Experiment 1	The University of Texas at Tyler Department of Electrical Engineering Electric Power Systems Lab (EENG 4110)	TYLER

Three-Phase Power Measurement

Objectives

By the end of this lab, you will:

1. Understand the difference between balanced and unbalanced three-phase power systems.
2. Measure the total power in a three-phase circuit using two wattmeters.
3. Measure the power factor of a balanced three-phase circuit.

Equipment and Components

1. Two wattmeters (2A/150-300V)
2. Voltmeter (150/300V)
3. Ammeter (2A)
4. A 3-phase regulated power supply (0-240V L-L, 60 Hz, 10A)
5. A 3-phase resistive load (300/600/1200 Ω, 100 W)
6. A 3-phase inductive load (0.8/1.6/3.2 H, 100 VAR)

Introduction

Three-phase circuits may be classified as balanced or unbalanced. In the case of balanced circuits, if three wattmeters are connected (one in each phase), equal readings will be obtained. Therefore, only one wattmeter needs to be connected to any phase and the total power will be obtained by multiplying the power reading per phase by three.

In the case of an unbalanced circuit, three wattmeters must be used; one in each phase. The total power is obtained by adding the three wattmeter readings. However, there are some practical difficulties in doing so. For example, the load neutral may not be accessible in case of a Y-connected load and hence the supply neutral must be connected. Or in a Δ-connected loads, it may not be possible to cut through the delta to connect the meters.

A more convenient and popular method of measuring three-phase power is to use two wattmeters in a particular way. The method is known as the “two watt-meters method” since only two wattmeters are required. Moreover, this method is valid for measuring three-phase power in balanced as well as unbalanced systems.

Procedure

Part A: Balanced Three-Phase Circuit

1. Make sure that the power supply is switched off, and the voltage control knob is turned fully to zero.
2. Connect the circuit as shown in Figure 1. To create the Multisim circuit, place the following components and instruments on your workspace and connect them as shown in Figure 1c:

Component/instrument	Name	Location	Settings
3-Phase AC Power Supply	THREE_PHASE_WYE	Sources/POWER_SOURCES	120Vrms/60Hz
Ground	GROUND	Sources/POWER_SOURCES	None
Resistor (R_1, R_2, R_3)	Resistor	Basic/RISISTOR	See instructions
Inductor (L_1, L_2, L_3)	Inductor	Basic/INDUCTOR	See instructions
Wattmeter (P_{oc})	XWM1	Instrument Toolbar	None
Wattmeter (P_{oc})	XWM2	Instrument Toolbar	None

3. With the load off, set the voltage of the three-phase supply to 208V line to line (120V line to neutral).
4. Set the load such that $R_1 = R_2 = R_3 = 240\Omega$ (use 1200Ω || 300Ω to set this value) and $L_1 = L_2 = L_3 = 0$ H. This is a **balanced pure resistive** load. In this case, we can assume that $V_O = 0$.
5. Using the following equations, calculate phase voltages, phase currents, power angle, power factor, total real power (P_T), and total reactive power (Q_T). Record the calculated values in Table 1.

$$|V_{ph}| = 120\text{V} \tag{1}$$

$$|I_{ph}| = \frac{|V_{ph}|}{|Z|} = \frac{|V_{ph}|}{|R + jX_L|} == \frac{|V_{ph}|}{|R + j\omega L|} \tag{2}$$

$$\phi = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}\left(\frac{\omega L}{R}\right) \tag{3}$$

$$\text{pf} = \cos\phi \tag{4}$$

$$P_\text{T} = 3|V_{ph}||I_{ph}|\cos\phi = \sqrt{3}|V_L||I_L|\cos\phi \tag{5}$$

$$Q_\text{T} = 3|V_{ph}||I_{ph}|\sin\phi = \sqrt{3}|V_L||I_L|\sin\phi \tag{6}$$

6. Measure and record the reading of each wattmeter. $W_1 =$ ________ and $W_2 =$ ________.
7. Measure the same quantities in step 5 using the Multisim circuit and the real circuit and record the readings in Table 1. Use the following formulas:

