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by Joshua Rees

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Introduction and Background Theory

Electricity is transmitted around the country through three and four wire systems. Three wire system is a 3 phase supply configured in star or delta, with a four wire system including a neutral return. In this assignment, experiments will be carried out to show the relationship between voltage and current and how they vary in different configurations and how they are affected by different loads.

Research

3 Phase Transmission

Electricity is transmitted through a 3 phase basis to optimize efficiency. 3 phase supply allows for a higher transmission at a lower current and provides more power for the same current which increases power efficiency. This makes it cheaper as cable sizes and costs are lower.

(Edvard, 2011)

Voltage is generated from renewable or non-renewable sources and is then stepped up to 400KV in a substation by step-up transformers, this makes less energy wasted in the cables when travelling long distances. Once reached its destination it is stepped down in distribution substations.

(Hayes, 2017)

Transformer connections

There are 4 ways of connecting arrangements of star and delta in transformer applications. To meet specific requirements the primary and secondary windings are connected in different configurations. In star connection one end of each coil is connected into a neutral point. In delta connection the opposite ends of the coils are connected to each other forming a triangle as shown in figure 1.

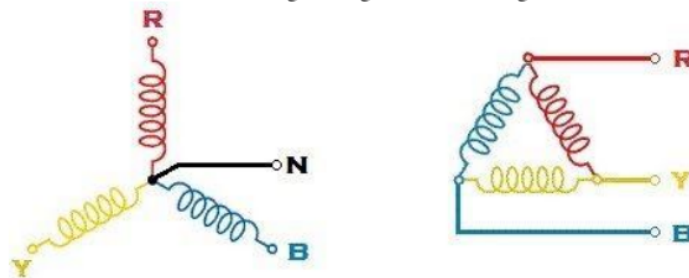


Figure 1 - Star/Delta configurations (technology, n.d.)

Star-Star Connection

In this application the phase current and line current are equal, with the phase voltage being $1/\sqrt{3}$ of the line voltage through the primary and secondary. This connection is used if the connected load is balanced, it is typically used for high voltage transformers as it requires less number of turns.

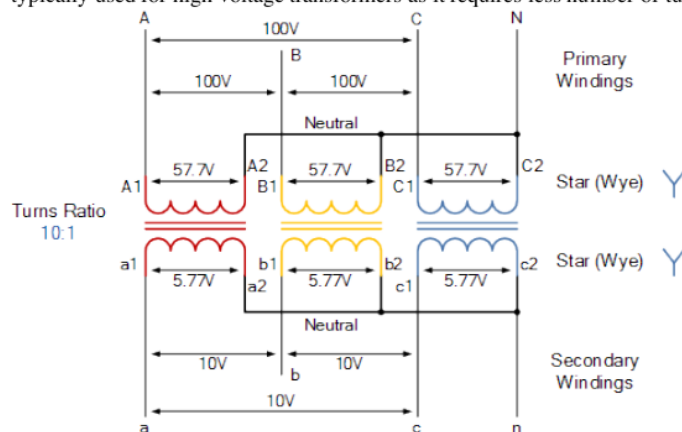


Figure 2 - Star-Star Connection

(Tutorial, 2020)

Delta-Delta Connection

In this connection the phase voltage is equal to the line voltage, with the phase current being $1/\sqrt{3}$ of the line current. There is no neutral connection in this application. This can be used for unbalanced loading but is typically used in low voltage transformers as the number of turns is greater than star.

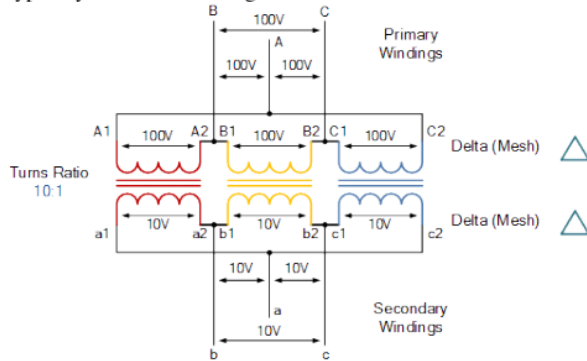


Figure 3 - Delta-Delta Connection

(Tutorial, 2020)

Star-Delta Connection

In this application star configuration is used to connect the primary windings and delta configuration is used to connect the secondary windings. This is usually used in step down transformers in substations.

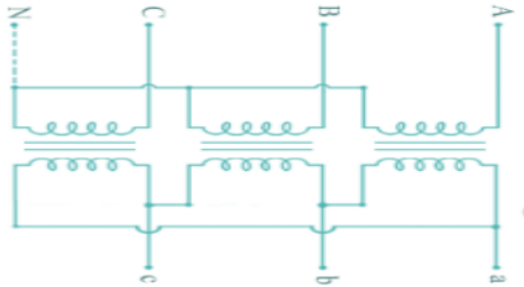


Figure 4 - Star-Delta Connection

(Daware, 2020)

Delta-Star Connection

The primary windings in this connection is connected in delta configuration. The secondary windings are connected in star. This connection is usually used in low power distribution systems with the primary windings giving a balanced load and the star in secondary being used to create a neutral point.

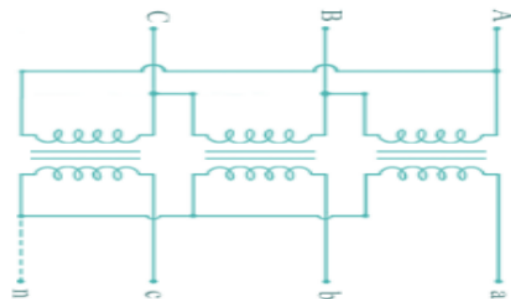


Figure 5 - Delta-Star Connection

(Daware, 2020)

Experimental Procedures and Results

Star R-L Series Load

This circuit has a 3 phase supply with a 210V line voltage at 50Hz. Each phase has a 100Ω resistor and a 200mH inductor in series connected in star configuration. The calculations are found in appendices, figures 13 to 15, this shows the calculations for the currents and voltage with a scaled phasor diagram, and the calculations for the power triangle with the power factor. The circuit was designed on multisim to prove the calculations as shown in figure 6.

