
California State University, Sacramento
College of Engineering and Computer Science
Electrical and Electronic Engineering Department

EEE131

**Lab #1: Measuring Voltage, Current, and Circuit Parameters of Single and Three Phase
Power circuits**

Abstract:

The purpose of this lab is to show us how to measure quantities in three phases, how to use those measurements to calculate power and other properties of the circuit, and how those properties change in different setups of a three phase circuit. We built eight circuits in this lab. In order, the circuits we set up were:

1. Single phase RLC circuit
2. Resistive balanced load in wye with neutral
3. Resistive unbalanced load in wye without neutral
4. Resistive unbalanced load in wye with neutral
5. RL balanced load in wye without neutral
6. RL unbalanced load in wye without neutral
7. RL balanced load in delta
8. RL unbalanced load in delta

List of major equipment:

- 2 analog voltage meters
- 3 analog ammeters
- 2 analog wattmeters
- 1 digital multimeter
- Multiple wires

The single phase circuit is just to see if we know how to use the measuring devices provided in the lab. When we set up the balanced load in wye we expect to see voltage and current phasors that add to zero. In the unbalance load without a neutral the currents should still add to zero since they're provided by an unchanging source, but the voltages should add together to equal whatever voltage is measured on the neutral node. The RL wye connected loads should have similar results as the resistive wye connected loads. The balanced load should have voltages add to zero, the unbalanced load should have voltages add to V_N . The RL balanced load in delta should have all voltages and currents add to zero, but the RL unbalanced load in delta should have currents that don't add to zero.

Introduction

The purpose of this lab is to discover how different three-phase circuit setups will affect measured values. We're given eight different circuits to set up with known supplied voltage, resistor and inductor values. We'll measure line currents, line to line voltages and power dissipated. We'll use these values to calculate phase currents, phase voltages, circuit properties,

power dissipated, reactive power dissipated, and error between our measured and calculated values.

The theory should be elaborated in section.

Team:

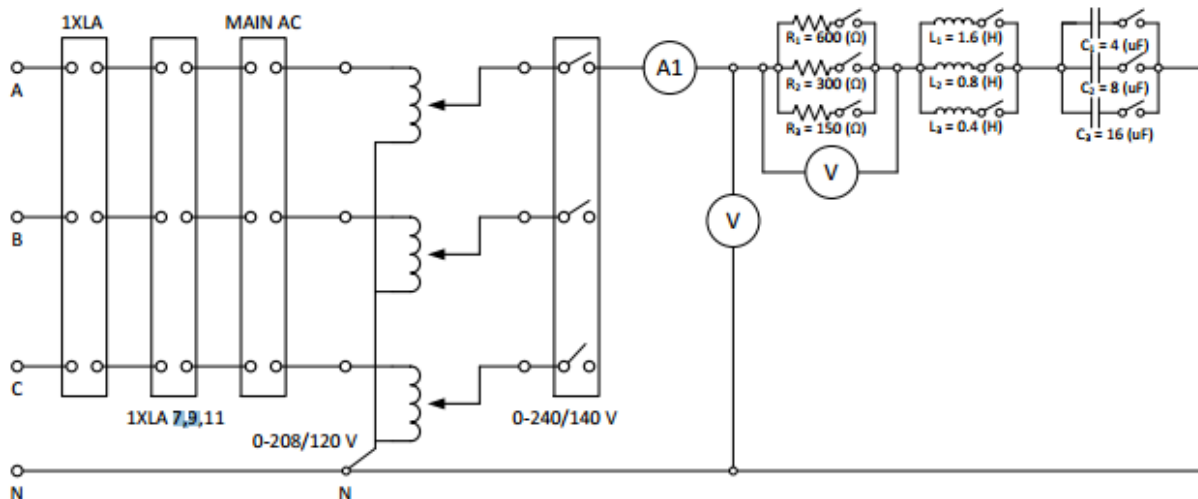
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Since there were only two of us working on this lab, we both wired and verified each circuit. We also double checked each other's recordings to make sure we agreed on the measured value.

Implementation and Results:

Part 1: Single-phase RLC circuit

Figure 1.1: Single-phase RLC circuit



We set up the first circuit without any problems. We measured the voltage across each component of the load and the current through the entire circuit. We then calculated the properties of each load device using ohm's law and the relationship between impedance and inductance/capacitance.

Table 1.1: Measured and computed values for a single phase RLC circuit

Measured Data					Calculated Data		
V_S (V)	V_R (V)	V_L (V)	V_C (C)	I_{RLC} (A)	R (Ω)	L (H)	C (μ F)
120.4	71.5	218.2	301.2	.845	84.6	.685	7.44

$$R = \frac{V_R}{I_R} = \frac{71.5}{.845} = 84.6 \, \Omega$$

$$L = \frac{V_L}{\omega I_L} = \frac{218.2}{2\pi 60 * .845} = .685 \, H$$

$$C = \frac{I_C}{\omega V_C} = \frac{.845}{2\pi 60 * 301.2} = 7.44 * 10^{-6} \, \mu F$$

For the phasor diagrams we had to know that the angle between the voltage and current was the same as the angle between the real part of the total impedance and the total impedance. Once we applied what we knew about phase changes due to resistors, inductors, and capacitors, we could draw the phasor diagram. It can be seen that if the three voltage drops are added together, they come close to equaling the source voltage. The reason they don't equal exactly is due to the usage of ideal resistance in calculations when, in reality, the resistors are not exact values. We should have measured the actual resistance before setting up the circuit to see more accurate phasor diagrams.

$$\phi = \tan^{-1} \left(\frac{98.3}{85.6} \right) = 48.95^\circ$$

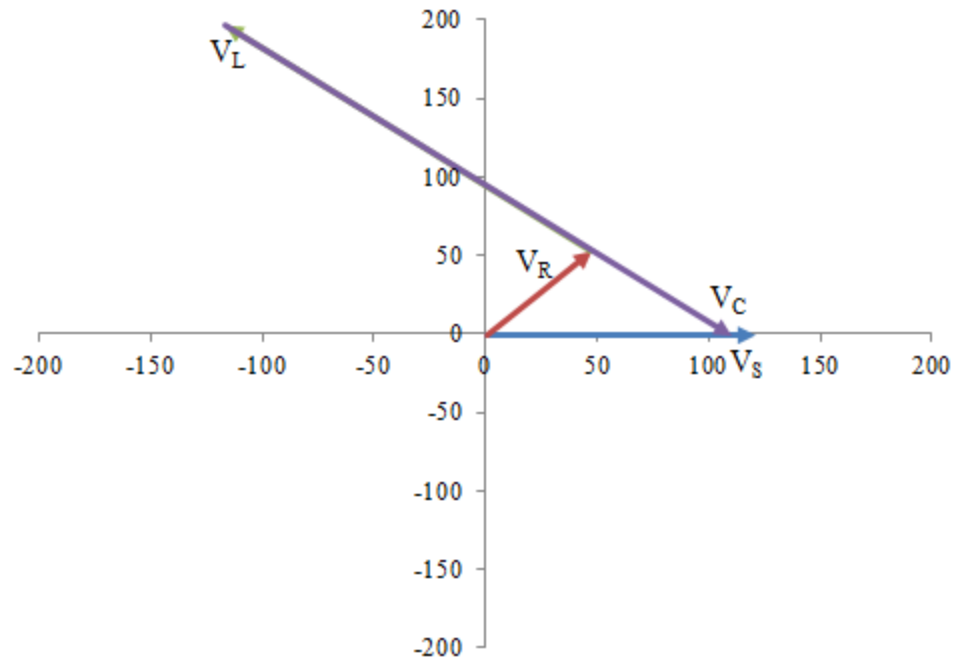
$$I_{RLC} = |I_{RLC}| \angle \phi = .845 \angle 48.95^\circ \, A$$

$$V_R = |V_R| \angle \phi = 71.5 \angle 48.95^\circ \, V$$

$$V_L = |V_L| \angle (\phi + 90^\circ) = 218.2 \angle 138.95^\circ \, V$$

$$V_C = |V_C| \angle (\phi - 90^\circ) = 301.2 \angle 41.05^\circ \, V$$

Figure 1.2: Phasor diagram of voltage drops around the RLC circuit.



