EE 256: POWER AND ENERGY

Experiment: Power Factor Improvement

(3 hours)

DATE: 29/052025..................................

CAUTION: High voltages are present in this Laboratory Experiment! Do not make any connections when the power is on. The power should be turned off after completing each set of measurements.

INTRODUCTION

The course EE256 - Power and Energy contains sections of (i) Three phase Systems, (ii) Measurement of Power/Energy, (iii) Tariff and Demand Side Management sections. This experiment covers power measurement of single-phase system and power factor improvement with a capacitor.

LEARNING OUTCOMES:

- LO 2: Discuss and demonstrate different methods of power measurements (covering attributes of WAl and WA2)
- LO 5: Calculate the power factor correction capacitors required for different applications (covering attributes of WA1 and WA2)

OBJECTIVES:

To understand

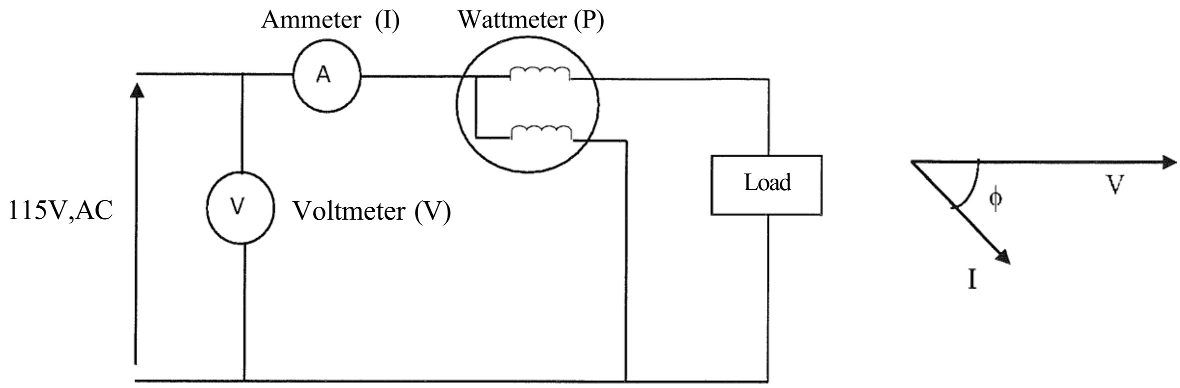
1. the load voltage and current waveform patterns for different types of loads (LO2)
2. power factor improvement with fixed capacitors (LO 5)

APPARATUS:

- Single Phase Transformer: 220V/110V
- Single Phase Wattmeter: 5A, 240V (YOKOGAWA)
- AC Ammeter: 0 SA (YOKOGAWA)
- AC Voltmeter: 0 300V (YOKOGAWA) & 0-150V (YOKOGAWA)
- Variable resistor: 1H/13A
- Variable AC Supply
- Digital Oscilloscope
- Resistive Load: 330a/2A.
- Variable Capacitor: (Terco MV1102)
- Variable Inductor: (ITALTEC or Terco MV1102)

TMEORY

1. Power factor calculation using meter readings



(a) Meter connections (b) Phasor diagram

Figure 1. Power factor calculation

Consider Figure 01.

Active Power P,

$$P = V \times I \times \cos\phi$$

$$\text{Power Factor} = \frac{P}{(V \times I)}$$

2. Power factor calculation using wave forms

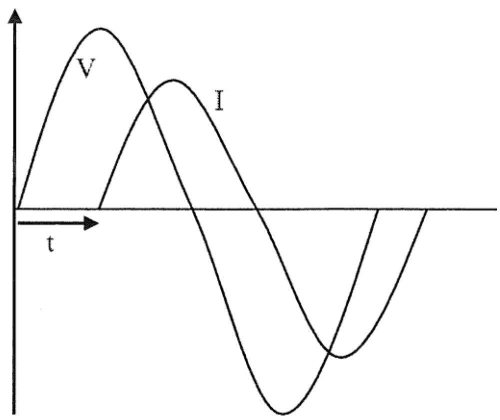


Figure 2: Voltage and Current Waveforms

Consider Figure2.

