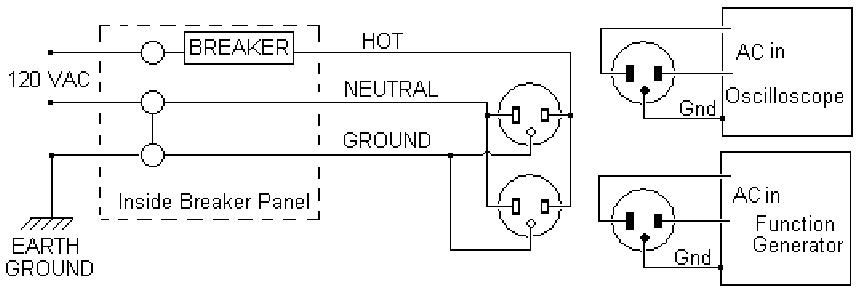
Experiments with Three-Phase Power

Introduction: Grounds

These lab exercise require a 3-Phase voltage source that can output 12V p-p per phase and a current of at least 100mA rms per phase. When making measurements it is important to know if the power supply and test equipment share a common ground or if they are isolated. Battery operated instruments can be considered isolated. Some instruments that use a power transformer may be isolated. In some cases an isolation transformer may be used.

Study the diagram of a typical 120 VAC power system below. All of the receptacles have a common ground connection. The grounds of the oscilloscope and function generator are connected together through the receptacles. These instruments are not isolated since they share a common ground. The result is that the oscilloscope's input probe ground and the function generator's output ground are also connected together through the ground receptacle. Connecting the grounds of these instruments to different nodes in the circuit would create a short circuit between those two nodes.



The Z_3PS 3-phase voltage source is isolated, but if two non-isolated instruments are used to make measurements, a short circuit could still occur. In this case, the ground probes of non-isolated instruments should not be connected to different nodes of the circuit.

Preparation

A knowledge of phasor analysis, node voltage and mesh current analysis, and 3-phase circuit analysis is required to perform these lab exercises. The student should be able to connect circuits on a solder-less breadboard and be able to use a multi-meter and oscilloscope. The student should be able to use the oscilloscope to make magnitude and phase angle measurements.

Objectives

These experiments involve the measurement of the magnitude and phase of voltages and currents in 3-phase wye and delta connected power systems. The effect of balanced and unbalanced loads measured. Measured results will be compared to calculations and simulations. The first three experiments involve simple resistive loads. The complexity of the experiments is in part dependent on the level and depth of the analysis expected.

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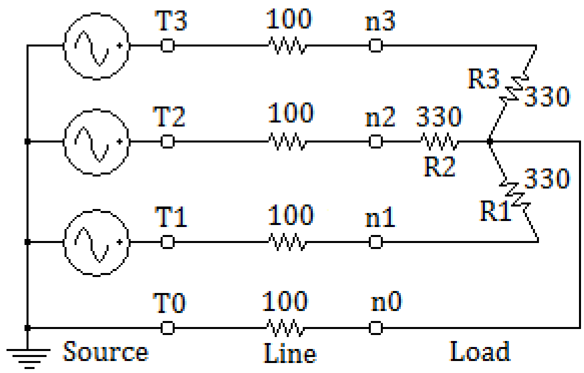
Equipment and Parts Required

3-Phase Voltage Source: 12V p-p per phase.
Exp 1, 2 and 3: 30mA rms/phase minimum. Exp 4: 100mA rms/phase minimum.
Simulation software such as PSpice® or LTspice®.
Spreadsheet software such as Excel®. Scientific calculator and/or math software.
Oscilloscope, multi-meter (DMM), and breadboard.
Resistors: four 330Ω, four 100Ω, four 47Ω, three 180Ω, all ¼ watt, 5%.
Inductor: 100mH, 65mA min., 90Ω DC, 10% (JW Miller 5900-104-RC)

Experiment 1: 4 Wire Wye Load

1. Connect the circuit on the right.



2. Connect channel 1 of the oscilloscope to T1 (ground to T0). Set the trigger to channel 1. T1 will be the reference for phase angle measurement.

