EE256 – THREE PHASE MEASUREMENTS

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E/21/345

SEMESTER 4

GROUP EE.21.B.23

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EE 256: POWER AND ENERGY

Experiment: Three Phase Measurements

Pre-Lab Questionnaire

1. Describe the different methods of three phase measurements for balanced three phase load & Unbalance three Phase loads?

2. Compare the pros & cons of the methods you described in question 1?

3. Derive the equation of total load power in a wye (Y) configuration for two watt meter method?

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PRE LAB – EE256 : POWER AND ENERGY | THREE PHASE MEASUREMENTS.

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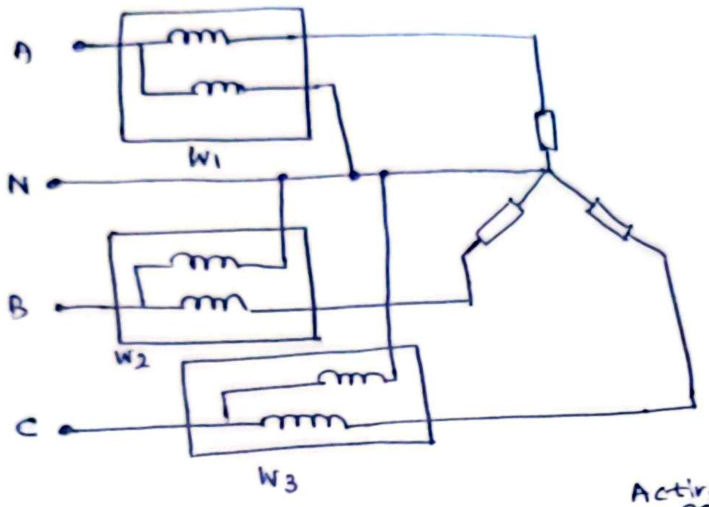
1. Describe the different methods of three phase measurements for balanced three phase load & unbalanced three phase loads?

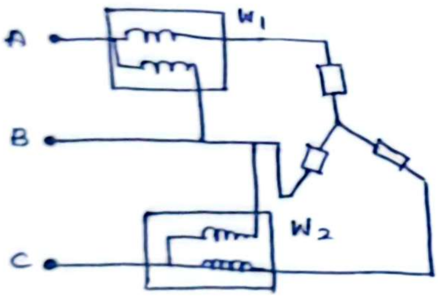
(i.) Three-wattmeter method



- configuration – each wattmeter is connected to a line (A, B, C) with common neutral
- Used for – balanced and unbalanced loads
- this configuration requires a neutral connection.

Active power → $P = W_1 + W_2 + W_3$

(ii.) Two-wattmeter method



- configuration : wattmeters are connected between two lines.
- Used for → balanced ~~system~~ loads : star or delta
- unbalanced ~~system~~ loads : only in 3-wire systems (no neutral)

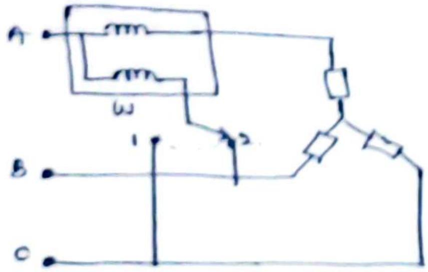
Active power = $W_1 + W_2$

Reactive power = $\sqrt{3}\,(W_2 - W_1)$

$\phi = \tan^{-1}\left(\frac{\sqrt{3}\,(W_2 - W_1)}{(W_1 + W_2)}\right)$

$\cos\phi$ → power factor

(iii.) One-wattmeter method.



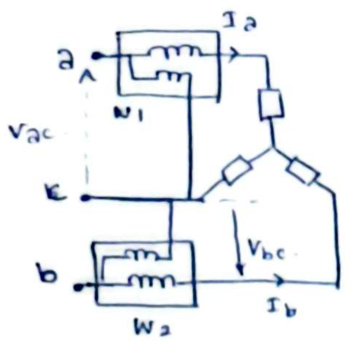
- configuration : one wattmeter connected and reading taken with switching connections.
- Used only for balanced loads.