Phase difference in time = t s

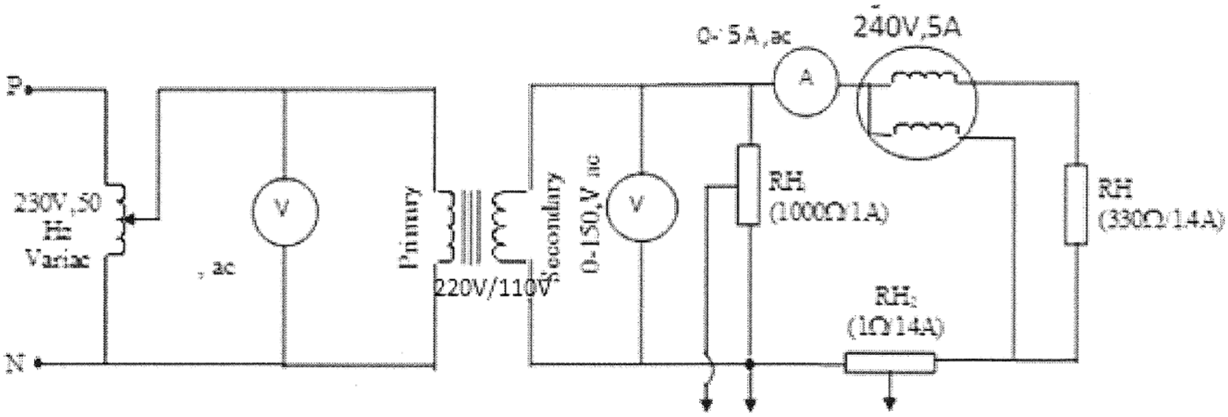
$$\omega = 2\pi f$$

Phase difference in angle = (ωt) rad

Power factor = $\cos(\omega t)$

PART 01: RESISTIVE LOAD

1. Connect the circuit as shown in Figure 3.



CH COM CH2

Figure 3. Circuit Diagram

2. Set the **Variac to zero position.**
3. Set the rheostat ‘RH_1 and ‘RH_2’ to the minimum position.
4. Show the circuit to the instructor in-charge of the experiment.
5. Turn on the oscilloscope.
6. Set the Time/DIV of the oscilloscope to 0.2 ms/DIV.
7. Set the Volts/DIV of CH_1 Of oscilloscope to 1V/DIV.
8. Set the Volts/DIV of CH_2 of oscilloscope to 1V/DIV.
9. Connect the input, as in Figure 3, to the supply.
10. Turns on the supply
1i. Increase the Variac voltage gradually until the secondary voltage is 110V.
12. Adjust the rheostats ‘RH_1’ and ‘RH_2’ slightly to get the full wave form on the oscilloscope screen.
13. Observe record the voltage and current waveforms
14. Record waveforms displayed on the screen of the oscilloscope.
15. Record the readings of wattmeter, ammeter and voltmeters
16. **Gradually reduce the Variac output until the primary voltage of the transformer is zero.**
17. **Turn off the supply.**
18. **Disconnect the circuit input from the supply.**