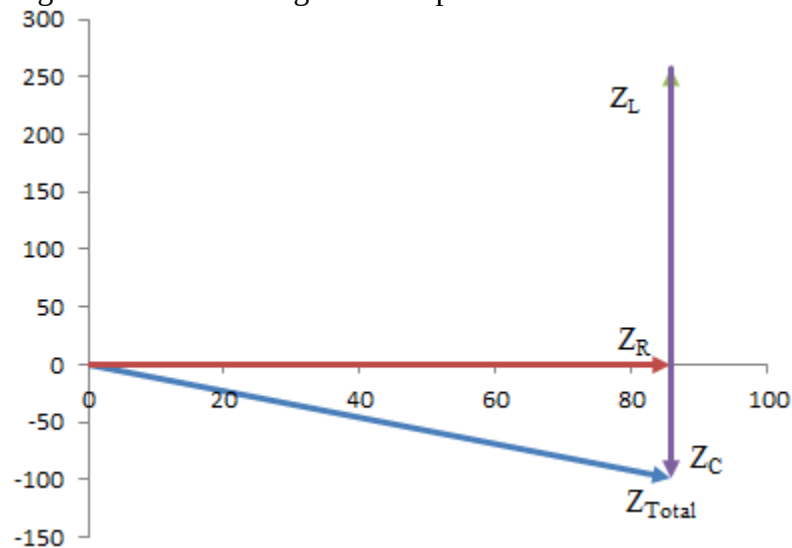
For the next phasor diagram we had to calculate impedances of each component. Z_R required no calculation since the impedance of a resistor is equal to the resistor's value. As can be seen in the diagram, the impedances all add together to equal the total impedance

$$Z_L = j\omega L = j * 2\pi 60 * .685 = j258.24 \Omega$$

$$Z_C = -\frac{j}{\omega C} = -\frac{j}{2\pi 60 * 7.44 * 10^{-6}} = -j356.53 \Omega$$

$$Z_{Tot} = R + Z_L + Z_C = 85.6 + j258.24 - j356.53 = 85.6 - j98.3 \Omega$$

Figure 1.3: Phasor diagram of impedances in the RLC circuit



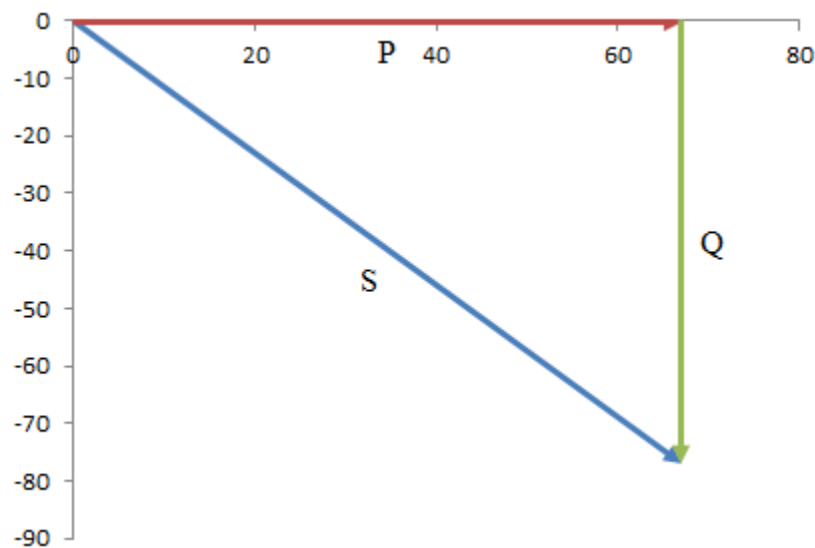
Next we calculated the power dissipated in the circuit. It was easier to solve for apparent power and take the real part to be the real power and the imaginary part to be the reactive power.

$$S = VI^* = 120.4(.845\angle 48.95)^* = 101.74\angle -48.95^\circ \text{ VA}$$

$$P = |S| \cos(\varphi) = 101.74 \cos(-48.95) = 66.85\angle 0^\circ \text{ W}$$

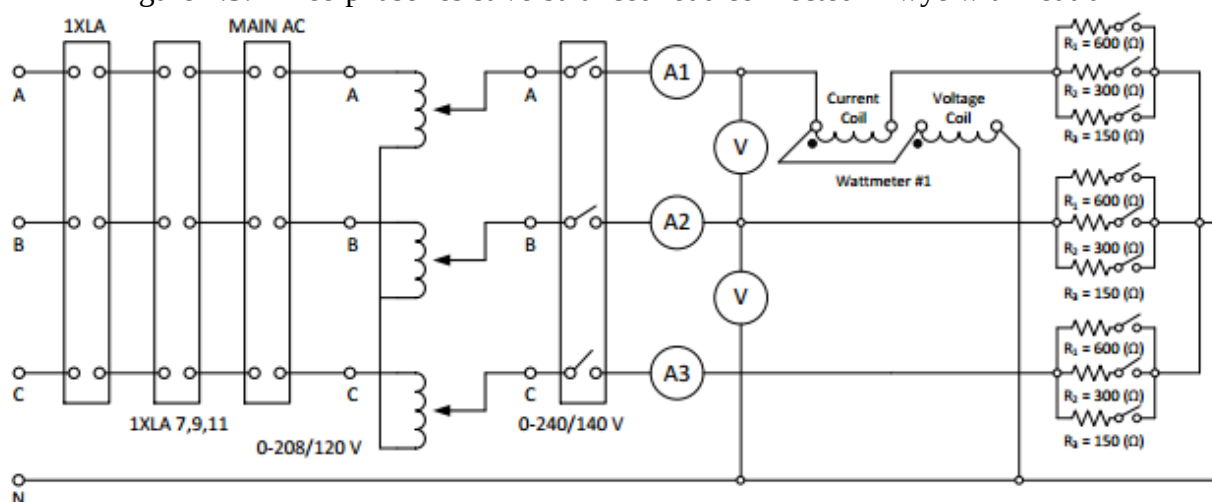
$$Q = |S| \sin(\varphi) = 101.74 \sin(-48.95) = -76.70\angle -90^\circ \text{ VAR}$$

Figure 1.4: Phasor diagram of power dissipated in RLC circuit



Part 2: Three-phase resistive balanced load connected in wye with neutral

Figure 1.5: Three-phase resistive balanced load connected in wye with neutral



The next circuit was a more complicated setup than the first. Once set up, all the meters were set up to measure what we needed. The only change we had to make after turning the circuit on were the scale factors on the ammeters and wattmeters. We used the values we measured to calculate single-phase and three-phase power dissipation. Our error, mainly due to internal resistance and analog readings, was small.

