

EE 330L Energy Systems Lab (Fall 2026)

Laboratory 4 Three-Phase Loads- Part 1

Introduction

In this laboratory, the voltages, currents, impedances, phase angles, power factors, and real & reactive power in three-phase systems will be measured and studied. In particular, a balanced 4-wire Y-Y, unbalanced 4-wire Y-Y, balanced 3-wire Y-Y, unbalanced 3-wire Y-Y, and balanced Δ - Δ three-phase systems will be considered. In addition to using three power meters, the two power meter method is introduced.

Preliminary

A. Balanced 4-wire Y-Y Three-Phase System

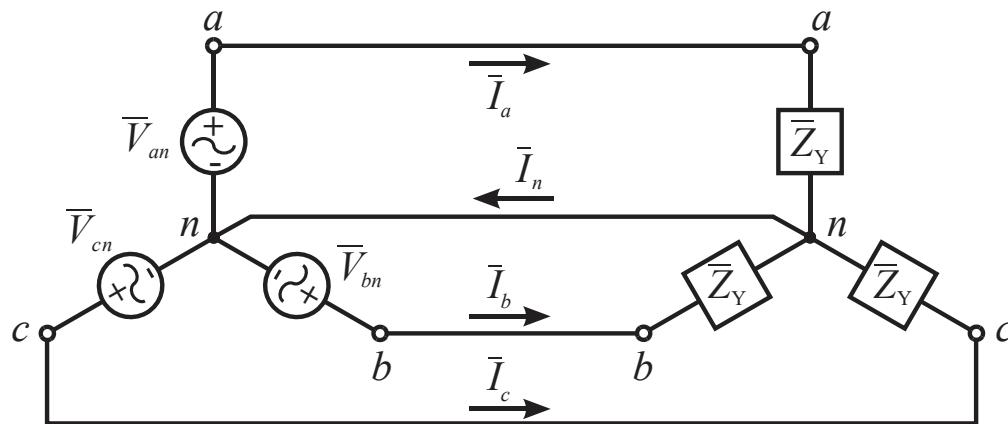


Figure 1 Balanced 4-wire Y-Y Three-Phase System

As shown in Figure 1, we will examine a balanced Y-Y three-phase system with a physical neutral (N) wire present. For the circuit, the phase voltage is $V_\phi = 69.3 \text{ V}_{\text{rms}}$ and $\bar{V}_{an} = V_\phi \angle 0^\circ$, $\bar{V}_{bn} = V_\phi \angle -120^\circ$, & $\bar{V}_{cn} = V_\phi \angle -240^\circ$. The Y-configured loads are $\bar{Z}_Y = 300 + j300 \Omega$.

- 1) Compute the RMS phasor currents as well as RMS phasor line-to-line voltages $\bar{V}_{ab}$, $\bar{V}_{bc}$, & $\bar{V}_{ca}$ shown in Figure 1. Then, complete Table 1 with RMS magnitudes (not phasors).

Table 1 Currents and Voltages for Balanced 4-wire Y-Y Three-Phase System

Quantity	Value
$I_L = I_a = I_b = I_c$	
I_n	
$V_{LL} = V_{ab} = V_{bc} = V_{ca}$	

- 2) Compute the ratio V_{LL} / V_ϕ . Is the ratio consistent with the text (give text equation)?

- 3) Next, use the phasor RMS currents and voltages to compute the complex powers for the three phases as well as overall. Then, complete Table 2 with real, reactive, & apparent powers and power factors (PFs).