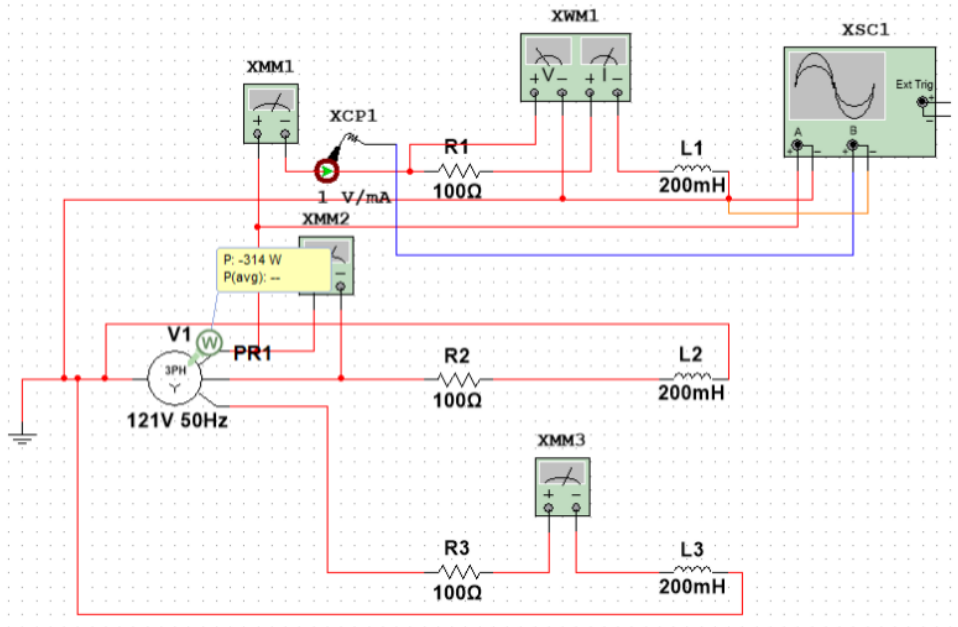


Figure 6 - Star R-L Load

Star R-L Result

Table 1 - Star R-L Load Results

	Calculated	Measured
Phase Current	1.02 A	1.024 A
Line Current	$I_l = I_p$	$I_l = I_p$
Phase Voltage	121.24 V	121 V
Line Voltage	210 V	209.573 V
True Power	314.15 W	314 W
Apparent Power	371.01 VA	$314 / 0.84596 = 371.18 \text{ VA}$
Reactive Power	197.37 VAR	$371.18 \times \sin(32.14) = 197.46 \text{ VAR}$
Power Factor	0.85	0.84596
θ	32.14°	Figure 7