Table 1.2: Measured and computed values for a three phase balanced resistive circuit

Measured Data					Calculated Data		
R (Ω)	V _{L-L} (V)	V _{L-N} (V)	I _{avg} (A)	P _{1Φ msd} (W)	P _{1Φ calc} (W)	P _{3Φ calc} (W)	P _{Error} (%)
300	208.5	119.5	.39	44.5	46.6	139.8	4.51

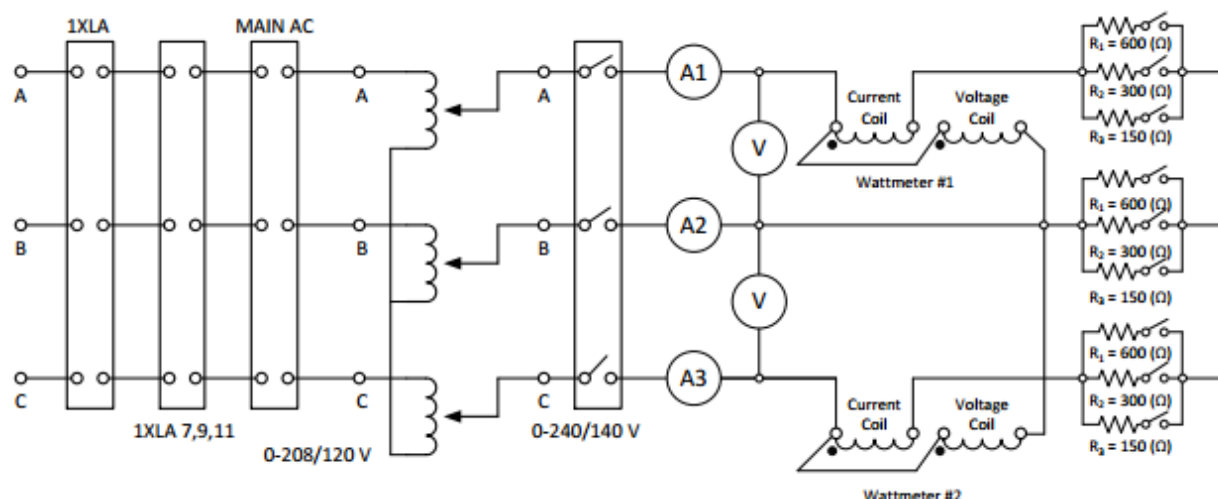
$$P_{1\Phi \text{ calc}} = V_{L-N} I_R = (119.5)(.39) = 46.6 \text{ W}$$

$$P_{3\Phi \text{ calc}} = 3P_{1\Phi \text{ calc}} = 3(46.6) = 139.8 \text{ W}$$

$$P_{\text{Error}} = \left(1 - \frac{P_{1\Phi \text{ msd}}}{P_{1\Phi \text{ calc}}}\right) * 100\% = \left(1 - \frac{44.5}{46.6}\right) * 100\% = 4.51 \%$$

Part 3: Three-phase resistive unbalanced load connected in wye without neutral

Figure 1.6: Three-phase resistive unbalanced load connected in wye without neutral



This circuit only required slight modifications of our previous circuit. The addition of the wattmeter was simple, but we almost forgot to disconnect the neutral wire. We were reminded, however, and proceeded to take the measurements required.

Table 1.3: Measured values for a three phase unbalanced resistive circuit connected in wye without a neutral wire

V_{AB} (V)	V_{CB} (V)	V_N (V)	I_A (A)	I_B (A)	I_C (A)	P_{W1} (W)	P_{W2} (W)	$P_{3\Phi}$ (W)
207.7	207.4	49.3	.25	.89	.98	36	196	232

The first things we calculated were the equivalent resistances due to the parallel combinations of resistors. Next we calculated the voltage on the neutral. This was tricky because we didn't realize that the voltage generated had to be balanced. Therefore we knew what V_A was with respect to ground. Using this knowledge we could calculate V_N . We then found the phase currents and the power dissipated in each phase.

Table 1.4: Calculated values for a three phase unbalanced resistive circuit connected in wye without a neutral wire

R_{eA} (Ω)	R_{eB} (Ω)	R_{eC} (Ω)	V_N (V)	I_A (A)	I_B (A)	I_C (A)	P_A (W)	P_B (W)	P_C (W)	$P_{3\Phi}$ (W)	$P_{3\Phi \text{ Error}}$ (%)
600	120	85.7	48.9 $\angle 160.9^\circ$	.278 $\angle -5.5^\circ$	1.01 $\angle -96.6^\circ$	1.04 $\angle 98.9^\circ$	46.4	122.4	92.7	261.7	11.3

$$R_{eA} = 600 \, \Omega$$

$$R_{eB} = \frac{600 * 150}{600 + 150} = 120 \, \Omega$$

$$R_{eC} = \frac{1}{\frac{1}{600} + \frac{1}{300} + \frac{1}{150}} = 85.7 \, \Omega$$

$$\frac{V_{an} - V_N}{R_{eA}} + \frac{V_{bn} - V_N}{R_{eB}} + \frac{V_{cn} - V_N}{R_{eC}} = 0 \quad V_N = -46.15 + j16 = 48.85 \angle 160.9^\circ V$$

$$I_A = \frac{V_{an} - V_N}{R_{eA}} = \frac{120 \angle 0^\circ - 48.9 \angle 160.9^\circ}{600} = .278 \angle -5.5^\circ A$$

$$I_B = \frac{V_{bn} - V_N}{R_{eB}} = \frac{120 \angle -120^\circ - 48.9 \angle 160.9^\circ}{120} = 1.01 \angle -96.6^\circ A$$

$$I_C = \frac{V_{cn} - V_N}{R_{eC}} = \frac{120 \angle 120^\circ - 48.9 \angle 160.9^\circ}{85.7} = 1.04 \angle 98.9^\circ A$$