$$P_\text{T} = W_1 + W_2 \tag{7}$$

$$Q_\text{T} = \sqrt{3}(W_1 - W_2) \tag{8}$$

$$\phi = \tan^{-1}\left(\frac{Q_\text{T}}{P_\text{T}}\right) = \tan^{-1}\left(\frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}\right) \tag{9}$$

$$\text{pf} = \cos\phi \tag{10}$$

8. Set the reactive load such that $R_1 = R_2 = R_3 = 240\Omega$ and $L_1 = L_2 = L_3 = 1.1$ H (use 1.6H || 3.2H to set this value). This is a **balanced inductive** load.
9. Repeat steps 5 - 7 and record the values in Table 2. If one of the watt-meters shows a negative reading, reverse the pressure coil of that wattmeter and add its reading with a negative sign.
10. Set the reactive load such that $R_1 = R_2 = R_3 = 240\Omega$ and $L_1 = L_2 = L_3 = 1.6$ H.
11. Repeat steps 5 - 7 and record the values in Table 3. If one of the watt-meters shows a negative reading, reverse the pressure coil of that wattmeter and add its reading with a negative sign.

Part B: Unbalanced Three-Phase Circuit

12. Set the reactive load such that $R_1 = R_2 = 300\Omega$, $R_3 = 600\Omega$, $L_1 = L_2 = 0.8$ H, and $L_3 = 1.6$ H. This case represents a **balanced-source unbalanced-load** three-phase circuit in which $V_O \neq 0$.
13. Derive an expression for V_O, and calculate and record its value in Table 4.
14. Repeat steps 5 - 7 and record the values in Table 4.

Report requirements

Your lab report must include:

1. Different wattmeter connections used to measure 3-phase power.
2. A brief explanation of the two-wattmeter method.
3. The phasor diagram for the two-wattmeter method.
4. Proof of the measured real and reactive power equations (7) and (8).
5. Derivation of the expression for V_O for a general unbalanced three-phase load.
6. Explain the results recorded in steps 7, 9, and 11.