   Check that the amplitude on channel 1 is about 12 V peak-to-peak.

3. Connect channel 2 of the oscilloscope to T2, T3, n0, n1, n2, and n3 one at a time to measure the voltage amplitude and phase at those nodes..

4. Set up a spreadsheet table as shown below to record your measurements. You may do this in your lab notebook and transfer the data to a spreadsheet table later.

	T1	T2	T3	n0	n1	n2	n3
Magnitude Volts p-p							
Phase Angle Degrees							

5. Record channel 1 data in column T1 above. The phase angle will be zero degrees. Use channel 2 to measure the voltage magnitude and phase angle at the other nodes.

6. Connect a 330 ohm resistor in parallel with R1 and repeat the measurements at nodes n0, n1, n2, and n3. Record results in a table as shown on the right.

	n0	n1	n2	n3
Magnitude Volts p-p				
Phase Angle Degrees				

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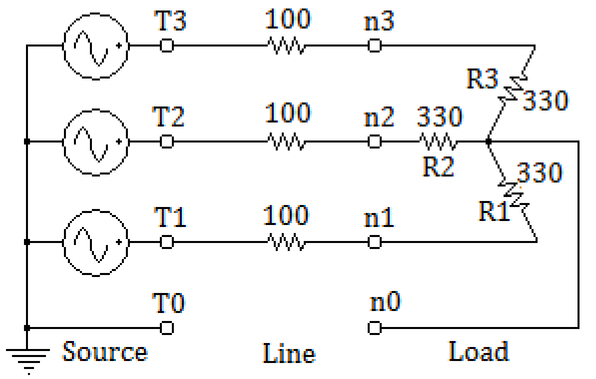
Experiment 2: 3 Wire Wye Load



1. Modify the circuit in part 1 by removing the 100 ohm resistor between nodes T0 and n0. Also remove the extra 330 ohm resistor across R1(from part 1).

   Refer to the circuit on the right. The voltages at nodes T1, T2 and T3 will be the same as those measured in part 1. You can copy the values from part 1.

2. Channel 1 should remain connected to node T1 as a phase zero reference.

3. Connect channel 2 of the oscilloscope to n0, n1, n2, and n3 one at a time to measure the voltage amplitude and phase angle at those nodes..

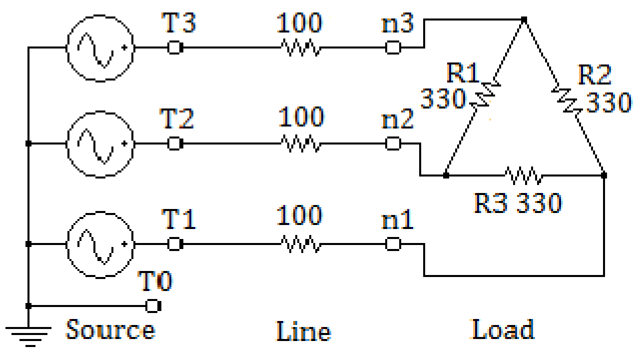
4. Set up a spreadsheet table as shown below to record your measurements. You may do this in your lab notebook and transfer the data to a spreadsheet table later.

	T1	T2	T3	n0	n1	n2	n3
Magnitude Volts p-p							
Phase Angle Degrees							

5. Connect a 330 ohm resistor in parallel with R1 and repeat the measurements at nodes n0, n1, n2, and n3. Record results in a table as shown on the right.

	n0	n1	n2	n3
Magnitude Volts p-p				
Phase Angle Degrees				

Experiment 3: Delta Load



1. Modify the circuit in part 2 by connecting the 330 ohm resistors in a delta configuration as shown on the right.

. The voltages at nodes T1, T2 and T3 will be the same as those measured in part 1. You can copy the values from part 1.

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2. Channel 1 should remain connected to node T1 as a phase zero reference.

3. Connect channel 2 of the oscilloscope to n1, n2, and n3 one at a time to measure the voltage amplitude and phase angle at those nodes..

4. Set up a spreadsheet table as shown below to record your measurements. You may do this in your lab notebook and transfer the data to a spreadsheet table later.