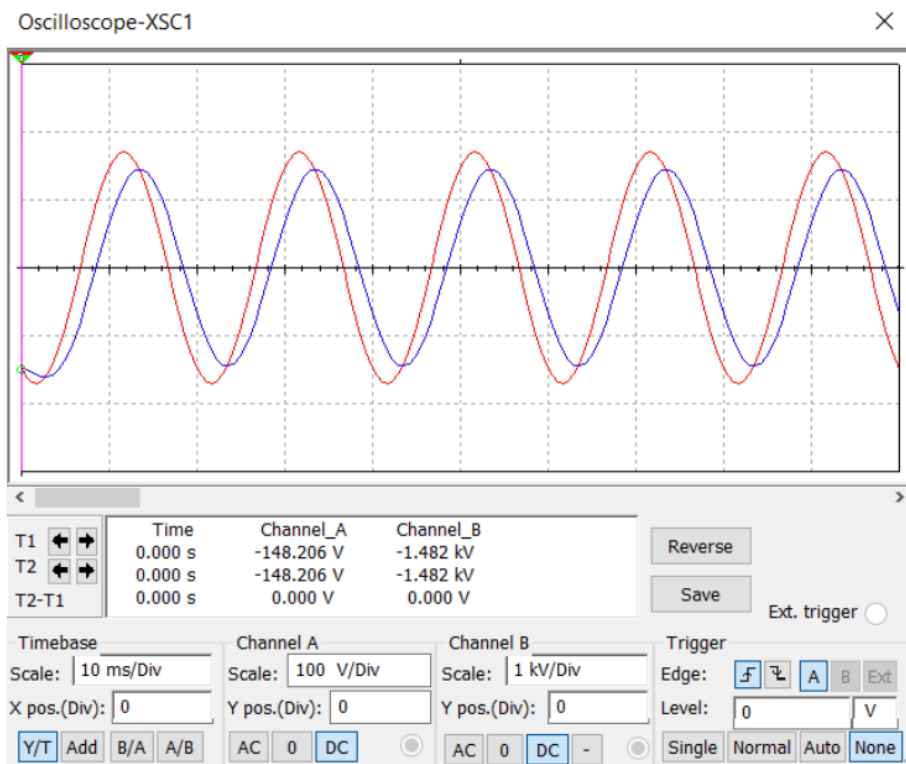


Figure 7 - Phase Shift Star R-L Load

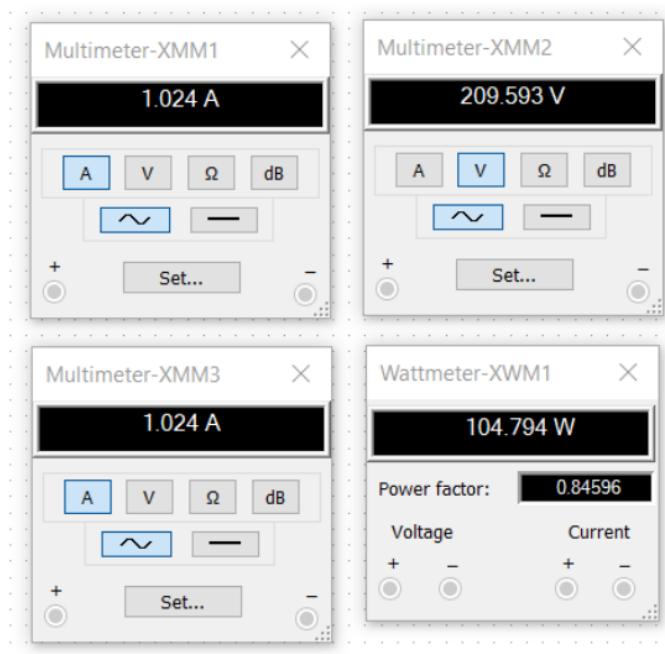


Figure 8 - Star R-L Load Meter Readings

Delta R-L Series Load

The circuit in figure 6 was reconfigured into delta configuration. The different currents and voltages are calculated in figures 16 to 18 in the appendices, with a drawn scaled phasor diagram, and also all calculations for the power triangle. Figure 9 shows the delta circuit that was created on multisim to prove the calculations.

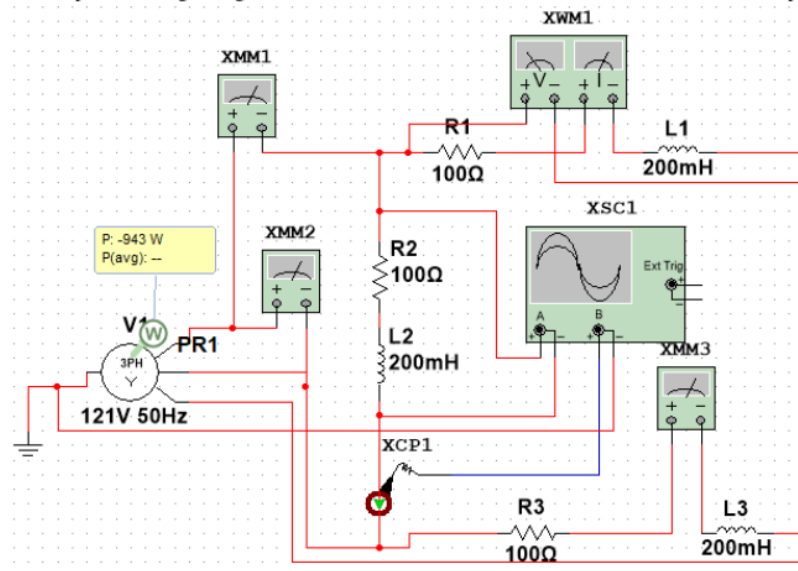


Figure 9 - Delta R-L Load

Delta R-L Results

Table 2 - Delta R-L Results

	Calculated	Measured
Phase Current	1.78 A	1.773 A
Line Current	3.08 A	3.071 A
Phase Voltage	210 V	209.594 V
Line Voltage	$V_l = V_p$	$V_l = V_p$
True Power	948.61 W	943 W
Apparent Power	1120.29 VA	$943 / 0.84596 = 1114.71 \text{ VA}$
Reactive Power	595.98 VAR	$1114.71 \times \sin(32.14) = 593.01 \text{ VAR}$
Power Factor	0.85	0.84596
θ	32.14°	Figure 10