$$P_A = |I_A|^2 R_{eA} = (.278)^2 600 = 46.4 W$$

$$P_B = |I_B|^2 R_{eB} = (1.01)^2 120 = 122.4 W$$

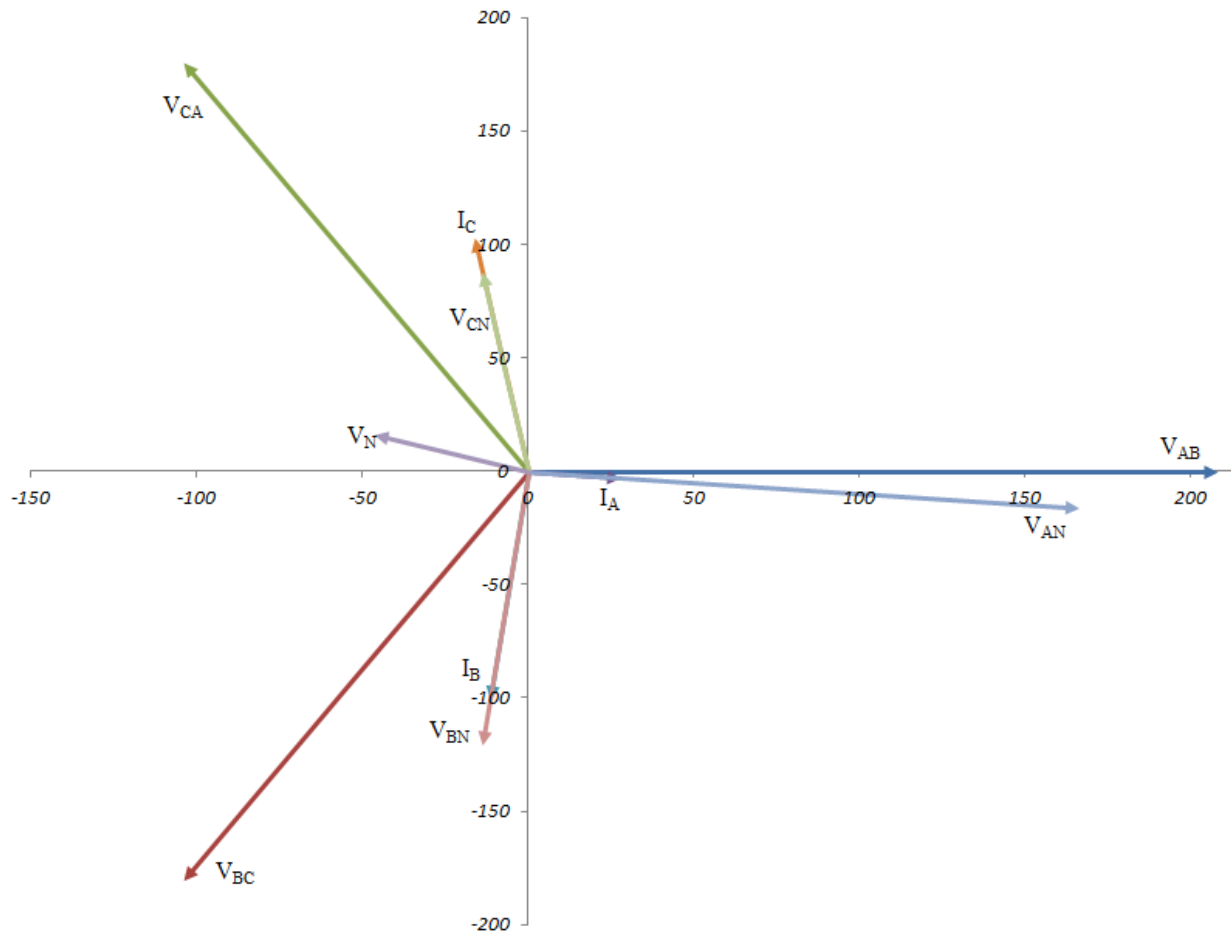
$$P_C = |I_C|^2 R_{eC} = (1.04)^2 85.7 = 92.7 W$$

$$P_{3\Phi} = P_A + P_B + P_C = 46.6 + 122.4 + 92.7 = 261.7 W$$

$$P_{3\Phi \text{ Error}} = \left(1 - \frac{P_{3\Phi \text{ msd}}}{P_{3\Phi \text{ calc}}}\right) * 100\% = \left(1 - \frac{232}{261.7}\right) * 100\% = 11.3\%$$

Next we graphed the phasors of each voltage and current in the unbalanced wye connected load. V_{AB} was the constant, generated voltage. V_{AN} was the voltage in the A phase, and V_N was the voltage attributed to the neutral point. It can clearly be seen that V_{AN} , V_{BN} , and V_{CN} won't add to zero. This is because of the unbalanced loads and the lack of a neutral wire. The voltages will add to equal V_N . We took measurements of the phase voltages to compare to our calculated phase voltages. We saw that in a balanced load without a neutral wire, the phase voltages are all nearly equal. When we unbalanced the load, the phase voltages became different from each other. When we connected the neutral wire, the phase voltages became similar to each other again. When the wire is connected, it provides a path for excess current to travel back to the generator without interfering with the other loads. When it is not, the current travels through the neutral node into other loads to dissipate extra power, or return it to the generator. Since the magnitudes of the current are so much smaller compared to voltage, the current phasors have been scaled by a factor of 100 so that they're more visible.

Figure 1.7: Voltage and current phasors for resistive unbalanced load connected in wye without neutral



Part 4: Three-phase resistive unbalanced load connected in wye with neutral

The next circuit is the same as the last, but with a neutral wire attached. We took the measurements below and compared the $P_{3\phi}$ to that of the previous circuit. The power dissipated should be the exact same, but because of the neutral wire, the meters show different numbers.

Table 1.5: Measured data of a three phase unbalanced resistive circuit connected in wye with a neutral wire

V_{AB} (V)	V_{CB} (V)	I_A (A)	I_B (A)	I_C (A)	P_{W1} (W)	P_{W2} (W)	$P_{3\phi}$ (W)
208.3	207.6	.18	.87	1.38	26	228	254

The two wattmeter method of measuring three-phase power doesn't work with a neutral connection because

$$I_B^* = I_N^* - (I_A^* + I_C^*)$$

This means that

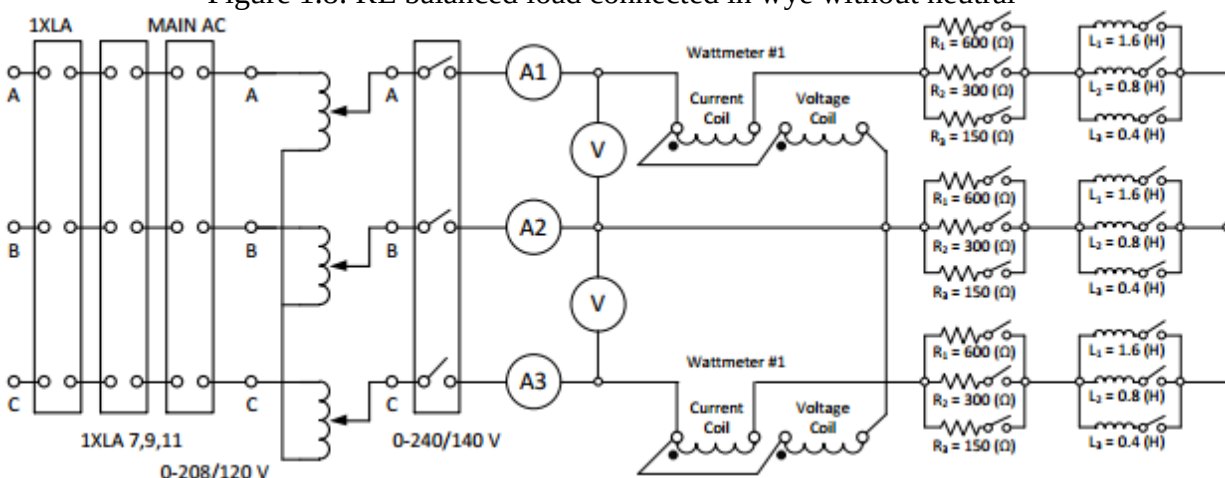
$$S_{3\phi} = V_{AN}I_A^* + V_{BN}(I_N^* - I_A^* - I_C^*) + V_C I_C^*$$

$$= V_{AB}I_A^* + V_{CB}I_C^* + V_{BN}I_N^*$$

Since we don't know V_{BN} or I_N^* this cannot be solved without additional measurements.

Part 5: Three-phase RL balanced load connected in wye without neutral

Figure 1.8: RL balanced load connected in wye without neutral



We took our previous circuit, disconnected the neutral, and added inductors to the end of the circuit. We then balanced the loads, and made the following measurements.

Table 1.6: Measured data of a three-phase balanced circuit with resistive and inductive load elements connected in wye without a neutral connection

R (Ω)	L (H)	V _{AB} (V)	V _{CB} (V)	I _{avg} (A)	P _{W1} (W)	P _{W2} (W)	P _{3Φ} (W)
300	.8	207.9	207.9	.26	15	44	59

From these measurements we calculated the following properties. We assumed ideal values for R and L, and used those values to find the power factor. We then calculated real and reactive power using voltage, current, and power factor. 10% error is more than I would like to see, but our values seem reasonable.