Active power = $W_1 + W_2$

② Compare the pros & cons of the methods you described in q1?

Method	Pros	Cons.
Three-wattmeter.	• Suitable for 4-wire systems with neutral • Accurate for both balanced & unbalanced systems.	• Requires 3 wattmeters. • Need access to the neutral point • Complex wiring.
Two-wattmeter	• Works for both balanced and unbalanced loads. (in 3-wire systems) • Can be used to calculate power factor. • Does not require neutral • Only two wattmeters required.	• Accuracy reduce at lower power factors. • Not suitable for 4-wire systems.
One-wattmeter	• Economical, only needed one wattmeter. • Simple setup for balanced loads.	• Only works for balanced loads. • Required switching for full measurement.

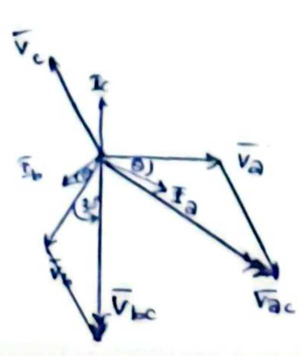
③ Derive the equation of total load power in a wye(Y) configuration for two-watt meter method.



assume that reference is $\bar{V}_a$, and power factor is $\cos\theta$ (lagging).

$$W_1 = |\bar{I}_a||\bar{V}_{ac}|\cos(30-\theta)$$
$$= I_L V_L \cos(30-\theta) \quad -①$$

$$W_2 = |\bar{I}_b||\bar{V}_{bc}|\cos(30+\theta)$$
$$W_2 = I_L V_L \cos(30+\theta) \quad -②$$



$$①+② \Rightarrow W_1+W_2 = I_L V_L\left[\cos(30-\theta)+\cos(30+\theta)\right]$$
$$= I_L V_L\left[2\cos 30 \cos\theta\right]$$
$$W_1+W_2 = \sqrt{3}\, I_L V_L \cos\theta$$

Active power $= \sqrt{3}\, V_L I_L \cos\theta$

$\therefore$ Active power $= W_1 + W_2$

03/07

EE 256: POWER AND ENERGY

Experiment: Three Phase Measurements

(3 hours)

DATE: ..2025/07/05...............

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:

This experiment covers power measurement of three phase system. In this section, the students will get hand on experience on measuring voltage and current in a real three phase system. Also, they will get an exposure on power measurements on three phase Delta connected/ Wye connected balanced and unbalanced loads using one wattmeter and two wattmeters.

LEARNING OUTCOMES:

- LO 1: Calculate the voltages, currents and power of delta and star connected three phase systems (covering attributes of WA1 and WA2)
- LO 2: Discuss and demonstrate different methods of power and energy measurements (covering attributes of WA1 and WA2)

OBJECTIVES:

1. Verify the relationship between the phase and line quantities of a balanced and unbalanced three phase system. (LO1)
2. Discuss and demonstrate different methods of three phase power measurement using Wattmeter. (LO2)

a) Measurements on a real three phase system

APPARATUS:

- Clip-on meter

PROCEDURE:

Step 1 – Use the clip-on ammeter to measure currents in each phase and the neutral of the incoming feeder to the lab. Note down the readings.

Step 2 – Use the multi-meter to measure the voltage of each phase with respect to the neutral and voltage between phases. Note down the readings.

OBSERVATIONS:

I_A / A	3.50
I_B / A	3.49
I_C / A	3.44
I_N / A	0.06

V_{AN}/V	242.9
V_{BN}/V	237.7
V_{CN}/V	244.6
V_{AB}/V	415.0
V_{BC}/V	412.0
V_{AC}/V	413.0

CALCULATIONS:

Calculate the apparent power of the three-phase system.