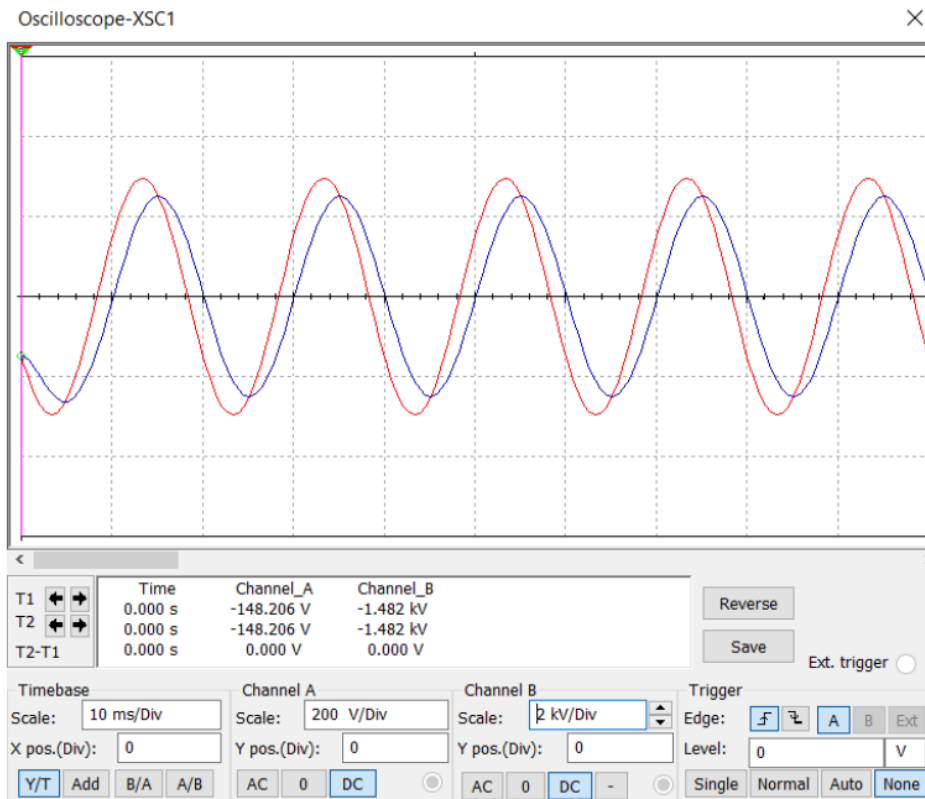


Figure 10 - Phase Shift Delta R-L

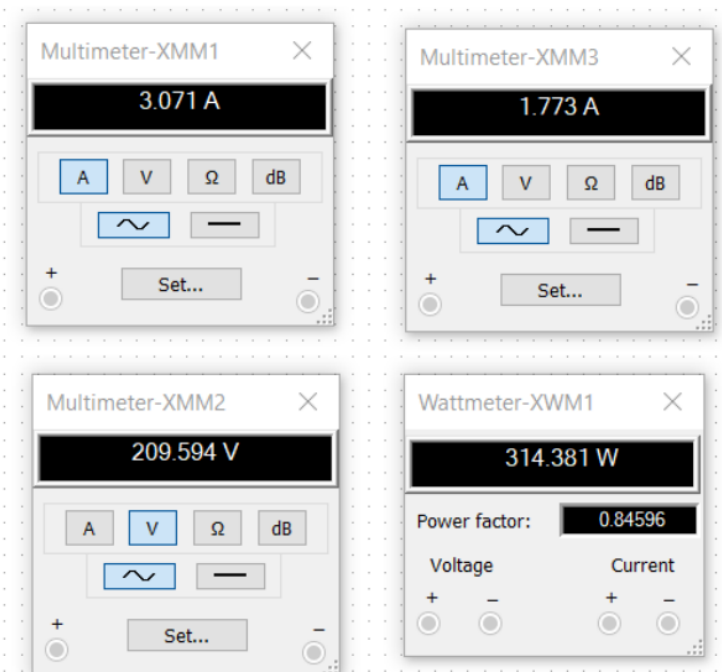


Figure 11 - Delta R-L Results

Star R Load

The circuit was redesigned into a purely resistive load and connected to 3 phase supply in a star configuration. Each phase having a different resistance. Red phase with a resistance of 50Ω , yellow with 70Ω , and blue with 100Ω . The circuit design is shown in figure 12. And calculations are shown in figures 19 and 20 in the appendices, with a scaled phasor diagram.

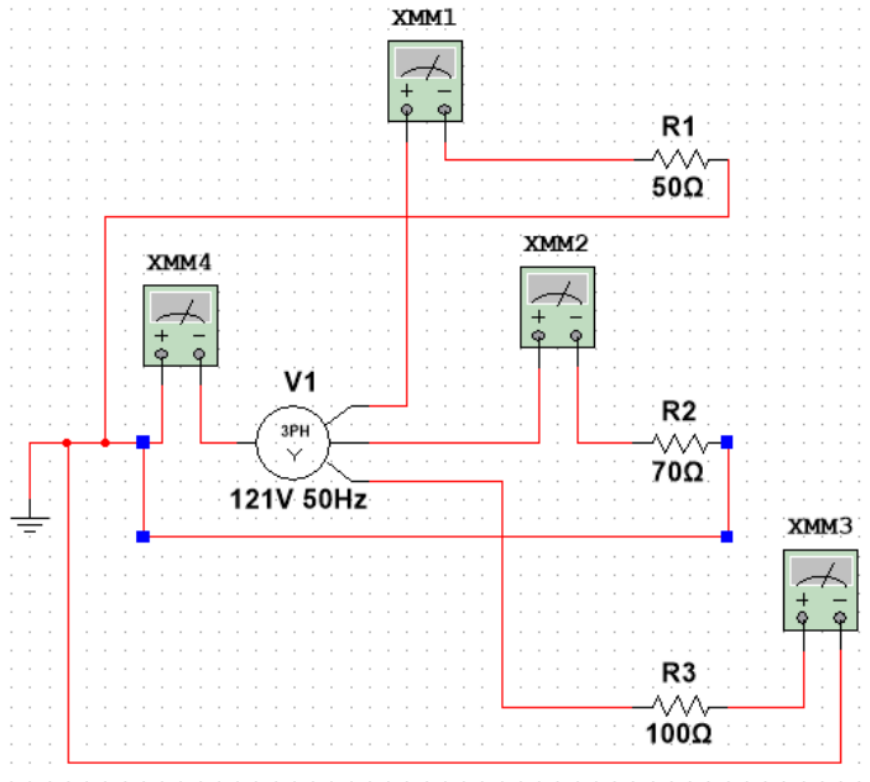


Figure 12 - Star R Load

Star R Load Results

Table 3 - Star R Load Results

	Calculated	Measured
Red Phase Current	2.42 A	2.42 A
Yellow Phase Current	1.73 A	1.729 A
Blue Phase Current	1.21 A	1.21 A
Neutral Current	1.05 A	1.052 A