	T1	T2	T3	n1	n2	n3
Magnitude Volts p-p						
Phase Angle Degrees						

5. Connect a 330 ohm resistor in parallel with R1 and repeat the measurements at nodes n1, n2, and n3. Record results in a table as shown on the right.

	n1	n2	n3
Magnitude Volts p-p			
Phase Angle Degrees			

6. Use a DMM set to measure AC volts (RMS) to measure the line voltages across the load resistors, R1, R2, and R3 (V(n2-n3), V(n3-n1), and V(n1-n2) respectively). Use a DMM set to measure AC volts (RMS) to measure the line voltages across the source (V(T2-T3), V(T3-T1), and V(n1-n2) respectively). Record below:

(V(n2-n3)__________ V(n3-n1)__________ V(n1-n2)__________

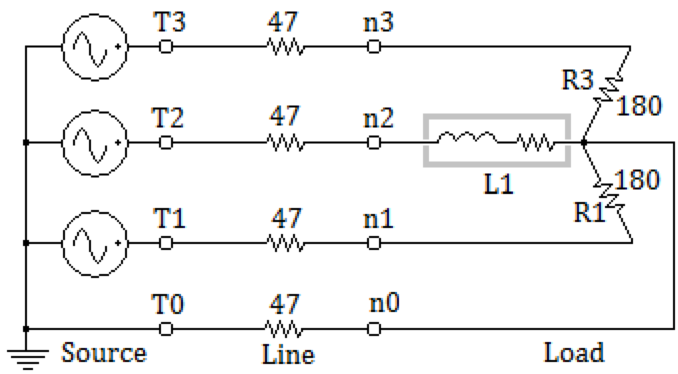
(V(T2-T3)__________ V(T3-T1)__________ V(n1-n2)__________

Experiment 4: Wye Load with Inductance

1. Connect the circuit on the right.

2. Connect channel 1 of the oscilloscope to T1 (ground to T0). Set the trigger to channel 1.

T1 will be the reference for phase angle measurement.



Note: This experiment requires a 100mA per phase source and an inductor whose DC resistance is between 80 and 120 ohms and capable of a current of 65mA rms.

3. Connect channel 2 of the oscilloscope to T2, T3, n0, n1, n2, and n3 one at a time to measure the voltage amplitude and phase at those nodes..

4. Set up a spreadsheet table as shown below to record your measurements. You may do this in your lab notebook and transfer the data to a spreadsheet table later.

	T1	T2	T3	n0	n1	n2	n3
Magnitude Volts p-p							
Phase Angle Degrees							

5. Record channel 1 data in column T1 above. The phase angle will be zero degrees. Use channel 2 to measure the voltage magnitude and phase at the other nodes.

6. Modify the circuit by removing the 47 ohm resistor between nodes T0 and n0.

   Repeat the measurements at nodes n1, n2, and n3. Record results in a table as shown on the right.

	n1	n2	n3
Magnitude Volts p-p			
Phase Angle Degrees			

7. Connect a 180 resistor in parallel with R1.

   Repeat the measurements at nodes n1, n2, and n3. Record results in a table as shown on the right.

	n1	n2	n3
Magnitude Volts p-p			
Phase Angle Degrees			

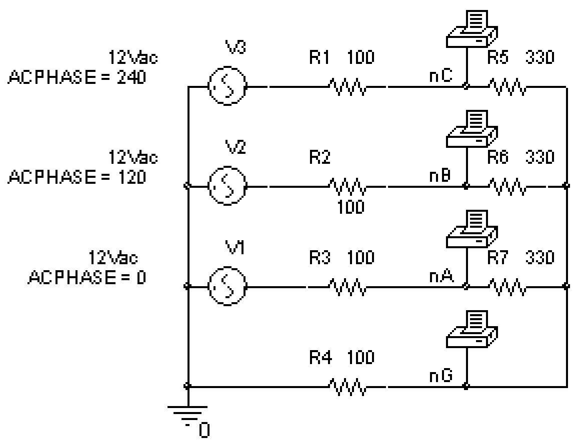
PSpice 3 Phase Simulation: 4 Wire Wye Load

Three phase circuits can be simulated using three "VAC" sources from the source library.