Apparent Power $= V_{AN} I_A + V_{BN} I_B + V_{CN} I_B$

$= (242.9 \times 3.50) + (237.7 \times 3.49) + (244.6 \times 3.44)$

$= \underline{\underline{2,521.147 \text{ VA}}}$

b) Power measurements of a three-phase delta connected balanced system using single wattmeter

APPARATUS:

- Single Phase Wattmeter: 5A, 480V (YOKOGAWA)
- AC Ammeter: 0~5A (YOKOGAWA) x 2Nos
- AC Voltmeter: 0~750V (YOKOGAWA)
- Three Phase Inductive Load: (Terco MV1101) – position 4 value = 185mH
- Water Load: Low Position value = 120Ω

PROCEDURE:

Step 1 – Connect the circuit as shown in Figure 1. Here the load is formed by parallel connection of the resistive and inductive loads.

Step 2 – Keep the water load at low position (120Ω). Set the inductor bank to position 4 (185mH).

Step 3 – Switch on the three-phase voltage supply.

Step 4 – Obtain meter readings

Step 5 – Switch off the supply.

Step 6 – Then, connect voltage coil of the wattmeter between;

i. A and C

ii. B and C

Step 7 – Then, follow the steps 2 – 5 for above two cases.

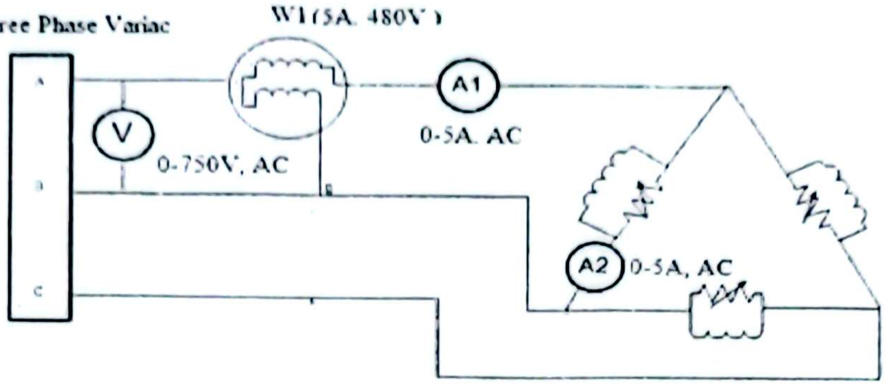


Figure 1: Circuit diagram for power measurement using single wattmeter

OBSERVATIONS:

Meter	V coil at A & B	V coil at A & C	V coil at B & C
V_1	225 V	225V	220V
A_1	3.4 A	3.5A	3.4A
A_2	2.0 A	2.0A	2.0 A
W_1	700 W	680W	660W

CALCULATIONS:

Calculate the **Active power** using watt meter reading:

Active power = $W_1(AB) + W_1(AC)$

= 700W + 680W

= 1380W

Calculate the **Reactive power** using wattmeter reading:

Reactive power = $\sqrt{3} \cdot W_1(BC)$

= $\sqrt{3} \times 660W$

= 1143.15 Var

RESULTS:

Active Power	1380W
Reactive Power	1143.15Var

c) Power measurements of a balanced three phase system using two wattmeter method

A. *Delta connected balanced system*

APPARATUS:

- Single Phase Wattmeter: 5A, 480V (YOKOGAWA) x 2Nos
- AC Ammeter: 0-5A (YOKOGAWA) x 2Nos
- AC Voltmeter: 0-750V (YOKOGAWA)
- Three Phase Inductive Load: (Terco MV1101) – position 4 value = 185mH
- Water Load: Low Position value = 120Ω

PROCEDURE:

Step 1 – Connect the circuit as shown in Figure 2. Here the load is formed by parallel connection of the resistive and inductive loads.