PART 02: RESISTIVE LOAD PARALLEL WITH INDUCTIVE LOAD

1. Connect the circuit as shown in Figure 4

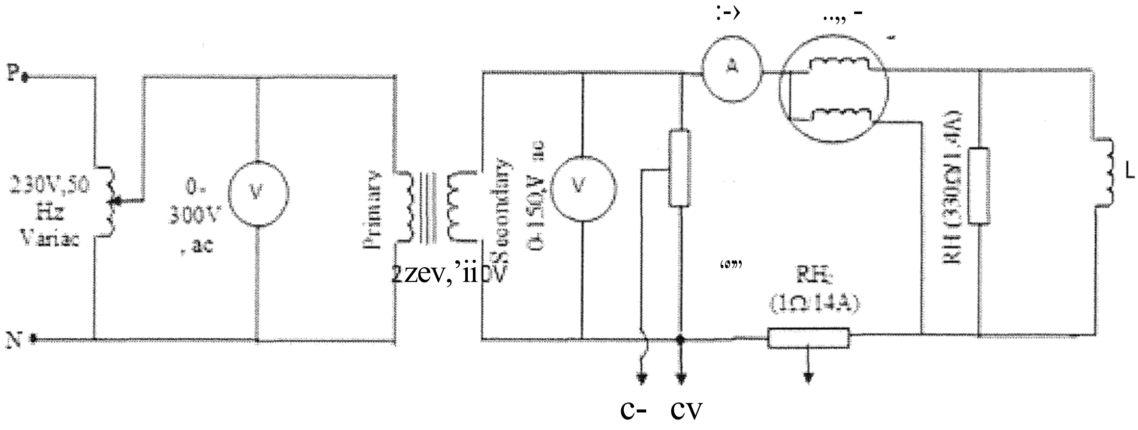


Figure 4: Circuit Diagram

2. Set the **Variac to zero position.**
3. Set the rheostat RH_1, RH_2 to the minimum position.
4. Show the circuit to the instructor in-charge of the experiment.
5. Turn on the oscilloscope.
6. Set the Time/DIV of the oscilloscope to 0.5 ms/DIV.
7. Set the Volts/DIV of CH_1 of oscilloscope to IV/DIV.
8. Set the Volts/DIV of CH_2 of oscilloscope to 1V/DIV.
9. Connect the input, as in Figure 4, to the supply.
10. Turn on the supply
i1. Increase the Variac voltage gradually until the secondary voltage is 110V.
12. Adjust the Rheostats RH_1 and RH_2 slightly to get the voltage and total current full wave form on the oscilloscope screen. Observe and record the voltage wave form and total current waveform.
13. **Gradually reduce the Variac to zero position and power off the circuit.**
14. Connect the circuit as shown in Figure 05 Adjust the Rheostats RH_1 and RH_3 slightly to get the voltage and inductor current full wave form on the oscilloscope screen. Observe record the voltage waveform and current flowing through the inductor waveform.

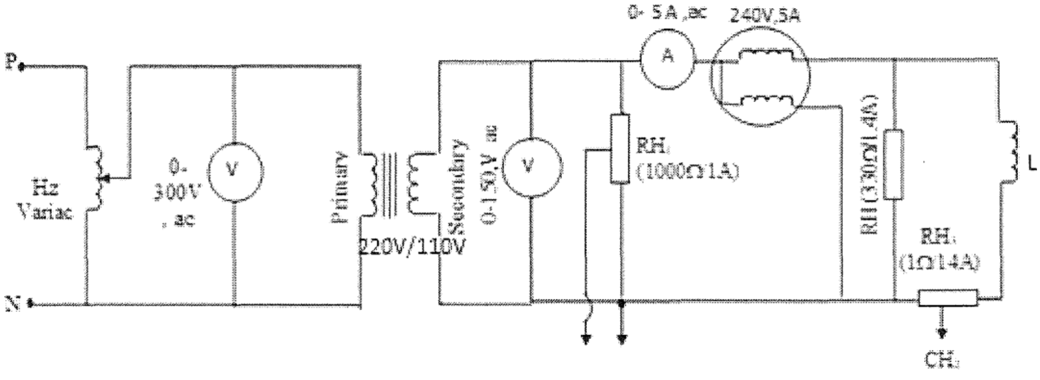
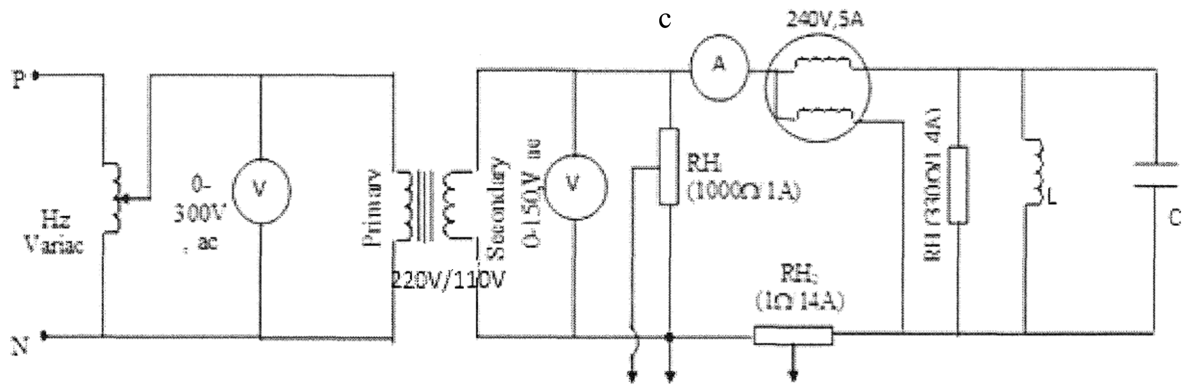


