are known as reactive power, measured in VAR. Reactive power is needed to generate a magnetic field and flux in its applications. For capacitive loads, the phase of the current will lead behind the voltage phase, while in inductive load, the phase of the current will lag behind the voltage phase.

Capacitive components store energy in the electric field, whereas inductive components store energy in the magnetic field, they do not consume real power, but affect the power consumed by other components.

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What is the definition of power factor and apparent power?
Power factor refers to the ratio of real power to the apparent power in an AC circuit. Apparent power is the magnitude of the vectorial sum of the real and reactive power

How can the power factor be expressed in terms of circuit impedance and circuit power?
pf = cos(arctan(X/R)) or pf = R/Z

pf = P/|S|

where X is the reactance of the system, R is the resistance of the system, P is the real power of the system, and S is the complex power of the system.

Power factor can also be calculated by the angle between real power (P) and complex power (S), which is the cosine of the angle of the circuit impedance

2. What are the difficulties encountered during the experiment? Justify the differences between the measured values and calculated values if there are any discrepancies? In your opinion, which of the obtained values (measured values or calculated values) are more accurate? In real-world practice, suggest at least five steps which can be taken to prevent any measurement error(s)? [10 Marks]

The difficulties of this experiment is the inexperience of handling the equipment. As this is the first time we ever encountered high voltage-high current equipment, we had a hard time trying to work around it and familiarizing ourselves with the procedures to use it. While the lab supervisor did demonstrate the necessary steps in the experiment, he needs to understand that students need practice and time to get used to the equipment, and not just questioning whether the student was paying attention or not when students are seeking assistance.

There were discrepancies in the values measured and calculated, which can be attributed to the non-ideality of the lab equipment such as internal resistance, stray inductance and stray capacitance in different equipment. Calibration errors and loose connections in the setup could also lead to the discrepancy in values.

In my opinion, the measured values should be more accurate as it reflects real life non-idealities of the equipment.. The calculated values only present a guideline to how far the values can deviate when measured. However, this only holds true provided all preventive measures have been taken care of, which would be explained below.

In real world practice, to prevent any measurement errors, the following steps can be taken
- *Calibrate any measuring equipment to prevent errors like zero offset errors*
- *Check the initial setup of all equipment (CRO probes and scaling, tight connections etc.) to make sure that the there is no mistakes in the setup that could lead to wrong measurements*
- *Always perform safety measures taught in the lab, like turning on the power supply only when resistance is maximum to limit current flow, turning off the power supply when not in use, turning off measuring equipment when not in use. All of these measures serve to lengthen the shelf life of the equipment and allow it to be accurate when measuring.*

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- *The experiment has to be conducted in a controlled environment that is free from environment variables like temperature.*
- *Multiple measurements can be taken and averaged out to reduce the possibility of measurement error.*

Conclusion and Findings [14 Marks]

This experiment introduced us to single phase AC networks and demonstrated the relationship between voltage and current with different types of load - resistive, inductive, and capacitive.

The experimental results prove the following statements:

When the load is purely resistive, both the voltage and current are in phase [1], [2]. A purely resistive load consumes only real power, which means that the reactive power in the system is zero, and that the total apparent power is equal to the real power. Since the power factor is the cosine of the phase difference between the voltage and current [1], [5], or the ratio between real power and apparent power [1], [5], the system must have a power factor of one. However, in a real environment, where there are parasitic inductance and capacitance within the components of the system, the power factor can never be one, but close to it.

When the load is purely inductive, the current ***lags*** *the voltage with a phase difference of 90 degrees [1], [2]. A purely inductive system consumes only reactive power and therefore, the real power consumed must be zero, and that the total apparent power equals the reactive power. Using the definition of power factor defined in the paragraph above, the power factor of a purely inductive circuit must be zero. In a real environment where nothing is ideal, there is bound to be internal resistance in the components of the system, which only allows the power factor to be close to zero but never exactly zero.*

When the load is purely capacitive, the current ***leads*** *the voltage with a phase difference of 90 degrees [1], [2]. Similar to purely inductive loads, the apparent power of the system is fully converted into reactive power. This means that the power factor of a purely capacitive circuit is also zero. However, the presence of internal resistances within components like wires, power supplies, etc., are bound to consume some real power, causing the power factor to be close to zero but never exactly zero.*

By investigating these three basic types of load, we can conclude that more complicated loads are just a combination of R, L, and C components [3]. Simply put, all types of load can be represented by having a certain weightage of resistive, inductive, and capacitive components. The power factor of the load will then be determined by how much real and reactive power the load consumes, and the dominant type of load will dictate whether the power factor is close to unity, leading, or lagging [4].

In summary, we have learnt the distinctions and characteristics of resistive, capacitive, and inductive loads. We have observed how similar the theoretical values align with the experimental values obtained. Although they are not completely identical, we can say with confidence that these deviations are expected due to non-controllable factors such as internal resistances and parasitic inductance or capacitance [6].

checked

References (Minimum 3 References) [6 Marks]

[1] C. R. Sarimuthu, "Power Systems Analysis- AC Systems", ECE3051 - Electrical Energy Systems, Department of Electrical and Computer Systems Engineering, Monash University Malaysia, 2020

[2] A. Javeri, "Top 3 Types of Electrical Load - Resistive, Inductive & Capacitive", 2022, https://www.ny-engineers.com/blog/top-3-types-of-electrical-load-resistive-inductive-capacitive (Accessed on 16 March 2023).

[3] K. Beck, "Types of Electrical Loads", 2018, https://sciencing.com/types-electrical-loads-8367034.html (Accessed on 16 March 2023).

[4] Fluke, "What is Power Factor and Why Is It Important?", https://www.fluke.com/en-my/learn/blog/power-quality/power-factor-formula#:~:text=It%20is%20found%20by%20multiplying,than%20a%2075%25%20power%20factor. (Accessed on 16 March 2023).

[5] All About Circuits, "Calculating Power Factor", https://www.allaboutcircuits.com/textbook/alternating-current/chpt-11/calculating-power-factor/ (Accessed on 16 March 2023).

[6] Electrical Engineering Info, "Different Types of Errors in Electrical Measuring Instruments", 2016, https://www.electricalengineeringinfo.com/2016/11/what-different-types-of-errors-in-electrical-measuring-instruments-gross-systematic-random.html (Accessed on 16 March 2023).

******** THE END *******

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