Single-Phase Power Systems

In the United States 60Hz AC Electric power is typically supplied to a residence by a 240VAC center tapped transformer. This transformer may be supplied by one phase of a three-phase distribution system. It may be on a pole or underground. The transformer's center tap is connected to earth ground. Figure 3-5 is a simplified diagram showing a step-down transformer, power meter, and breaker panel.

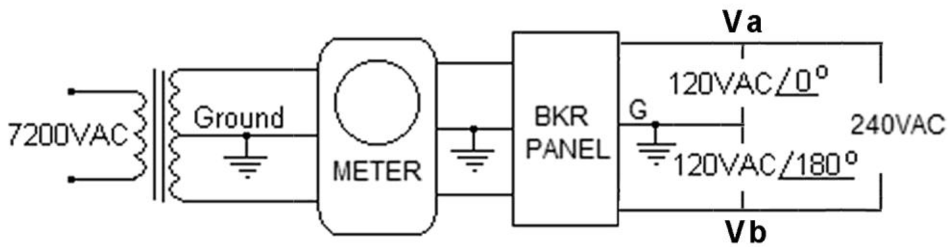

Figure 3-5

This transformer provides 120VAC on each side of the tap (**Va** to **G** and **Vb** to **G**) and 240VAC across the entire secondary (**Va** to **Vb**). Note that **Vb** to **G** is 180^0 out of phase with **Va** to **G**.

The actual voltage available at a 120VAC or 240VAC outlet is current dependent. The Voltage dropped across the transformer windings and distribution wires is proportional to current flow. This results in a power loss in the wiring resistance that is proportional to the square of the current. Other types of losses occur in power transformers which typically range from 2% to 4% of the power being supplied.

This chapter's Experiment 4 demonstrates some of the characteristics of a center tapped transformer distribution system. However, the voltages are scaled down so that the experiment may be safely performed on a breadboard. It uses the same transformer as used in Experiment 3.

The transformer is powered by a 400Hz sine wave from a signal generator. 400Hz is used here because the small 400mW transformer is less efficient at 60Hz. 400Hz is a common power distribution frequency on aircraft and marine vehicles because the transformers can be lighter. Alternately, a 12VAC center tapped line operated transformer could be used to do this experiment.

Experiment 3b: Center Tapped Transformer

The operating characteristics of a center tapped transformer power source will be measured. The transformer's input power, output power. and efficiency will be determined.

Equipment and Parts

Function Generator, Oscilloscope, DMM, and Breadboard.
Transformer, 500Ω CT to 500Ω CT, 400mW. Refer to appendix 2.
Recommended: ZICON 42TU500-RC (from Mouser Electronics)
Resistors: Two 10Ω, three 470Ω, all ¼ watt, 5%.

Procedure: Part 1, Balanced Load

1. Connect the circuit in Figure 3-6. Set the generator to produce a 400Hz, 12V p-p sine wave with no offset. Connect oscilloscope channel 1 to measure Vp and channel 2 to measure Vs. Trigger on channel 1.

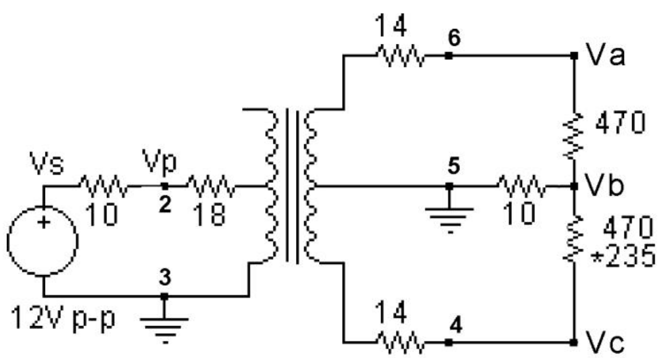

Figure 3-6

2. Measure and record the magnitude Vs and Vg.

   Vs ____________V p-p   Vg ____________ V p-p

3. Measure and record the magnitude and phase angle of the voltage Va with channel 2 of the oscilloscope.

   Va(mag.) ____________V p-p.   Va(angle) ____________ degrees.

4. Measure and record the magnitude and phase angle of the voltage Vb with channel 2 of the oscilloscope.

   Vb(mag.) ____________V p-p.   Vb(angle) ____________ degrees.

5. Measure and record the magnitude and phase angle of the voltage Vc with channel 2 of the oscilloscope.

   Vc(mag.) ____________V p-p.   Vc(angle) ____________ degrees.

Procedure: Part 2, Un-Balanced Load

1. Connect a 470 ohm resistor in parallel with the resistor connected between Vb and Vc.
2. Measure and record the magnitude Vs and Vg.