Table 1.7: Calculated data of a three-phase balanced circuit with resistive and inductive load elements connected in wye without a neutral connection

R (Ω)	L (H)	Cos(φ) (PF)	P _{1Φ calc} (W)	Q _{1Φ calc} (VAR)	P _{3Φ calc} (W)	Q _{3Φ calc} (VAR)	P _{3Φ Error} (%)
300	.8	.705	22	22.1	66	66.3	10.6

$$\cos(\varphi) = \cos\left(\tan^{-1}\left(\frac{Z_L}{Z_R}\right)\right) = \cos\left(\tan^{-1}\left(\frac{2\pi 60 \cdot .8}{300}\right)\right) = .705$$

$$P_{1\Phi} = \frac{V_{L-L}}{\sqrt{3}} I \cos(\varphi) = \frac{207.9}{\sqrt{3}} \cdot .26 (.705) = 22 \text{ W}$$

$$Q_{1\phi} = \frac{V_{L-L}}{\sqrt{3}} I \sin(\varphi) = \frac{207.9}{\sqrt{3}} \cdot 26 \sin(\cos^{-1}(.705)) = 22.1 \text{ VAR}$$

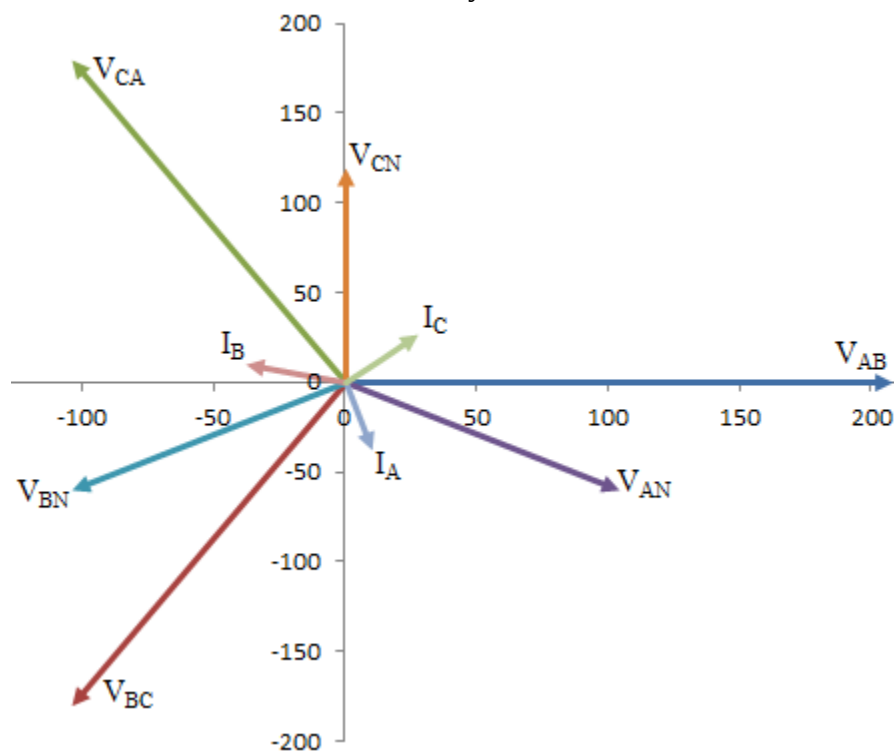
$$P_{3\phi} = 3P_{1\phi} = 3(22) = 66 \text{ W}$$

$$Q_{3\phi} = 3Q_{1\phi} = 3(22.1) = 66.3 \text{ VAR}$$

$$P_{3\phi \text{ Error}} = \left(1 - \frac{P_{3\phi \text{ msd}}}{P_{3\phi \text{ calc}}}\right) * 100\% = 10.6 \%$$

The phasor diagram for this circuit clearly shows that the phase voltages add to zero and the phase currents add to zero. This is to be expected in a balanced load. We know the phase voltage is lagging the line voltage by 30 degrees, and the current is lagging the line voltage by the power factor angle. This can be seen in the phasor diagram. Again it's important to note that the currents have been scaled up by a factor of 150 so that they are visible on the same diagram as the voltages.

Figure 1.9: Phasor diagram for voltages and currents of a circuit with balance RL load connected in wye



Part 6: Three-phase RL unbalanced load connected in wye without neutral

This circuit is the same as our last one, just with the loads changed. We changed the loads so that the circuit was unbalanced and made the following measurements. I'm not sure why we

measured the real resistor values. It would have worked out much more nicely if we had used ideal values all the way through the lab.

Table 1.8: Measured data of a three-phase unbalanced circuit with resistive and inductive load elements connected in wye with no neutral connection

R_A (Ω)	R_B (Ω)	R_C (Ω)	V_{AB} (V)	V_{CB} (V)	I_A (A)	I_B (A)	I_C (A)	P_{W1} (W)	P_{W2} (W)	$P_{3\Phi}$ (W)
631	123.8	88.2	207.8	207.5	.16	.67	.68	6	106	112

Using those values, we calculated the equivalent impedance of each phase and the phase currents that we expected to see.

Table 1.9: Calculated data of a three-phase unbalanced circuit with resistive and inductive load elements connected in wye with no neutral connection

Z_{eA} (Ω)	Z_{eB} (Ω)	Z_{eC} (Ω)	I_A (A)	I_B (A)	I_C (A)
$873\angle 43.7^\circ$	$170\angle 45.1^\circ$	$121.6\angle 45.1^\circ$	$.137\angle -43.7^\circ$	$.706\angle -165.1^\circ$	$.987\angle 74.9^\circ$

$$Z_{eA} = R_A + j\omega L_A = 631 + j(2\pi 60)(1.6) = 873\angle 43.7^\circ \Omega$$

$$Z_{eB} = R_B + j\omega L_B = 120 + j(2\pi 60)\left(\frac{1.6 * .4}{1.6 + .4}\right) = 170\angle 45.1^\circ \Omega$$

$$Z_{eC} = R_C + j\omega L_C = 85.7 + j(2\pi 60)\left(\frac{1}{\frac{1}{1.6} + \frac{1}{.8} + \frac{1}{.4}}\right) = 121.6\angle 45.1^\circ \Omega$$

$$\frac{V_{an} - V_N}{R_{eA}} + \frac{V_{bn} - V_N}{R_{eB}} + \frac{V_{cn} - V_N}{R_{eC}} = 0 \quad V_N = 48.5\angle 159.6^\circ$$

$$I_A = \frac{V_{an} - V_N}{R_{eA}} = \frac{120\angle 0^\circ + 48.5\angle 159.6^\circ}{873\angle 43.7^\circ} = .191\angle -49.4^\circ$$

$$I_B = \frac{V_{bn} - V_N}{Z_B} = \frac{120\angle -120^\circ + 48.5\angle 159.6^\circ}{170\angle 45.1^\circ} = .706\angle -140.9^\circ$$

$$I_C = \frac{V_{cn} - V_N}{Z_C} = \frac{120\angle 120^\circ + 48.5\angle 159.6^\circ}{121.6\angle 45.1^\circ} = .727\angle 54.3^\circ$$

Once we had the currents and impedances we could easily find power dissipated and compare to our measured value. We introduced some error by using real resistor values, calculated current values, and ideal voltage values, but the overall error was 7.9% which wasn't too bad.