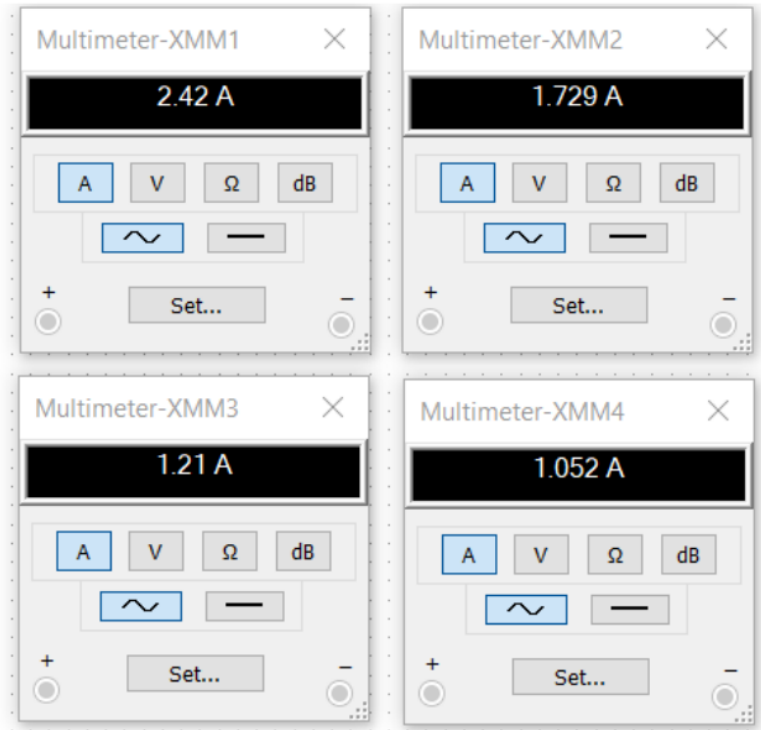


Figure 13 - Star R Load Phase and Neutral Currents

Discussion of Results

Star R-L Load Analysis

From table 1, it shows all the results, the calculated phase current was 1.02 A, with the measured results being close with 1.024 A, each phase has the same series so the current will be the same through them all. As this is an inductive load there will be a phase shift between current and voltage this is shown as $\theta = 32.14^\circ$ and is shown in figure 7, the current lags the voltage by 32.14° . As proven in the research, in a star configuration the line current is the same as the phase current. However the line voltage and phase voltage are different as shown in table 1, this proves the research was correct as the line voltage is $\sqrt{3} \times V_p$. The true power of both results were close, with the calculated result being .15 W greater than that of the 314 W measured by the probe on the source in the circuit. The apparent power was calculated to be 371.01 VA and came out as 371.18 VA on the measured circuit by dividing the true power by the power factor, the power factor of the circuit was 0.84596 with the calculated being 0.85. The reactive power was calculated to be 197.37 VAR and the measured results worked out to be 197.46 VAR by multiplying the apparent power with $\sin(\theta)$. All of these figures are used to create the power triangle in figure 14 which is scaled. The phasor diagram in figure 15 is also scaled. This shows the phase and line voltages for each phase and the current calculations with its phase angle.

Delta R-L Load Analysis

Table 2 shows all the calculated and measured results for the delta configuration. 1.78 A was calculated for the phase current, with the measured being 1.773 A through each phase with a lag of 32.14° . As this is now configured in delta, this means the line current will be $\sqrt{3}$ multiplied with the phase current as stated in the research. Line current was calculated to be 3.08 A but 3.71 A was the measured value. The phase and line voltage are the same in a delta configuration, and that is proven by the results with the calculated being 210 V and measured 209.594 V. The results between the powers were slightly out. For true power 948.61 W was calculated with the final measurement being 943 W. The apparent power was calculated to be 1120.29 VA, after dividing the measured true power by the power factor of 0.84596, the apparent power of the circuit was 1114.71 VA this will be off as the true power was previously off. The reactive power results were slightly closer, with

595.98 VAR and 593.01 VAR after multiplying the apparent power by $\sin(\theta)$. The power triangle is shown in figure 18 and is to scale, along with the phasor diagram. Thus showing the phase angle and difference in line and phase current.

Star R Load Analysis

Because this is a purely resistive load there will be no phase angle as the current neither leads or lags. However the phases have different resistance values. This means the current will vary between the phases. For the Red phase the current was calculated to be 2.42 A with the measured value being spot on with 2.42 A. The yellow phase had a 0.01 A difference between its calculated 1.73 A and its measured 1.729 A. 1.21 A was calculated for the blue phase with the measured value at 1.21 A. The calculated neutral current for this circuit was 1.05 A with 1.052 A actually measured. The phasor diagram in figure 20 shows the different currents with the voltages and no phase angle meaning the phase voltage and phase current are aligned.

Conclusion

In conclusion the results of all the experiments went as expected, with slight differences, but this can be down to rounding errors. The results prove that of what was said in the research with the differences between star and delta with the voltage and currents changing and its effects on the power. It also proves the effect the load itself can have on the current as different resistor values will vary the current between the phases and inductive loads will cause the current to lag behind the voltage as proven by the phasor diagrams.



References

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- Tutorial, E., 2020. *Electronics Tutorial*. [Online]
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Appendices

Task 1 - Star

$$V_L = 210 \text{ V} \quad V_P = V_L \div \sqrt{3}$$

$$F = 50 \text{ Hz} \quad = 210 \div \sqrt{3}$$

$$R = 100 \, \Omega \quad = 121.24 \text{ V}$$

$$L = 200 \text{ mH}$$

Impedance

$$X_L = 2\pi FL$$

$$X_L = 2\pi \times 50 \times 200 \times 10^{-3}$$

$$X_L = 62.83 \, \Omega$$

$$Z_P = R + j(X_L - X_C)$$

$$Z_P = 100 + j62.83 \, \Omega \rightarrow \text{Polar Conversion} = Z = \sqrt{100^2 + 62.83^2} = 118.10$$

$$Z_P = 118.10 \angle 32.14^\circ \, \Omega \quad (\angle) = \tan^{-1} \left(\frac{62.83}{100} \right) = 32.14$$

Phase and Line currents - IR as reference 0°

$$I_L = I_P$$

$$I_P = \frac{V_P}{Z_P}$$

$$I_P = \frac{121.24 \angle 0^\circ}{118.10 \angle 32.14^\circ}$$

$$I_P = 1.02 \angle -32.14^\circ \text{ A}$$

Cartesian Conversion

$$I_{R1} = 1.02 \angle -32.14^\circ \text{ A} \rightarrow 1.02 \times \cos(-32.14) = 0.85$$

$$= 0.86 - j0.54 \text{ A} \quad 1.02 \times \sin(-32.14) = -0.54$$

$$I_{R2} = 1.02 \angle 120 - 32.14^\circ \rightarrow 1.02 \times \cos(-152.14) = -0.90$$

$$= 1.02 \angle -152.14^\circ \text{ A} \quad 1.02 \times \sin(-152.14) = -0.48$$

$$= -0.90 - j0.48 \text{ A}$$

$$I_{R3} = 1.02 \angle 120 - 32.14^\circ \rightarrow 1.02 \times \cos(87.86) = 0.04$$

$$= 1.02 \angle 87.86^\circ \text{ A} \quad 1.02 \times \sin(87.86) = 1.02$$

$$= 0.04 + j1.02 \text{ A}$$

Figure 13 - Star R-L Load Current Calculations

Power

True Power

$$\begin{aligned} P &= \sqrt{3} V_L I_L \cos \theta \\ &= \sqrt{3} \times 210 \times 1.02 \times \cos(32.14) \\ &= 314.15 \text{ W} \end{aligned}$$