Table 2 Powers and PFs for Balanced 4-wire Y-Y Three-Phase System

Phase/Total	P (W)	Q (var)	S (VA)	PF
a				
b				
c				
total				

B. Unbalanced 4-wire Y-Y Three-Phase System

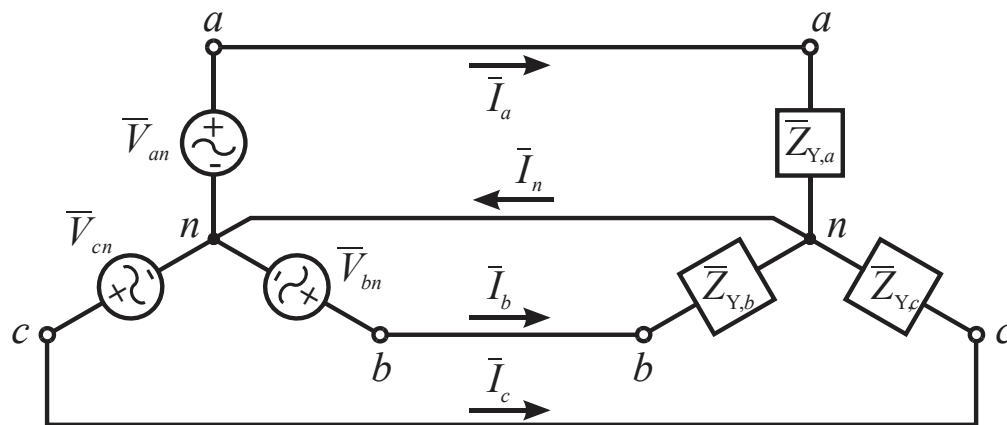


Figure 2 Unbalanced 4-wire Y-Y Three-Phase System

Next, we will examine an unbalanced Y-Y three-phase system with a physical neutral (N) wire present as shown in Figure 2. The phase voltage is $V_\phi = 69.3 \text{ V}_{\text{rms}}$ and $\bar{V}_{an} = V_\phi \angle 0^\circ$, $\bar{V}_{bn} = V_\phi \angle -120^\circ$, & $\bar{V}_{cn} = V_\phi \angle -240^\circ$. The loads are $\bar{Z}_{Y,a} = 300 + j300 \Omega$, $\bar{Z}_{Y,b} = 600 + j300 \Omega$, & $\bar{Z}_{Y,c} = 300 + j600 \Omega$.

- 1) Compute the RMS phasor currents as well as RMS phasor line-to-line voltages $\bar{V}_{ab}$, $\bar{V}_{bc}$, & $\bar{V}_{ca}$ shown in Figure 2. Then, complete Table 3 with RMS magnitudes.

Table 3 Currents and Voltages for Unbalanced 4-wire Y-Y Three-Phase System

Quantity	Value
I_a	
I_b	
I_c	
I_n	
$V_{LL} = V_{ab} = V_{bc} = V_{ca}$	

- 2) Next, use the phasor RMS currents and voltages to compute the complex powers for the three phases as well as overall. Then, complete Table 4 with real, reactive, & apparent powers and PFs.

Table 4 Powers and PFs for Unbalanced 4-wire Y-Y Three-Phase System

Phase/Total	P (W)	Q (var)	S (VA)	PF
a				
b				
c				
total				

C. Balanced 3-wire Y-Y Three-Phase System

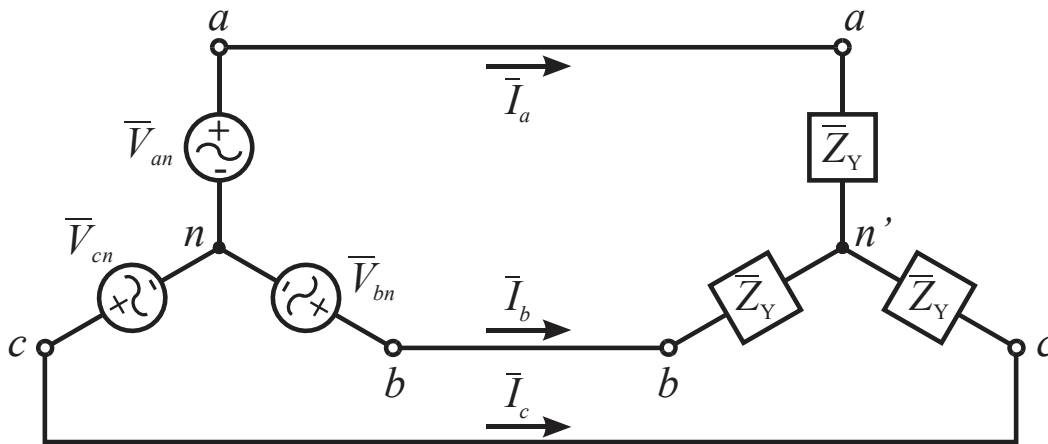


Figure 3 Balanced 3-wire Y-Y Three-Phase System

Next, we will examine a balanced Y-Y three-phase system without a neutral (N) wire (Figure 3). For the circuit, the phase voltage is $V_\phi = 69.3 \text{ V}_{\text{rms}}$ and $\bar{V}_{an} = V_\phi \angle 0^\circ$, $\bar{V}_{bn} = V_\phi \angle -120^\circ$, & $\bar{V}_{cn} = V_\phi \angle -240^\circ$. The Y-configured loads are $\bar{Z}_Y = 300 + j300 \Omega$.