Table 1.10: Calculated data of a three-phase unbalanced circuit with resistive and inductive load elements connected in wye with no neutral connection

P_A (W)	P_B (W)	P_C (W)	$P_{3\Phi}$ (W)	$S_{3\Phi}$ (VA)	$P_{3\Phi \text{ Error}}$ (%)
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18.1	45.9	57.6	121.6	$113.6\angle 138.7^\circ$	7.9
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$$P_A = I_A^2 Z_{eA} \cos(\varphi) = 18.1 \text{ W}$$

$$P_B = I_B^2 Z_{eB} \cos(\varphi) = 45.9 \text{ W}$$

$$P_C = I_C^2 Z_{eC} \cos(\varphi) = 57.6 \text{ W}$$

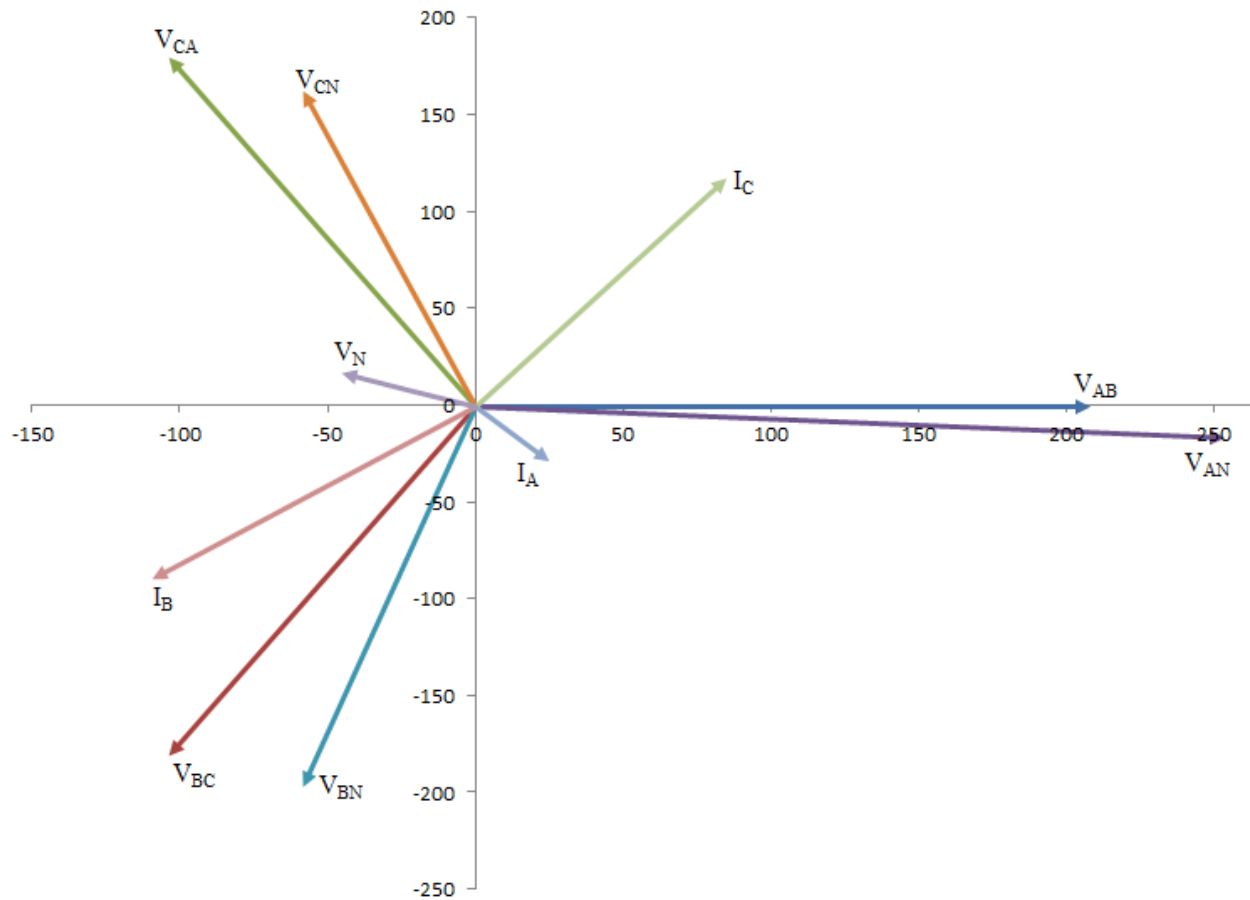
$$P_{3\phi} = P_A + P_B + P_C = 18.1 + 45.9 + 57.6 = 121.6 \text{ W}$$

$$S_{3\phi} = V_{AN}I_A + V_{BN}I_B + V_{CN}I_C = 113.6\angle 138.7^\circ \text{ VA}$$

$$P_{3\phi \text{ Error}} = \left(1 - \frac{P_{3\phi \text{ msd}}}{P_{3\phi \text{ calc}}}\right) * 100\% = \left(1 - \frac{112}{121.6}\right) * 100\% = 7.9\%$$

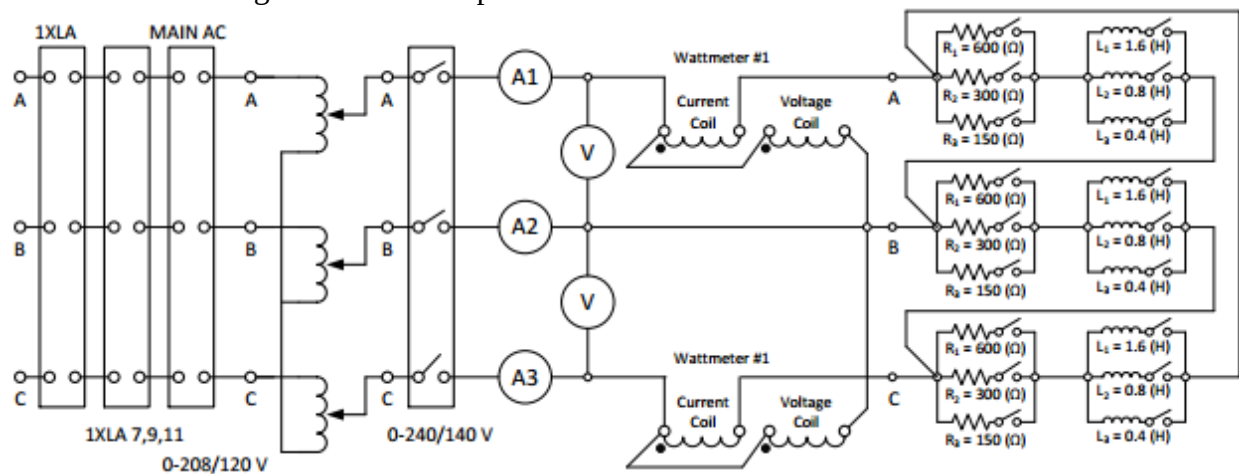
Since the load is imbalanced, the phase voltages shouldn't, and don't, add to zero. Instead their sum is the voltage at the neutral node, V_N . You can see from the phasor diagram that $V_A + V_B + V_C + V_N = 0$, but the phase currents will not equal zero because some current is going through the neutral node into other phases. These current phasors have been scaled by a factor of 200 to make them more clearly visible on the same diagram as voltages.

Figure 1.10: Phasor diagram of voltages and currents in the RL circuit with unbalanced load connected in wye



Part 7: Three-phase RL balanced load connected in delta

Figure 1.11: Three-phase RL balanced load connected in delta



We got rid of our short wires that connected the outputs of the inductors together and set up the delta configuration above. We changed our loads back to being balanced and took the measurements our meters were set up to read.