Apparent Power

$$\begin{aligned} S &= \sqrt{3} V_L I_L \\ &= \sqrt{3} \times 210 \times 1.02 \\ &= 371.01 \text{ VA} \end{aligned}$$

Reactive power

$$\begin{aligned} Q &= \sqrt{3} V_L I_L \sin \theta \\ &= \sqrt{3} \times 210 \times 1.02 \times \sin(32.14) \\ &= 197.37 \text{ VAR} \end{aligned}$$

$$\text{Power factor} = \frac{\text{True Power}}{\text{Apparent Power}} = \frac{314.15}{371.01} = 0.85$$

$$\text{P.f} = \cos(32.14)$$

$$0.85 = \cos(32.14)$$

Power Triangle

Scale:

$$P = 1 \text{ cm} : 31.415 \text{ W}$$

$$S = 1 \text{ cm} : 37.101 \text{ VA}$$

$$Q = 1 \text{ cm} : 19.737 \text{ VAR}$$

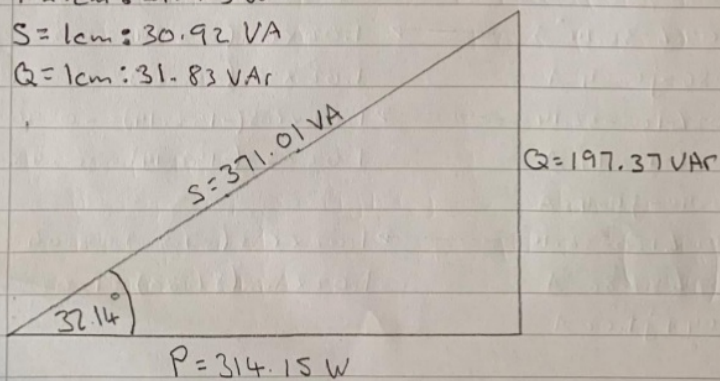


Figure 14 - Star R-L Load Power Calculations

Phasor Diagram

Scale:

Current = 1cm : 0.29A ($I_P = I_L$)

Voltage = 1cm : 35V

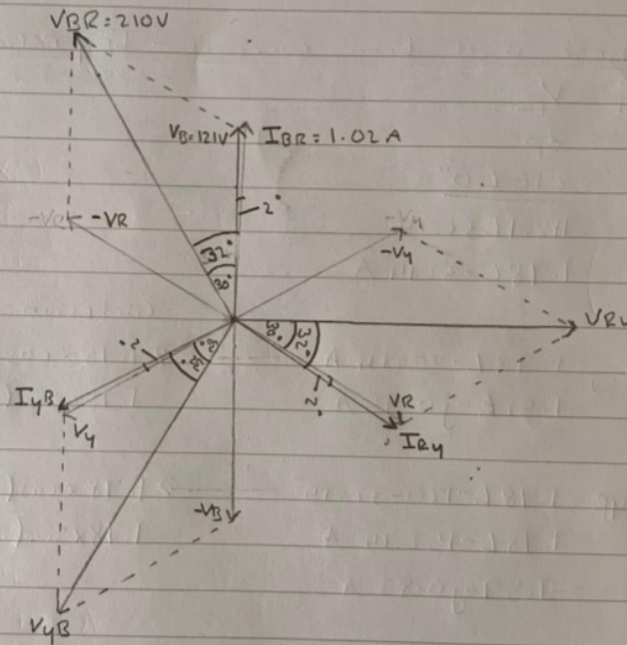


Figure 15 - Star R-L Load Phasor Diagram

Task 1 - Delta

$$V_L = V_P = 210 \text{ V}$$

$$F = 50 \text{ Hz}$$

$$R = 100 \, \Omega$$

$$L = 200 \text{ mH}$$

$$Z = 100 + j62.83 \, \Omega$$

$$= 118.10 \angle 32.14^\circ$$

Phase and Line currents - I_{Ry} reference to 0°

$$I_P = \frac{V_P}{Z_P}$$

$$= \frac{210 \angle 0^\circ}{118.10 \angle 32.14^\circ}$$

$$= 1.78 \angle -32.14^\circ \text{ A}$$

Cartesian Conversion

$$I_{Ry} = 1.78 \angle -32.14^\circ \text{ A} \longrightarrow 1.78 \times \cos(-32.14) = 1.51$$

$$= 1.51 - j0.95 \text{ A}$$

$$1.78 \times \sin(-32.14) = -0.95$$

$$I_{yB} = 1.78 \angle -120 - 32.14^\circ \longrightarrow 1.78 \times \cos(-152.14) = -1.57$$

$$= 1.78 \angle -152.14^\circ \text{ A}$$

$$1.78 \times \sin(-152.14) = -0.83$$

$$= -1.57 - j0.83 \text{ A}$$

$$I_{BR} = 1.78 \angle 120 - 32.14^\circ \longrightarrow 1.78 \times \cos(87.86) = 0.07$$

$$= 1.78 \angle 87.86^\circ \text{ A}$$

$$1.78 \times \sin(87.86) = 1.78$$

$$= 0.07 + j1.78$$

$$I_R = I_{Ry} - I_{BR}$$

$$= (1.51 - j0.95) - (0.07 + j1.78) \longrightarrow I = \sqrt{1.44^2 + 2.73^2} = 3.08$$