- 1) Compute the RMS phasor currents shown in Figure 2 as well as RMS phasor line-to-line voltages $\bar{V}_{ab}$, $\bar{V}_{bc}$, & $\bar{V}_{ca}$. Then, complete Table 5. [Hints: You CAN use a per-phase equivalent circuit as the voltages at n and n' are the same. Also, KVL/mesh analysis works and KCL is always true.]

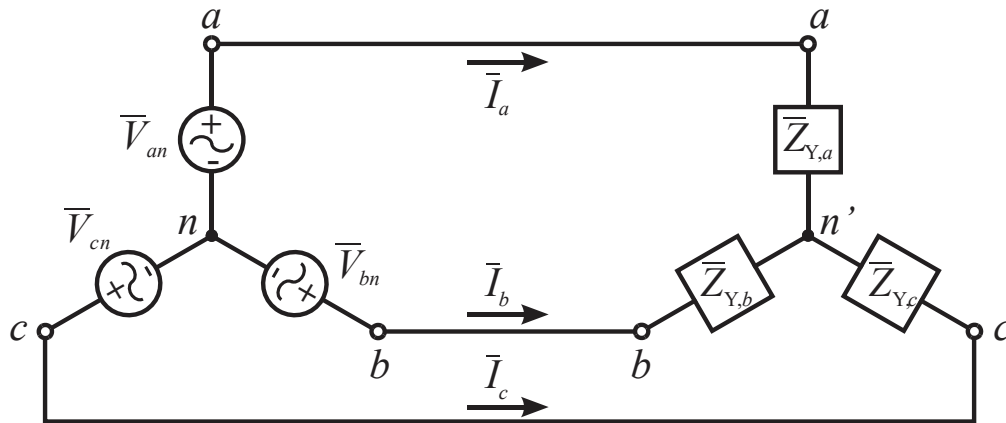
Table 5 Currents and Voltages for Balanced 3-wire Y-Y Three-Phase System

Quantity	Value
$I_L = I_a = I_b = I_c$	
$V_{LL} = V_{ab} = V_{bc} = V_{ca}$	

- 2) Next, use the phasor RMS currents and voltages to compute the complex powers for the three phases as well as overall. Then, complete Table 6 with real, reactive, & apparent powers and PFs.

Table 6 Powers and PFs for Balanced 3-wire Y-Y Three-Phase System

Phase/Total	P (W)	Q (var)	S (VA)	PF
a				
b				
c				
total				

D. Unbalanced 3-wire Y-Y Three-Phase System**Figure 4** Unbalanced 3-wire Y-Y Three-Phase System

Next, we will examine an unbalanced Y-Y three-phase system without a neutral (N) wire (Figure 4). The phase voltage is $V_\phi = 69.3 \text{ V}_{\text{rms}}$ and $\bar{V}_{an} = V_\phi \angle 0^\circ$, $\bar{V}_{bn} = V_\phi \angle -120^\circ$, & $\bar{V}_{cn} = V_\phi \angle -240^\circ$. The Y-configured loads are $\bar{Z}_{Y,a} = 300 + j300 \Omega$, $\bar{Z}_{Y,b} = 600 + j300 \Omega$, & $\bar{Z}_{Y,c} = 300 + j600 \Omega$.

- 1) Compute the RMS phasor currents as well as RMS phasor line-to-line voltages $\bar{V}_{ab}$, $\bar{V}_{bc}$, & $\bar{V}_{ca}$ shown in Figure 4. Then, complete Table 7 with RMS magnitudes. **[Hints:** You can NOT use a per-phase equivalent circuit as the voltages at n and n' are different, i.e., $\bar{V}_{an}$ is NOT across $\bar{Z}_{Y,a}$ etcetera. KVL/mesh analysis works. KCL is always true.]

Table 7 RMS Currents and Voltages for Unbalanced 3-wire Y-Y Three-Phase System

Quantity	Value
I_a	
I_b	
I_c	
$V_{LL} = V_{ab} = V_{bc} = V_{ca}$	

- 2) Next, use the phasor RMS currents and source phase voltages to compute the complex powers (e.g., $\bar{S}_{s,a} = \bar{V}_{an} \bar{I}_a^*$) for the three voltage source phases as well as the overall source. Then, complete Table 8 with real, reactive, & apparent powers and PFs.