Table 1.11: Measured data of a three-phase balanced RL circuit connected in delta

V_{AB} (V)	V_{CB} (V)	I_A (A)	I_B (A)	I_C (A)	P_{W1} (W)	P_{W2} (W)	$P_{3\Phi}$ (W)
207.4	207.4	.855	.88	.84	50	148	198

We then used the known resistor and inductor values to find the equivalent impedances. Since the load is balanced, each phase has the same impedance. We then used voltage and impedance to find phase current. Once we had phase current, it was simple to use KCL to find line currents.

Table 1.12: Calculated data of a three-phase balanced circuit with resistive and inductive loads connected in delta

Z_{eAB} (Ω)	Z_{eBC} (Ω)	Z_{eCA} (Ω)	I_{AB} (A)	I_{BC} (A)	I_{CA} (A)	I_A (A)	I_B (A)	I_C (A)
425.4 $\angle 45.2^\circ$	425.4 $\angle 45.2^\circ$	425.4 $\angle 45.2^\circ$	.488 $\angle -45.2^\circ$	.488 $\angle -165.2^\circ$	.488 $\angle 74.8^\circ$	.845 $\angle -75.2^\circ$	.845 $\angle 164.8^\circ$	.845 $\angle 44.8^\circ$

$$Z_{eAB} = Z_{eBC} = Z_{eCA} = 300 + j2\pi 60 * .8 = 425.4 \angle 45.2^\circ \Omega$$

$$I_{AB} = \frac{V_{AB}}{Z_{AB}} = \frac{207.4}{425.4 \angle 45.2^\circ} = .488 \angle -45.2^\circ A$$

$$I_{BC} = \frac{V_{BC}}{Z_{BC}} = \frac{207.4 \angle -120^\circ}{425.4 \angle 45.2^\circ} = .488 \angle -165.2^\circ A$$

$$I_{CA} = \frac{V_{CA}}{Z_{CA}} = \frac{207.4 \angle 120^\circ}{425.4 \angle 45.2^\circ} = .488 \angle 74.8^\circ A$$

$$I_A = I_{AB} - I_{CA} = .845 \angle -75.2^\circ A$$

$$I_B = I_{BC} - I_{AB} = .845 \angle 164.8^\circ A$$

$$I_C = I_{CA} - I_{BC} = .845 \angle 44.8^\circ A$$

Since we knew current and impedance we could easily solve for both real and reactive power. Our calculated and measured $P_{3\Phi}$ were very close to each other, which is a good sign that we did everything correctly.

Table 1.13: Calculated data of a three-phase balanced circuit with resistive and inductive loads connected in delta

P_{AB} (W)	P_{BC} (W)	P_{CA} (W)	$P_{3\Phi \text{ calc}}$ (W)	Q_{AB} (VAR)	Q_{BC} (VAR)	Q_{CA} (VAR)	$Q_{3\Phi \text{ calc}}$ (VAR)
71.4	26.5	97.9	195.8	71.9	97.8	25.9	195.6

$$P_{AB} = I_{AB}^2 Z_{AB} \cos(\varphi) = 71.4 \text{ W}$$

$$P_{BC} = I_{BC}^2 Z_{BC} \cos(\varphi) = 26.5 \text{ W}$$

$$P_{CA} = I_{CA}^2 Z_{CA} \cos(\varphi) = 97.9 \text{ W}$$

$$P_{3\Phi \text{ calc}} = P_{AB} + P_{BC} + P_{CA} = 195.8 \text{ W}$$

$$Q_{AB} = I_{AB}^2 Z_{AB} \sin(\varphi) = 71.9 \text{ VAR}$$

$$Q_{BC} = I_{BC}^2 Z_{BC} \sin(\varphi) = 97.8 \text{ VAR}$$

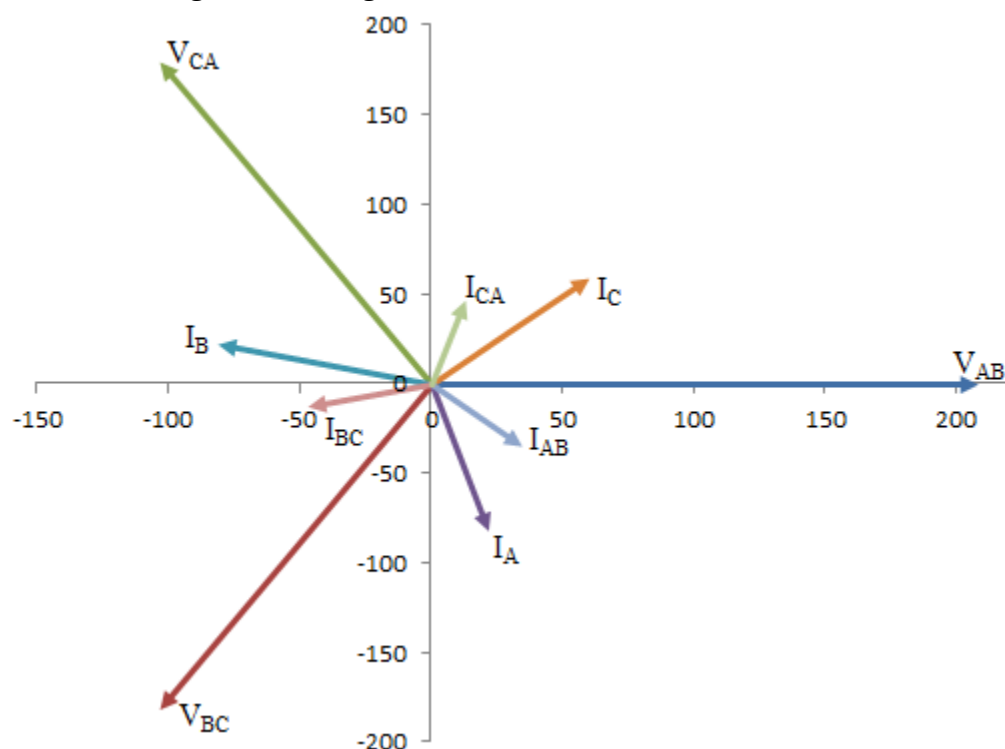
$$Q_{CA} = I_{CA}^2 Z_{CA} \sin(\varphi) = 25.9 \text{ VAR}$$

$$Q_{3\Phi \text{ calc}} = Q_{AB} + Q_{BC} + Q_{CA} = 195.6 \text{ VAR}$$

These values of power dissipation are clearly higher than those of the same load connected in wye. The reason for this is the fact that our load is the same. If you convert a load from wye connection to delta connection the wye impedance needs to be three times the impedance of the delta impedance. Since we didn't convert the loads, and just changed the configuration, the overall impedance went up by a factor of three. This increases power dissipation by a factor of three because $S = I^2 Z$.

Since the load was connected in delta, the line and phase voltages were the same. The line and phase currents were different though, and this can be seen in the phasor diagram below. The currents have been scaled up by a factor of 100 so that they are visible on the same diagram as the voltage phasors.

Figure 1.12: Phasor diagram of voltages and currents of a balanced RL circuit connected in delta



Part 6: Three-phase RL unbalanced load connected in wye without neutral

The last circuit set up was the same delta connected load as before, we just had to change the resistor and inductor values to make the load unbalanced.

Table 1.14: Measured data of a three-phase unbalanced circuit with resistive and inductive loads connected in delta

V_{AB} (V)	V_{BC} (V)	I_A (A)	I_B (A)	I_C (A)	P_{W1} (W)	P_{W2} (W)	$P_{3\Phi}$ (W)
206.9	206.2	1.5	1.3	2.5	16	456	440

With those measured quantities, we could solve for equivalent impedances, phase currents, and line currents in a process similar to the last circuit.