Figure 5: Circuit Diagram

15. Record the readings of wattmeter, ammeter and voltmeters
16. Bring the primary voltage of the transformer to zero.
17. Turn off the supply.
18. Disconnect the circuit input from the supply.

<u>PART 03: PARALLEL RLC (RESISTIVE, INDUCTIVE, CAPACITIVE) LOAD</u>

1. Connect the circuit as shown in Figure 6



<u>Figure 6: Circuit Diagram</u>

z. Set the **Variac to zero position.**
3. Show the circuit to the instructor in-charge of the experiment.
4. Set the rheostat RHi and RHz to the minimum posltion.
5. Turn on the oscilloscope.
6. Set the Time/DIV of the oscilloscope to 0.5 ms/DIV.
7. Set the Volts/DIV of CHi of oscilloscope to IV/DIV.
8. Set the Volts/DIV of CH2 Of oscilloscope to 1V/DIV.
9. Connect the input, as iii Figure 6, to the supply.
10. Turn on the supply.
1i. Increase the Variac voltage gradually until the secondary voltage is 115V.
12. Adjust the Rheostats RHiand RHz slightly to get the voltage and total current full wave form on the oscilloscope screen. Observe and record the voltage wave form and total current waveform
13. Gradually reduce the Variac position to zero and power off the circuit.
14. Connect the circuit as shown in Figure 7. Adjust the Rheostats RHi and RH3 slightly to get the voltage and capacitor current full wave form on the oscilloscope screen. Observe and record the voltage across the load waveform and current flowing through capacitor waveform.

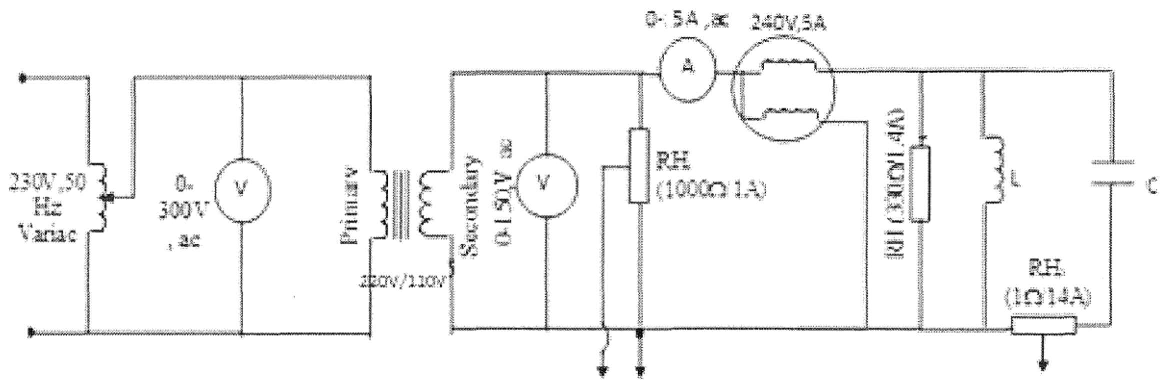


Figure 07: Circuit Diagram

15. Record the readings of wattmeter, ammeter and voltmeters.
16. Increase the capacitance in your circuit one step at a time. Note that the line current diminishes as capacitance is added. At some point, as you keep adding more capacitance the line current will start to increase. (The line current has gone through its minimum value). Minimum line current can be obtained graphically using the variation of the line current vs. capacitance.
17. **Bring the primary** voltage of **the transformer** to zero by **reducing** the Variac output voltage.
18. **Turn off the supply and disconnect the circuit input from** the supply.