Table 8 Source Powers and PFs for Unbalanced 3-wire Y-Y Three-Phase System

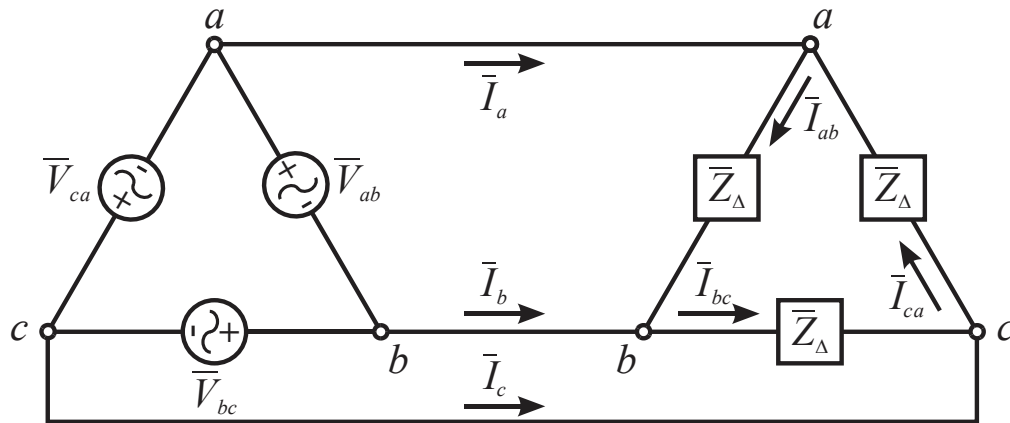
Phase/Total	P (W)	Q (var)	S (VA)	PF
a				
b				
c				
total				

- 3) Next, use the phasor RMS currents and load impedances to compute the complex powers (e.g., $\bar{S}_{L,a} = |\bar{I}_a|^2 \bar{Z}_{Y,a} = \bar{I}_a^2 \bar{Z}_{Y,a}$) for the three loads as well as the overall load. Then, complete Table 9 with real, reactive, & apparent powers and PFs.

Table 9 Load Powers and PFs for Unbalanced 3-wire Y-Y Three-Phase System

Phase/Total	P (W)	Q (var)	S (VA)	PF
a				
b				
c				
total				

E. Balanced Δ - Δ Three-Phase System

**Figure 5** Balanced Δ - Δ Three-Phase System

Next, we will examine a balanced Δ - Δ three-phase system as shown in Figure 5. The phase voltage is $V_{\phi} = 120 \text{ V}_{\text{rms}}$ and $\bar{V}_{ab} = V_{\phi} \angle 0^{\circ}$, $\bar{V}_{bc} = V_{\phi} \angle -120^{\circ}$, & $\bar{V}_{ca} = V_{\phi} \angle -240^{\circ}$. The Δ -configured loads are $\bar{Z}_{\Delta} = 300 + j300 \Omega$.

- 1) Compute the RMS phasor currents shown in Figure 5. Then, complete Table 10 with RMS magnitudes.

Table 10 Currents and Voltages for Balanced Δ - Δ Three-Phase System

Quantity	Value
$I_\phi = I_{ab} = I_{bc} = I_{ca}$	
$I_L = I_a = I_b = I_c$	
$V_{LL} = V_{ab} = V_{bc} = V_{ca}$	

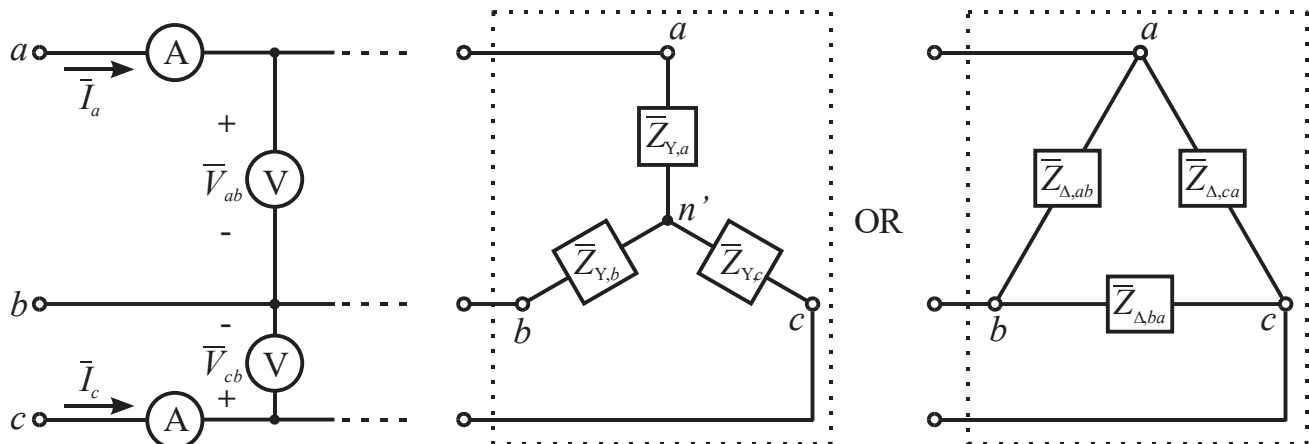
- 2) Compute the ratio I_L / I_ϕ . Is the ratio consistent with the text (give text equation)?
- 3) Next, use the phasor RMS currents and voltages to compute the complex powers (e.g., $\bar{S}_{ab} = \bar{V}_{ab} \bar{I}_{ab}^*$) for the three load phases as well as the overall load. Then, complete Table 11 with real, reactive, & apparent powers and power factors (PFs).