Table 1.15: Calculated data of a three-phase unbalanced circuit with resistive and inductive loads connected in delta

Z_{eAB} (Ω)	Z_{eBC} (Ω)	Z_{eCA} (Ω)	I_{AB} (A)	I_{BC} (A)	I_{CA} (A)	I_A (A)	I_B (A)	I_C (A)
850.8 $\angle 45.1^\circ$	170 $\angle 45.1^\circ$	121.6 $\angle 45.1^\circ$	.245 $\angle -45.1^\circ$	1.226 $\angle -165.1^\circ$	1.716 $\angle 74.9^\circ$	1.85 $\angle -98.4^\circ$	1.36 $\angle -173.9^\circ$	2.56 $\angle 50.5^\circ$

$$Z_{eAB} = 600 + j(2\pi 60)1.6 = 850.8 \angle 45.1^\circ \Omega$$

$$Z_{eBC} = \frac{600 * 150}{600 + 150} + j(2\pi 60) \frac{1.6 * .4}{1.6 + .4} = 170 \angle 45.1^\circ \Omega$$

$$Z_{eCA} = \frac{1}{\frac{1}{600} + \frac{1}{300} + \frac{1}{150}} + j(2\pi 60) \left(\frac{1}{\frac{1}{1.6} + \frac{1}{.8} + \frac{1}{.4}} \right) = 121.6 \angle 45.1^\circ$$

$$I_{AB} = \frac{V_{AB}}{Z_{eAB}} = \frac{206.9}{850.8 \angle 45.1^\circ} = .245 \angle -45.1^\circ \text{ A}$$

$$I_{BC} = \frac{V_{BC}}{Z_{eBC}} = \frac{206.2 \angle -120^\circ}{170 \angle 45.1^\circ} = 1.226 \angle -165.1^\circ \text{ A}$$

$$I_{CA} = \frac{V_{CA}}{Z_{eCA}} = \frac{206.9 \angle 120^\circ}{121.6 \angle 45.1^\circ} = 1.716 \angle 74.9^\circ$$

$$I_A = I_{AB} - I_{CA} = 1.85 \angle -98.4^\circ \text{ A}$$

$$I_B = I_{BC} - I_{AB} = 1.36 \angle -173.9^\circ \text{ A}$$

$$I_C = I_{CA} - I_{BC} = 2.56 \angle 50.5^\circ \text{ A}$$

Table 1.16: Calculated data of a three-phase unbalanced circuit with resistive and inductive loads connected in delta

P _{AB} (W)	P _{BC} (W)	P _{CA} (W)	P _{3Φ calc} (W)	P _{3Φ Error} (%)	Q _{AB} (VAR)	Q _{BC} (VAR)	Q _{CA} (VAR)	Q _{3Φ calc} (VAR)
35.86	65.98	344.8	446.64	1.49	36.05	246.25	92.39	374.69

$$S_{AB} = V_{AB} I_{AB} = 35.86 - j36.05$$

$$S_{BC} = V_{BC} I_{BC} = 65.98 + j246.25$$

$$S_{CA} = V_{CA} I_{CA} = -344.80 - j92.39$$

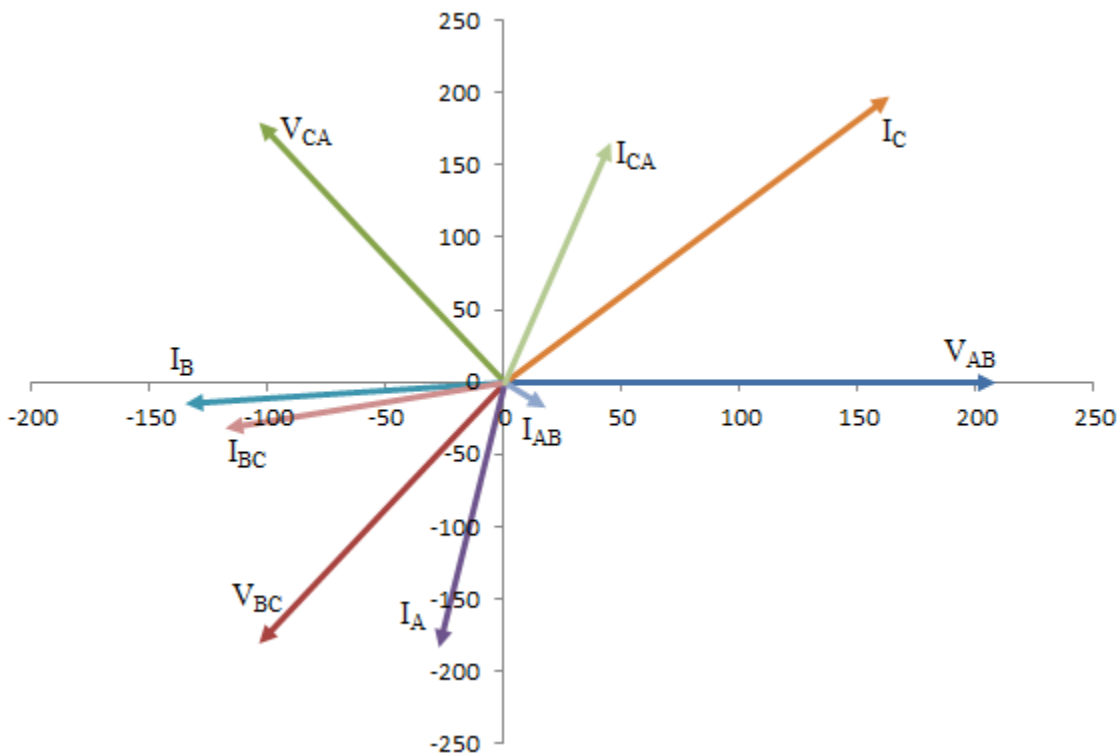
$$P_{3\Phi} = 35.86 + 65.98 + 344.8 = 446.64$$

$$Q_{3\Phi} = 36.05 + 246.25 + 92.39 = 374.69$$

$$P_{3\Phi \text{ Error}} = \left(1 - \frac{P_{3\Phi \text{ msd}}}{P_{3\Phi \text{ calc}}} \right) * 100\% = \left(1 - \frac{440}{446.64} \right) * 100\% = 1.49\%$$

The phase currents in this circuit clearly don't add to zero. The line currents have to add to zero because they're generated by an unchanging generator. They aren't, however, equally spaced from each other. As the phasor diagram shows, I_C is much larger than I_A or I_B , but I_A and I_B are closer together to cancel out I_C . Again, the currents have been scaled up by a factor of 100 so that they are visible on the same diagram as the voltage.

Figure1.13: Phasor diagram of voltages and currents for an unbalanced, RL, delta connected load

**Conclusion:**

The neutral wire in a wye connected load allows current to travel back to the generator without interfering with the load currents. This makes the two wattmeter method invalid. We would have to measure neutral current if the neutral wire is connected to our load to find three phase power.

A delta load is only equivalent to a wye connected load if the impedance of the wye connected load is three times as large as the delta impedance. If not, there will be three times as much power dissipated in the delta load as in the wye load.

An unbalanced wye load has phase voltages that don't equal zero. The voltage in the neutral will be the sum of the phase voltages unless a neutral wire is connected. An unbalanced delta load has phase currents that don't equal zero.

References:

EEE 131 Lab#1 manual, Rahimi.