OBSERVATIONS:

PART 01

Voltage and Current Waveforms

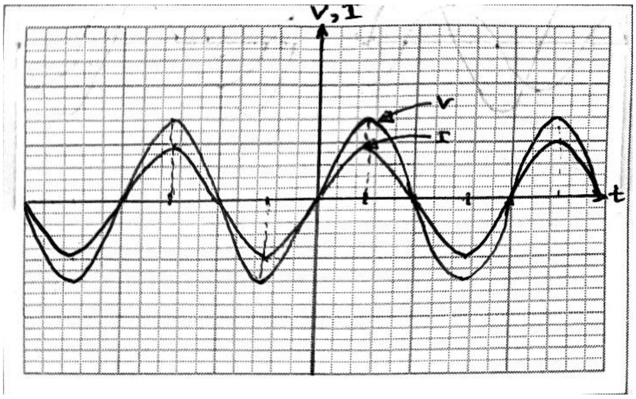
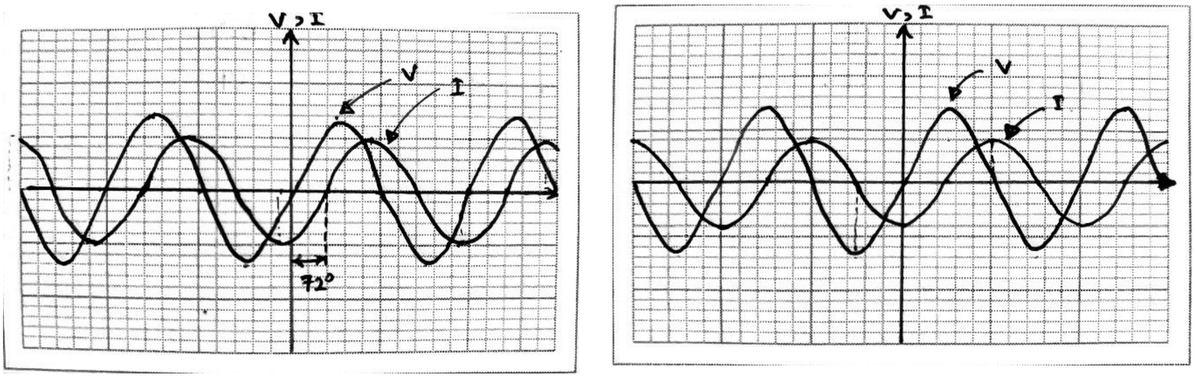


Figure 1: Voltage across the resistor and current flowing through the resistor

Meter readings

Voltmeter reading/V	Ammeter Reading/A	Wattmeter reading/W
110	0.32	34

PART 02



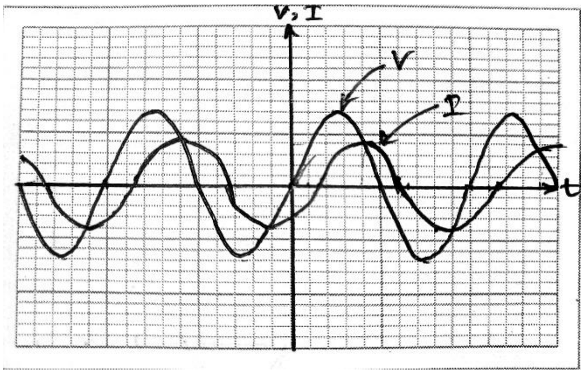
(a) Voltage and Total Current Waveforms (b) Voltage and Inductor Current Wave forms

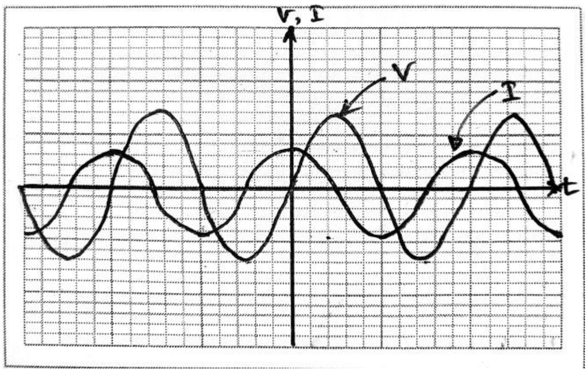
Figure 2: Voltages and currents of the system