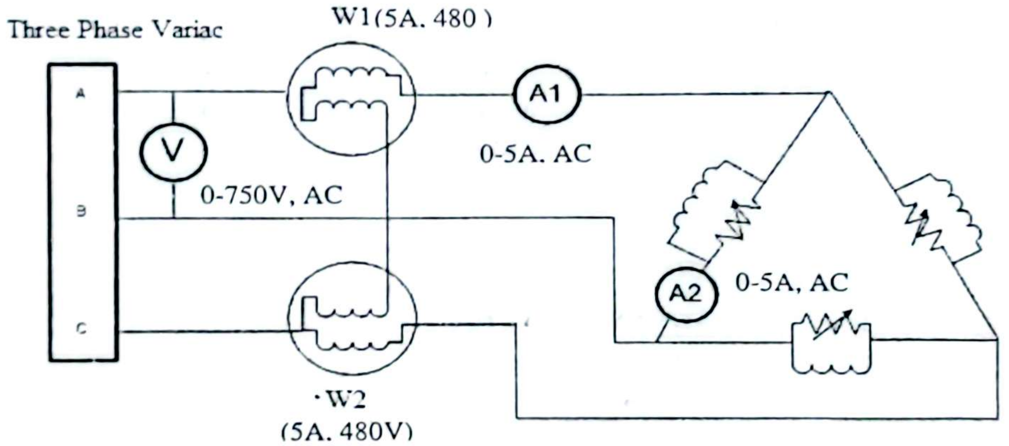


Figure 2: Circuit diagram for power measurement of a delta connected balanced system by two wattmeter method.

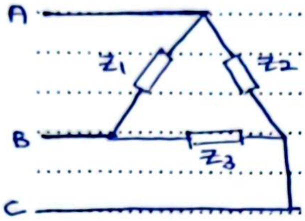
Step 2 – Keep the water load at low position (120Ω). Set the inductor bank to position 4 (185mH).
Step 3 – Switch on the three-phase voltage supply.
Step 4 – Obtain meter readings.
Step 5 – Switch off the supply.

OBSERVATIONS:

V_1	225V
A_1	3.8A
A_2	2.0A
W_1	680W
W_2	660W

CALCULATIONS:

i. Obtain the relationship between line and phase quantities:



phase voltage = Line Voltage

$V_P = V_L$ —①

$\sqrt{3} \times$ phase current = Line current

$\sqrt{3} \times I_P = I_L$

$\sqrt{3} I_P = I_L$ —②

ii. Calculate the active power factor, reactive power and apparent power of the system using wattmeter readings:

Active power = $W_1 + W_2$

$P = 680 + 660$ W

$= 1340W$

Reactive power = $\sqrt{3}(W_2 - W_1)$

$Q = \sqrt{3}(660 - 680)$

$= -34.64$ Var

Apparent power = $\sqrt{P^2 + Q^2}$

$S = \sqrt{(1340)^2 + (-34.64)^2}$

$S = 1340.45$ VA

iii. Calculate the power factor of the system using given impedance values:

$R = 120\ \Omega$

$L = 185mH \rightarrow Z_L = j\omega L$

$|Z_L| = 2\pi \times 50 \times 185mH$

$= 58.1195\ \Omega$

$Z_R = 120\Omega \quad Z_L = 58.1195j\ \Omega$

$Z_R \parallel Z_L = 52.31 \angle 64.16^\circ$

$\theta = 64.16^\circ$

power factor $= \cos(\theta) = \cos(64.16^\circ) = 0.436$

iv. Calculate the power factor of the system using voltmeter and ammeter readings:

Power factor $= \dfrac{P}{\sqrt{3} V_L I_L} = \dfrac{1340}{\sqrt{3} \times 225 \times 3.8} = 0.905$

iv. Calculate the power factor of the system using Wattmeter readings:

Power factor $= \cos\left[\tan^{-1}\left(\dfrac{\sqrt{3}(W_2 - W_1)}{W_1 + W_2}\right)\right]$

$= \cos\left\{\tan^{-1}\left[\dfrac{-34.64}{1340}\right]\right\}$

$= 0.9997 \approx 1$

B. Wye connected balanced system

APPARATUS:

- Single Phase Wattmeter: 5A, 480V (YOKOGAWA) x 2Nos
- AC Ammeter: 0-5A (YOKOGAWA) x 3Nos
- AC Voltmeter: 0-750V (YOKOGAWA) x 2Nos
- Three Phase Inductive Load: (Terco MV1101) – position 4 value = 185mH
- Water Load. Low Position value = 120Ω

Procedure:

Step 1 – Connect the circuit as shown in Figure 3.