$$= 1.44 - j2.73 \text{ A}$$

$$= 3.08 \angle -62.19^\circ \text{ A}$$

Polar Conversion

$$|I| = \tan^{-1} \left(\frac{-2.73}{1.44} \right) = -62.19$$

Figure 16 - Delta R-L Load Current Calculations

$$\begin{aligned}
 I_Y &= I_{YB} - I_{YB} \\
 &= (-1.57 - j0.83) - (1.51 - j0.95) \rightarrow I = \sqrt{3.08^2 + 0.12^2} \approx 3.08 \\
 &= -3.08 + j0.12 \text{ A} \quad |I| = \tan^{-1} \\
 &= 3.08 \angle 177.77^\circ \text{ A}
 \end{aligned}$$

$$\begin{aligned}
 I_B &= I_{BR} - I_{YB} \\
 &= (0.07 + j1.78) - (-1.57 - j0.83) \rightarrow I = \sqrt{1.64^2 + 2.61^2} \approx 3.08 \\
 &= 1.64 + j2.61 \text{ A} \quad |I| = \tan^{-1} \left(\frac{2.61}{1.64} \right) = 57.86 \\
 &= 3.08 \angle 57.86^\circ \text{ A}
 \end{aligned}$$

Power

True Power

$$\begin{aligned}
 P &= \sqrt{3} V_L I_L \cos \theta \\
 &= \sqrt{3} \times 210 \times 3.08 \times \cos(32.14) \\
 &= 948.61 \text{ W}
 \end{aligned}$$

Apparent Power

$$\begin{aligned}
 S &= \sqrt{3} V_L I_L \\
 &= \sqrt{3} \times 210 \times 3.08 \\
 &= 1120.29 \text{ VA}
 \end{aligned}$$

Reactive Power

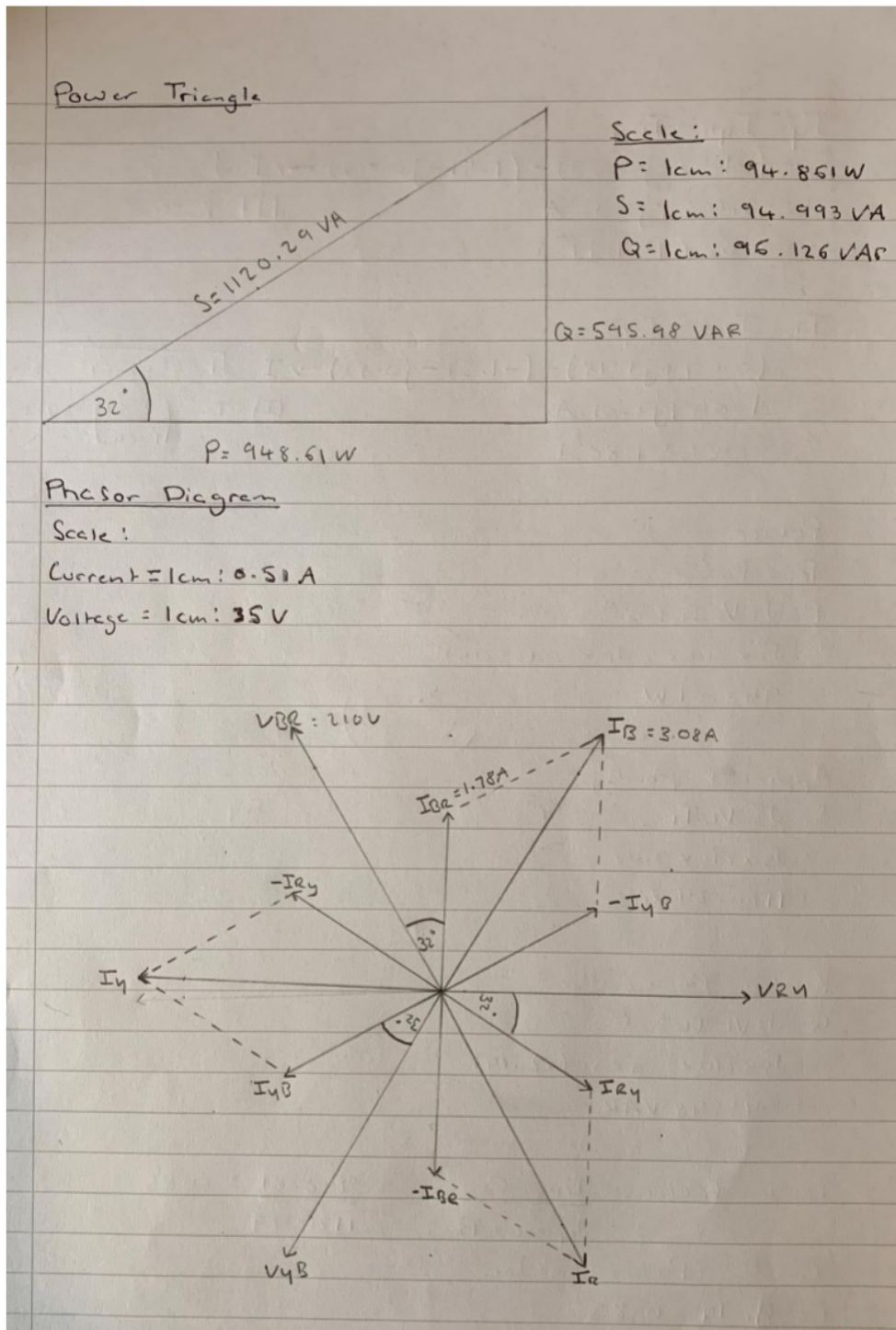
$$\begin{aligned}
 Q &= \sqrt{3} V_L I_L \sin \theta \\
 &= \sqrt{3} \times 210 \times 3.08 \times \sin(32.14) \\
 &= 595.98 \text{ VAR}
 \end{aligned}$$

$$\text{Power Factor} = \frac{\text{True Power}}{\text{Apparent Power}} = \frac{948.61}{1120.29} = 0.85$$