   Vs ____________V p-p   Vg ____________ V p-p

3. Measure and record the magnitude and phase angle of the voltage Va with channel 2 of the oscilloscope.

   Va(mag.) ____________V p-p.   Va(angle) ____________ degrees.

4. Measure and record the magnitude and phase angle of the voltage Vb with channel 2 of the oscilloscope.

   Vb(mag.) ____________V p-p.   Vb(angle) ____________ degrees.

5. Measure and record the magnitude and phase angle of the voltage Vc with channel 2 of the oscilloscope.

   Vc(mag.) ____________V p-p.   Vc(angle) ____________ degrees.

Note: All of the voltage measurements in this experiment are in peak-to-peak units. Power must be calculated using RMS units. A spreadsheet may be used to convert the peak-to-peak units to RMS units and to calculate the transformer's power input and output.

Analysis

1. Enter results into a spreadsheet. Calculate input power, output power and efficiency for parts 1 and 2. Refer to the example below:

	A	B	C	D	E	F	G	H	I	J	K
1	Part	Vs p-p	Vp p-p	Ip p-p	Va p-p	Vb p-p	Vc p-p	In p-p	Pin	Pout	%Eff.
2	1	12	11.57	0.043	10.43	0	10.43	0	0.062	0.058	93.05
4	2	12	11.4	0.06	9.95	0.188	8.69	0.019	0.086	0.061	71.85

   Equations in cells: D2: =(B2-C2)/10 H2: =F2/10 I2: =(C2*D2)/8

   J2: =(E2+G2)^2/(8*940) K2:=(J2/I2)*100

2. Explain the results for the phase angles between the source, Vp, and the voltages Va and Vc.
3. Simulate the circuit of Figure 3-6 and compare your results to the to your measurements.
4. Calculate the output power for parts 1 and 2 using the ideal transformer model and compare the calculated results to your measurements and simulation.

LTspice Example

The circuit in figure 3-7 below represents the circuit of part 2 of this experiment. It was simulated using the ideal transformer model and including the transformers primary and secondary resistances.

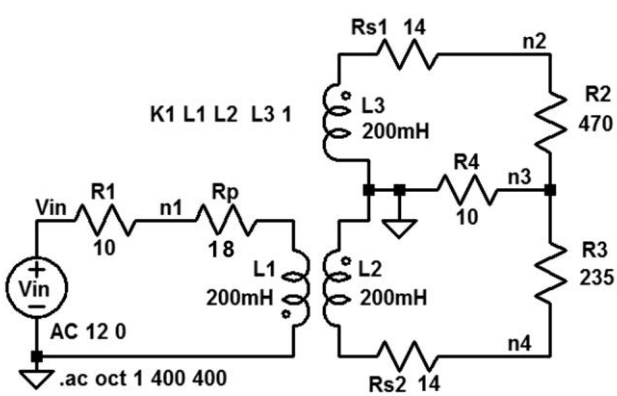

Figure 3-7

Analysis Results

```
--- AC Analysis ---  frequency:400Hz
V(vin): mag: 12.0     phase:    0.0°
V(n1):  mag: 11.37    phase:    0.8°
V(n2):  mag:  9.94    phase: -177.2°
V(n3):  mag:  0.18    phase:    2.7°
V(n4):  mag:  9.68    phase:    2.7°
```

In the circuit in figure 3-8 below the 10 ohm resistor between node n3 and ground is removed. It was simulated using the ideal transformer model and including the transformers primary and secondary resistances.

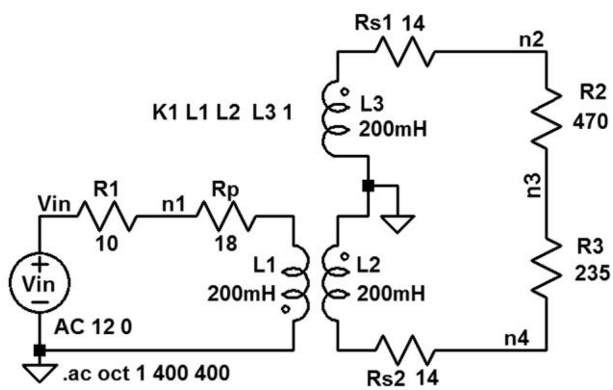

Figure 3-8

Analysis Results

Note below that the voltage at node n3 is 3.33 volts. This causes the voltage across R2 to increase to 13.33 volts and across R3 to decrease to 6.67 volts.

```
frequency:400Hz --- AC Analysis ---
V(n1):   mag: 11.42   phase:    0.89°
V(vin):  mag: 12.00   phase:    0.00°
V(n2):   mag: 10.00   phase: -177.23°
V(n3):   mag:  3.33   phase:    2.76°
V(n4):   mag: 10.00   phase:    2.76°
```