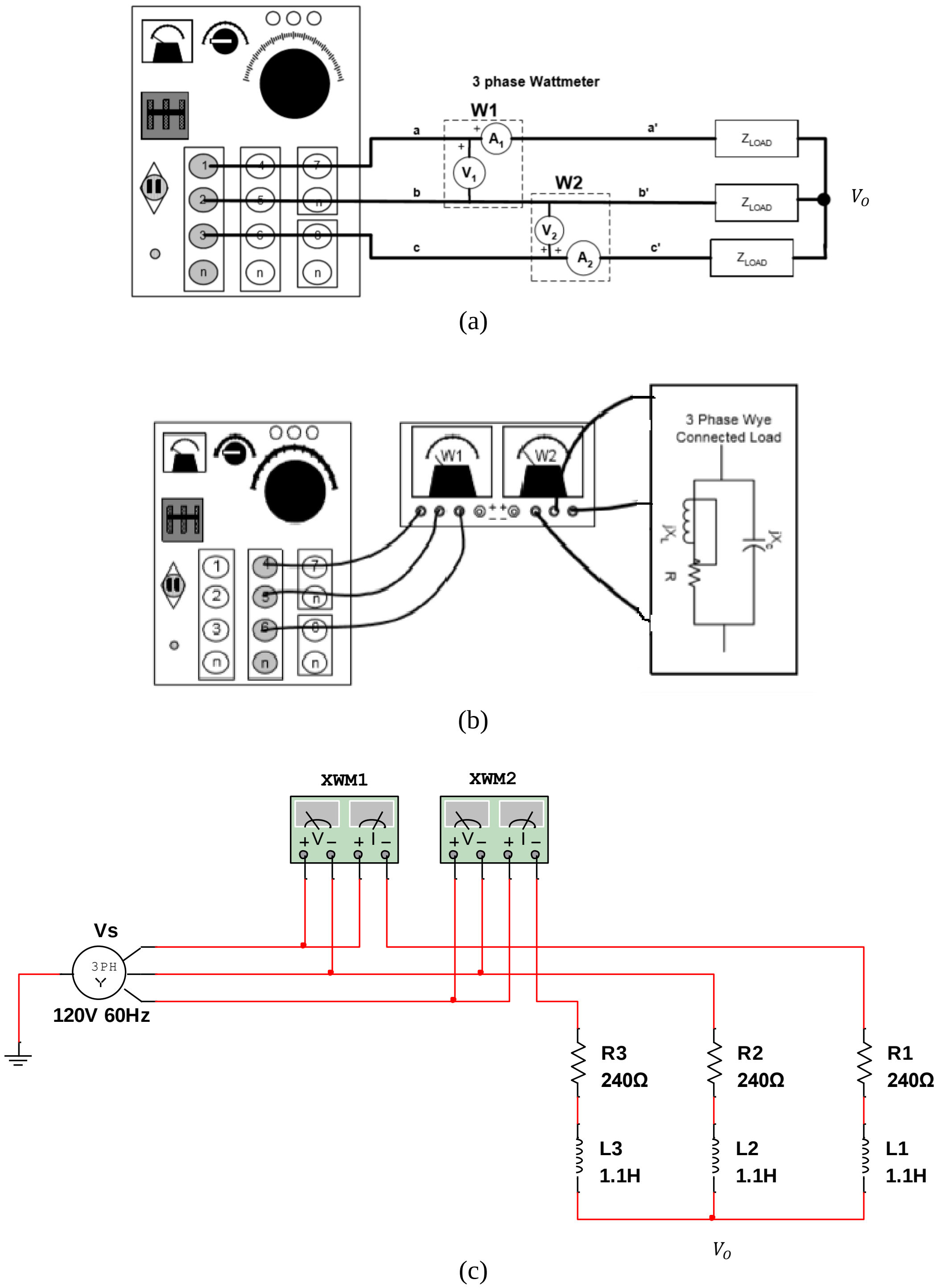

Figure 1: Connection diagram of the two-wattmeter method.
(a) Schematic diagram, (b) the two-wattmeter wiring, and (c) Multisim circuit.

Table 1: Balanced pure resistive load ($\phi = 0$).

	Calculated	Measured	
		Multisim	Actual
$\|V_{an}\|$	120V		
$\|V_{bn}\|$	120V		
$\|V_{cn}\|$	120V		
$\|V_O\|$	0 V		
$\|I_1\|$			
$\|I_2\|$			
$\|I_3\|$			
ϕ			
pf			
P_{T}			
Q_{T}			

Table 2: Balanced inductive load ($\phi = 60°$).

	Calculated	Measured	
		Multisim	Actual
$\|V_{an}\|$	120V		
$\|V_{bn}\|$	120V		
$\|V_{cn}\|$	120V		
$\|V_O\|$	0 V		
$\|I_1\|$			
$\|I_2\|$			
$\|I_3\|$			
ϕ			
pf			
P_{T}			
Q_{T}			

Table 3: Balanced inductive load ($60^\circ < \phi < 90^\circ$).

	Calculated	Measured	
		Multisim	**Actual**
$\lvert V_{an}\rvert$	120V		
$\lvert V_{bn}\rvert$	120V		
$\lvert V_{cn}\rvert$	120V		
$\lvert V_O\rvert$	0 V		
$\lvert I_1\rvert$			
$\lvert I_2\rvert$			
$\lvert I_3\rvert$			
ϕ			
pf			
P_{T}			
Q_{T}			

Table 4: Unbalanced inductive load.

	Calculated	Measured	
		Multisim	**Actual**
$\lvert V_{an}\rvert$	120V		
$\lvert V_{bn}\rvert$	120V		
$\lvert V_{cn}\rvert$	120V		
$\lvert V_O\rvert$			
$\lvert I_1\rvert$			
$\lvert I_2\rvert$			
$\lvert I_3\rvert$			
P_{T}			