Table 11 Load Powers and PFs for Balanced Δ - Δ Three-Phase System

Phase/Total	P (W)	Q (var)	S (VA)	PF
ab				
bc				
ca				
total				

F. Two Power Meter (AKA Two-Wattmeter) Method

For a real-world Δ -configured load, we often would NOT be able to measure the phase currents $\bar{I}_{ab}$, $\bar{I}_{bc}$, & $\bar{I}_{ca}$; all we would have access to is three external load terminals. Similarly, we would not have access to node n' in a Y-configured load with a 3-wire connection. In these cases, we can employ the **two power meter (AKA two-wattmeter) method** which uses two line-to-line voltages and two line currents, as shown in Figure 8, to find the overall powers to the load (or from the source).

**Figure 8** Two Power Meter (AKA Two-Wattmeter) Method

Since this method relies only on the line quantities, the load and source configurations do not matter (any combination of Δ and/or Y). Further, this measurement method works with balanced and unbalanced 3-wire systems. It can be shown that:

$$\bar{S}_{\text{tot}} = \bar{V}_{ab} \bar{I}_a^* + \bar{V}_{cb} \bar{I}_c^* = P_{\text{tot}} + jQ_{\text{tot}} = S_{\text{tot}} \angle \theta_{\text{tot}}.$$

The two power meter (AKA two-wattmeter) method only works on **balanced 4-wire** systems (proof depends on $\bar{I}_a + \bar{I}_b + \bar{I}_c = 0$ which is true only when $\bar{I}_n = 0$). This method does not work on unbalanced 4-wire systems where $\bar{I}_n \neq 0$.

- 1) For each of the preceding three-phase systems, use previously calculated values of P_{tot} , Q_{tot} , S_{tot} , & $\text{PF} = \cos \theta_{\text{tot}}$ and complete Table 12.

Table 12 Total Powers & PFs for Three-Phase Systems

System	P_{tot} (W)	Q_{tot} (var)	S_{tot} (VA)	PF_{tot}
A. Balanced 4-wire Y-Y				
B. Unbalanced 4-wire Y-Y				
C. Balanced 3-wire Y-Y				
D. Unbalanced 3-wire Y-Y				
E. Balanced Δ-Δ				

- 2) For each of the preceding three-phase systems, determine or use previously calculated values of $\bar{V}_{ab}$, $\bar{V}_{cb} = -\bar{V}_{bc}$, $\bar{I}_a$, & $\bar{I}_c$ to compute $\bar{S}_{\text{tot}}$ using the two power meter (AKA two-wattmeter) method. Then, find P_{tot} , Q_{tot} , S_{tot} , & $\text{PF} = \cos \theta_{\text{tot}}$ and complete Table 13.

Table 13 Total Powers & PFs for Three-Phase Systems using Two Power Meter Method

Three-Phase System	P_{tot} (W)	Q_{tot} (var)	S_{tot} (VA)	PF_{tot}
A. Balanced 4-wire Y-Y				
B. Unbalanced 4-wire Y-Y				
C. Balanced 3-wire Y-Y				
D. Unbalanced 3-wire Y-Y				
E. Balanced Δ-Δ				

- 3) Compare Table 12 with Table 13. For which three-phase system(s) do the results agree? For which three-phase system(s) do the results disagree?

Each group should write and submit one hard copy of a lab report on Part 1 of Lab 4 to the instructor following guidelines given in lab syllabus.

Due Friday October 2, 2026 by 4 pm to instructor's office or EECS mailbox.