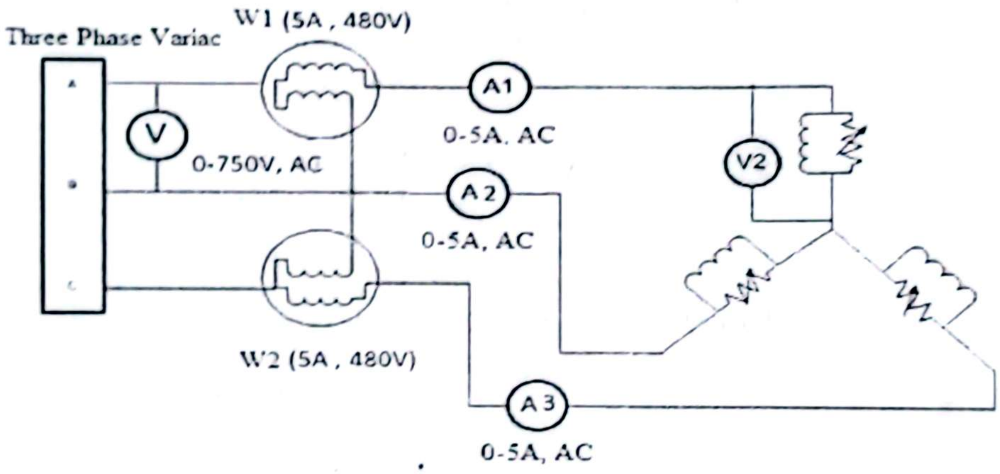


Figure 3: Circuit diagram for power measurement of a delta connected balanced system by two wattmeter method.

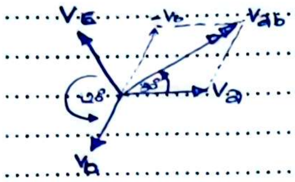
Step 2 – Keep the water load at low position. Set the inductor bank to position 4.
Step 3 – Switch on the three-phase voltage supply.
Step 4 – Obtain meter readings.
Step 5 – Switch off the supply.

OBSERVATIONS:

V_1	225V
V_2	130V
A_1	1.15A
A_2	1.10A
A_3	1.10A
W_1	220W
W_2	220W

CALCULATIONS:

i. Obtain the relationship between line and phase quantities:



Line current = phase current.

$I_L = I_P$

$V_{ab} = V_a \cos 30^\circ + V_b \cos 30^\circ$

$V_{ab} = 2V_P \cos 30^\circ$

$V_L = \sqrt{3}\, V_P \angle{+30^\circ}$

ii. Calculate the total power dissipated in the loads using Wattmeter readings:

Active power $(P) = W_1 + W_2 = 220 + 220 = 440W$

Reactive power $(Q) = \sqrt{3}(W_2 - W_1) = \sqrt{3}(0) = 0W$

Apparent power $(S) = \sqrt{P^2 + Q^2}$

$= \sqrt{440^2 + 0}$

$= 440VA$

iii. Calculate the power factor of the system using Voltmeter and Ammeter readings:

Power factor $= \frac{P}{\sqrt{3}\, V_L I_L} = \frac{440}{\sqrt{3} \times 225 \times 1.15}$

$= 0.9818$

iv. Calculate the power factor of the system using Wattmeter readings:

Power factor $= \cos\left[\tan^{-1}\left[\frac{\sqrt{3}(W_2 - W_1)}{W_2 + W_1}\right]\right]$

$= 1.00$

RESULTS:

	Delta connected System	Wye connected system
Active power	1340W	440W
Reactive power	34.64 Var	0 Var
Apparent power	1340.45 VA	440 VA
Power factor	1.0	1.0

d) Power measurement of unbalanced wye connected system

PROCEDURE:

Step 1 – Use the circuit in Figure 3

Step 2 – Keep the inductor bank at position 4.