Meter readings

Voltmeter reading/V	Ammeter Reading/A	Wattmeter reading/W
110	1.02	40

PART 03





(a) Voltage and Total Current Wave forms (b) Voltage and Capacitor Current Wave forms

Figure 3: Voltages and currents of the system

Meter readings

Capacitor Value/μF	Voltmeter reading/V	Ammeter Reading/A	Wattmeter reading/W
9.90	115	0.76	42
19.95	115	0.50	44
29.50	115	0.48	46
37.90	115	0.64	47
47.90	115	0.96	50
57.90	115	1.28	51

CALCULATIONS

PART 02

1. Calculate the power factor using meter readings

Power Factor = $\frac{P}{VI}$ = $\frac{40}{110 \times 1.02}$

= $\underline{\underline{0.357\ lagging}}$

2. Calculate the power factor of the system using waveforms

Phase lag = 72°

Power Factor = cos (72°)

= $\underline{\underline{0.309\ lagging}}$

PART 03

1. Calculate the power factor using meter readings

Data set 1,

Power Factor $= \frac{P}{VI} = \frac{42}{115 \times 0.76}$

$= \underline{\underline{0.481\ lagging}}$

Data set 3,

Power Factor $= \frac{P}{VI} = \frac{46}{115 \times 0.48}$

$= \underline{\underline{0.833\ lagging}}$

2. Calculate the power factor of the system using waveforms

Phase lag $= -140°$

Power Factor $= \cos(-140°)$

$= \underline{\underline{0.766\ leading}}$

3. Can you observe an improvement in the power factor compared to part2? Explain the reason

Compared Part 2, there is an improvement in power factor with the introduction of capacitive load into the system. Moreover, when the capacitance increased, phase difference reduced. Adding the capacitor in parallel to the system, compensates the lagging reactive power caused by the inductor. Therefore, the reactive part decrease and net power factor increase.

DISCUSSION

1. What is the purpose of using a transformer in the test set up?

In power factor test setups, the transformer serves multiple critical roles to ensure accuracy, safety, and measurement reliability. Primarily, it steps down high test voltages to levels compatible with measuring instruments, allowing controlled and realistic testing conditions. It also provides essential electrical isolation between the high-voltage source and the measuring equipment, protecting both personnel and devices from shocks or surges. Additionally, the transformer helps suppress high-frequency harmonic distortion, ensuring a cleaner sinusoidal waveform for accurate phase angle and power factor measurements. In more advanced setups, it may also facilitate impedance matching between the source and load or provide a neutral reference point for three-phase testing. Altogether, these functions make the transformer a vital component in achieving safe, repeatable, and precise power factor measurements.

2. Why the watt meter readings in Part 1 and Part 2 are different?

The wattmeter readings differ between Part 1 and Part 2 because of the change in load type. In Part 1, the load is purely resistive, so voltage and current are in phase, resulting in a power factor of 1. This means all supplied power is real power, and the wattmeter shows the maximum reading. In Part 2, the load includes an inductor, which causes the current to lag behind the voltage, reducing the power factor. As a result, some of the supplied power becomes reactive power, which the wattmeter does not measure. Although voltage and current magnitudes may remain similar, only the real power ($P = VI\cos\theta$) is recorded by the wattmeter. Since $\cos\theta$ is less than 1 due to the phase shift, the wattmeter shows a lower reading in Part 2.

3. Explain the reason for wave form distortion, when a capacitive load is connected.

   When a capacitive load is connected, wave distortion can occur due to the non-ideal behavior of real-world capacitors. Unlike ideal components, practical capacitors have dielectric losses and may respond nonlinearly, especially at high voltages. This nonlinearity affects the way capacitors charge and discharge, distorting the expected sinusoidal waveform of current or voltage. Additionally, switching capacitors in or out of the circuit can cause high-frequency transients—sudden spikes or abrupt changes—that further distort the waveform. These effects, including dielectric loss, nonlinearity, and switching transients, lead to waveform distortion and must be considered in AC system design where clean waveforms are essential.