$$\cos \theta = \text{Power Factor}$$

$$\cos 32.14 = 0.85$$

Figure 17 - Delta R-L Load Current Calculations continued and Power Calculations



Task 2

$$V_L = 210 \text{ V}$$

$$V_p = 121.24 \text{ V}$$

$$R_1 = 50 \Omega$$

$$R_2 = 70 \Omega$$

$$R_3 = 100 \Omega$$

Phase and Line currents

$$I_L = I_p$$

$$I_p = \frac{V_p}{R}$$

$$I_R = \frac{121.24}{50}$$
$$= 2.42 \text{ A}$$

$$I_Y = \frac{121.24}{70}$$
$$= 1.73 \text{ A}$$

$$I_B = \frac{121.24}{100}$$
$$= 1.21 \text{ A}$$

Neutral Current

$$I_n = \sqrt{I_R^2 + I_Y^2 + I_B^2 - I_R I_Y - I_Y I_B - I_B I_R}$$
$$= \sqrt{2.42^2 + 1.73^2 + 1.21^2 - 2.42 \times 1.73 - 1.73 \times 1.21 - 1.21 \times 2.42}$$
$$= 1.05 \text{ A}$$

Figure 19 - Star R Load Current Calculations

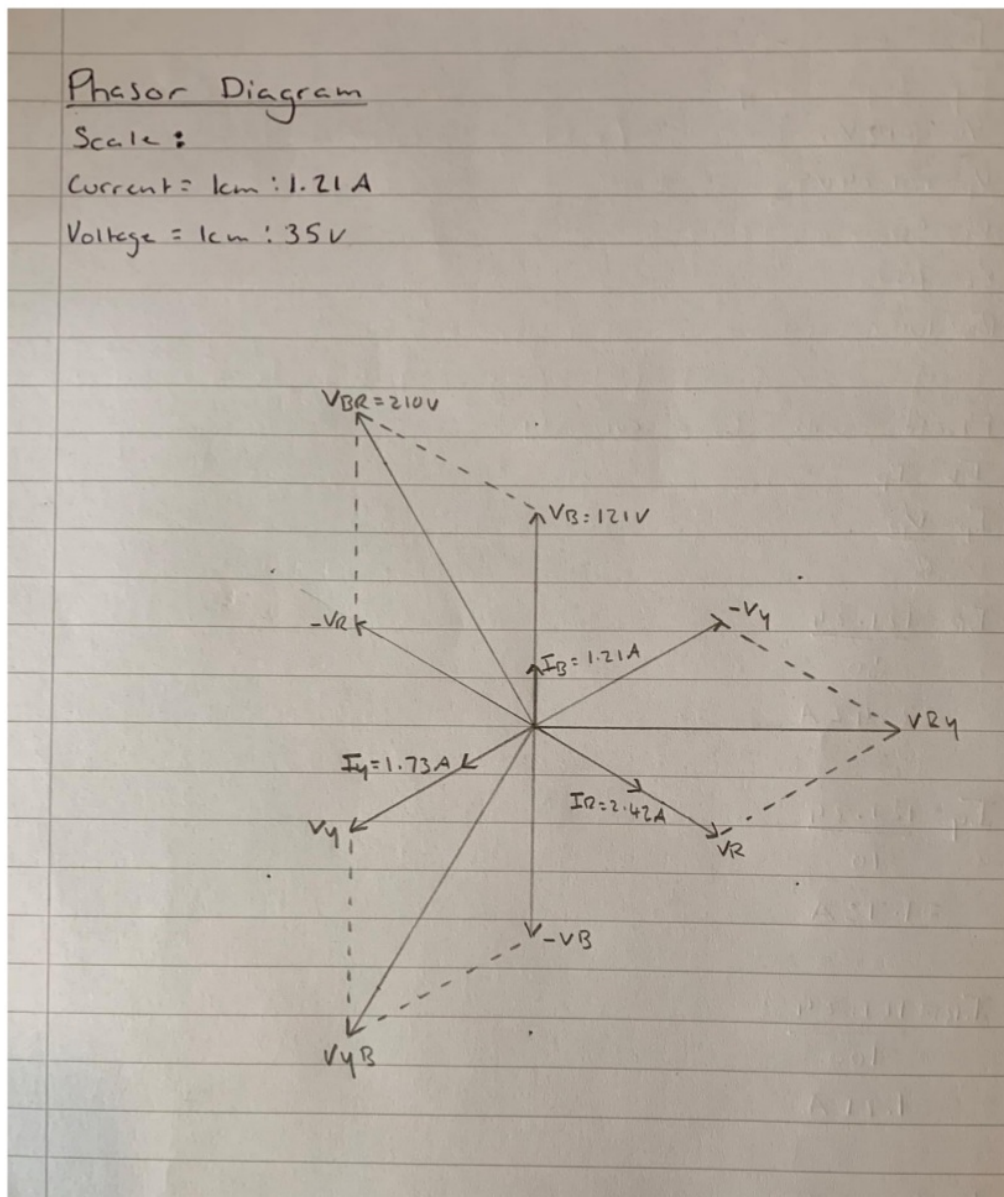


Figure 20 - Star R Load Phasor Diagram

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GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

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Comment 1

measurement of phi?

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Comment 2

delta x3 current and power?

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PAGE 14

GRADING FORM: NEW CSG-RUBRIC

JOSHUA REES

72

1. ENGAGEMENT WITH LITERATURE



A range of websites informs the research, a shame only one of the three research tasks was tackled, introduction contains some advantages of 3 phase but is far too brief. Use books/journals. 5/10

5

2. KNOWLEDGE AND UNDERSTANDING



Good level of basic underlying principles, calculations and measurements are comprehensive. Comparison of star and delta should be expanded. 13/20

14

3. COGNITIVE AND INTELLECTUAL



Tabulation of results is good, use cursors to find ϕ from CRO, conclusion lacks detail. 25/40

26

4. PRACTICAL APPLICATION



Good use of instruments and calculations done in a logical manner. Good phasor diagrams and power triangles. See points above. 15/20

15

5. TRANSFERABLE SKILLS



Good overall report, quality is good and communication effective. State that simulations and calculations are in appendix. 12/20

12