Step 3 – Change the water load connected to phase A, to medium position while keeping other water loads at low position.

Step 4 – Switch on the three-phase voltage supply.

Step 5 – Obtain meter readings.

Step 6 – Use the multi-meter to measure the voltage of the load neutral point (N') with respect to supply neutral (N) and phase voltage of each load.

Step 7 – Switch off the supply.

OBSERVATIONS:

Meter readings

V_1	230V
A_1	1.75A
A_2	1.30A
A_3	1.30A
W_1	340W
W_2	340W

Voltage of the load neutral point (N') with respect to supply neutral (N)

$V_{NN'}$	35V
$V_{AN'}$	99.5V
$V_{BN'}$	152.5V
$V_{CN'}$	151.0V

CALCULATIONS:

i. Calculate the total power dissipated in the loads using Wattmeter readings:

Power dissipated $= W_1 + W_2$

$= 340 + 340$

$= \underline{680W}$

ii. Calculate the power factor of the system using Wattmeter readings:

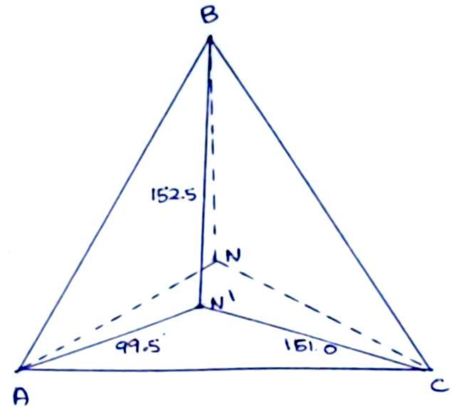
Power factor $= \cos\left[\tan^{-1}\left(\frac{\sqrt{3}(W_2 - W_1)}{W_2 + W_1}\right)\right]$

$= \cos\left[\tan^{-1}\left(\frac{0}{680}\right)\right]$

$= \underline{1.00}$

iii. Draw the phasor diagram to illustrate the neutral shift.

NN' → Neutral shift



TABULATION:

	1 wattmeter method, Δ, balanced	2 Wattmeter method		
		Balanced		Unbalanced
		Δ	Y	Y
Active Power	1380 W	1340W	440W	680W
Reactive power	1143.15 Var	34.64 Var	0 Var	0 Var
Apparent power	1791.98 VA	1340.45 VA	440 VA	680 VA
Power factor	0.77	1.00	1.00	1.00

DISCUSSION:

1. Compare the values obtained for the power factor in steps 1, 2 and 3 in your calculations.
2. What happens if the neutral connection in the lab supply is disconnected?

DISCUSSION

① Compare the values obtained for the power factor in step 1, 2 and 3 in calculations.

From one wattmeter method we obtained power factor as 0.77, while in step 2, 3. methods resulted in a unity power factor of 1. A perfect unity power factor is ideal but highly unlikely in a practical lab experiment, suggesting a potential error in two wattmeter measurements. This discrepencies likely arises from incorrect writing of the wattmeters or an instrument fault. Therefore, the lagging power factor of 0.77 is a more plausible and realistic for a typical inductive load, making the one-wattmeter method's result more credible in this case.

② What happens if the neutral connection in the lab supply is disconnected?

If the neutral connection from the lab supply disconnected, the three-phase system becomes dangerously unbalanced. Particularly. for loads connected in star configuration. Without the neutral wire providing a return path, the star point is no longer held at a stable potential. This causes the phase voltages across the load to become unequal. Some will experience over voltage, which may destroy or damage equipments, while some experience under voltage, causing them malfunction.

REFERENCES

[1.] E.-E. E. Portal, "Floating Neutral Impacts in Power Distribution", EEP-Electrical Engineering Portal, Aug. 27, 2012. https://electrical-engineering-portal.com/floating-neutral-impacts-in-power-distribution.