Double click on each source to open its property editor to set its phase angle. Click on "Display" and set each to display its name and value.

See the schematic diagram on the right and the edited simulation results below for a balanced and unbalanced load.

Use "AC Sweep analysis" with the start and end frequencies set to 60 Hertz and the number of points set to 1.



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The last two columns show the results when the load is unbalanced by replacing one of the 330 Ω resistors with a 1000 Ω resistor.

60 Hertz	R5=330, R6=330, R7=330.			R5=1K, R6=330, R7=330.	
Node	Mag V p-p	Phase Deg.		Mag V p-p	Phase Deg.
nC	9.209	-120		10.081	-120
nB	9.209	120		9.339	118.7
nA	9.209	0		9.339	1.35
nG	0	N.A.		1.092	60.0

PSpice Simulation: Delta Load with Line Inductance

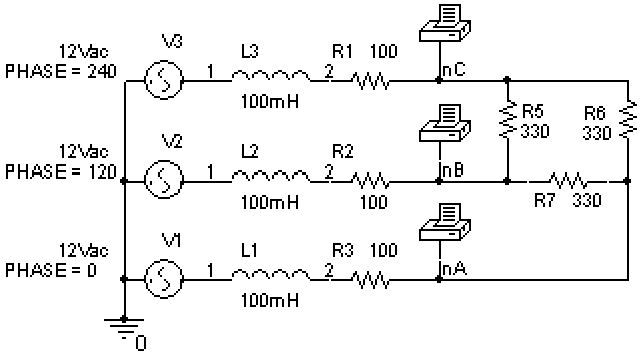
R1, R2, and R3 represent the DC resistance of the inductors.

Results for the circuit on the right.

FREQ	VM(NC)	VP(NC)
60	6.187	-130.2

FREQ	VM(NB)	VP(NB)
60	6.187	109.8

FREQ	VM(NA)	VP(NA)
60	6.187	-10.18



TI-89 Example of Delta Load

Let **V**(nA) = x, **V**(nB) = y, **V**(nC) = z.

Equations:

$$\frac{x-12\angle 0}{100+37.7i}+\frac{x-y}{330}+\frac{x-z}{330}=0 \text{ and } \frac{y-12\angle 120}{100+37.7i}+\frac{y-x}{330}+\frac{y-z}{330}=0 \text{ and } \frac{z-12\angle 240}{100+37.7i}+\frac{z-x}{330}+\frac{z-y}{330}=0$$

TI-89 input:

Balanced case:

csolve((x-12)/(100+37.7i)+(x-y)/330+(x-z)/330=0 and (y-(12∠120))/(100+37.7i)+(y-x)/330+(y-z)/330=0 and (z-(12∠240))/(100+37.7i)+(z-x)/330+(z-y)/330=0,{x,y,z})

x = (6.187∠-10.8) y = (6.187∠109.8) z = (6.187∠-130.2)

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Analysis Suggestions

Write a lab report on each lab incorporating the following:

1. Use the node voltage method to calculate the voltage at each node of the load for a balanced and unbalanced load.

2. Use the mesh current method to calculate the current supplied by the source for each phase or line for a balanced and unbalanced load.

3. Use PSpice, LTspice or other simulation program to simulate each circuit, balanced and unbalanced.

4. Discuss the neutral wire current for the four wire wye load for the balanced and unbalanced case.

5. Calculate the percent difference between the measured and calculated (or simulated) values of the voltages and currents for the balanced and unbalanced case.

6. Discuss any phase shifts that occur for balanced and unbalanced loads.

7. Calculate the power dissipated by the loads.

8. Discuss the effects of the line resistance (100Ω and 47Ω line resistors) on the results.

9. Evaluate the power supplied by the source, dissipated by the line resistance, and dissipated by the loads.

10. Calculate the power factor for the inductive load branch in experiment 4 for the balanced case.

11. Use copy and paste between spreadsheet programs, simulation programs, math programs, and data acquisition results as appropriate in your lab reports.

12. Include an abstract, introduction, and conclusion statement for each lab as appropriate.

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