U|T|S

University of Technology, Sydney
Faculty of Engineering

Subject: **48572 Power Circuit Theory**

Assignment Number: **2**

Assignment Title: **Lab 2 – Three-Phase Circuits**

Tutorial Group:

Students Name(s) and Number(s)

Student Number	Family Name	First Name

Declaration of Originality:

The work contained in this assignment, other than that specifically attributed to another source, is that of the author(s). It is recognised that, should this declaration be found to be false, disciplinary action could be taken and the assignments of all students involved will be given zero marks. In the statement below, I have indicated the extent to which I have collaborated with other students, whom I have named.

Statement of Collaboration:

Signature(s)

Marks

Hand Analysis	/1
Lab Work	/2
Questions	/2
TOTAL	/5

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key

Lab 2 – Three-Phase Circuits

Voltage, current and power in balanced and unbalanced loads. Power factor. Power factor improvement. Phase sequence.

Introduction

Modern electric power systems almost universally use three-phase AC voltages and currents to deliver real power to end-users. The delivery of electric power utilises both a 3-wire system and a 4-wire system, and the loads can be either balanced or unbalanced. It is important to realise what the implications are, in terms of voltage, current and power, for each combination of delivery method and load configuration.

The power factor of a load determines how efficient the delivery of real power to that load can be – the ideal is to have a "unity power factor". Special measures are normally taken in industrial and commercial settings to ensure that the power factor is as close to unity as possible (taking into consideration the usual economic and technical constraints).

A three-phase system has in inherent "order" or *sequence* in terms of the phase of each of the voltages. For a three-phase system there are two possible sequences for the voltage to be in: *abc* or *acb*. The phase sequence is important for three-phase rotating machines, since it determines either a clockwise or anticlockwise direction of rotation.

Unbalanced three-phase systems can lead to large voltages across a load, and is generally an undesirable situation that is avoided in practice.

Objectives

1. To become familiar voltage, current and power measurements in three-phase circuits with balanced and unbalanced loads.

2. To study the importance of the power factor of the load and means of power factor improvement.

3. To investigate the effect of phase sequence.

L2.2

Equipment

- 1 three-phase 240 V, 8A autotransformer – Warburton Franki Variac,

- 1 three-phase resistive load, 110 Ω per phase

- 1 three-phase capacitive load, 60 μF per phase

- 3 inductors, 0.5 H or 0.28 H each

- 2 AC voltmeter / ammeters – YEW

- 2 digital multimeters

- 1 clip-on auto-ranging wattmeter – YEW

- 1 clip-on power quality clamp meter – Fluke 345

- 1 motor and phase rotation indicator – Fluke 9062

Safety

Cat. B lab

This is a Category B laboratory experiment. Please adhere to the Category B safety guidelines (issued separately).

Warning!

Remember:

1. Choose suitable METER SCALES and <u>WIND DOWN</u> and <u>SWITCH OFF</u> the supply VARIAC when making circuit connections.

2. <u>Ensure equipment is earthed.</u>

Pre-work

1. Balanced Load, Lagging Power Factor
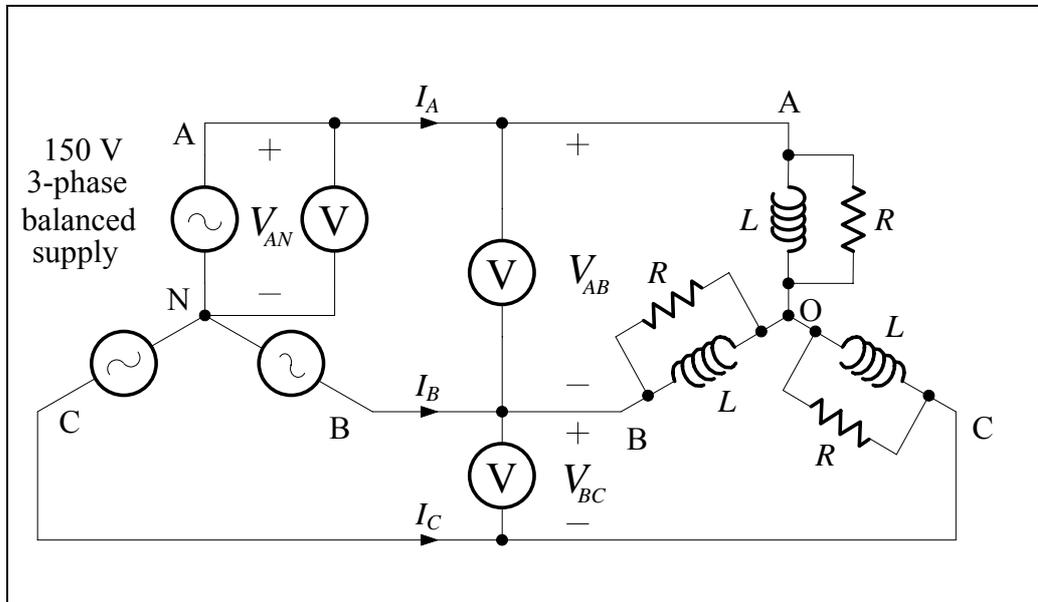
Consider a balanced three-phase circuit as shown below:

Figure 2.1 – Balanced three-phase circuit with lagging power factor

The circuit has:

- positive phase sequence *abc*

- $f = 50\,\text{Hz}$

- reference voltage $V_{AN} = 150\,\angle 0°$ volts RMS

- $R = 110\,\Omega$

- $L = 0.5\,\text{H}$

L2.4

1.1 Compute the quantities listed in Table 2.1 and record the results:

<table>
<tr><td colspan="3" align="center">Table 2.1</td></tr>
<tr><td colspan="3">$Z = \text{load per phase} = R \parallel jX_L =$</td></tr>
<tr><td>$V_{AN} = 150 \angle 0° \text{ V}$</td><td>$V_{AB} =$</td><td>$I_A = \dfrac{V_{AN}}{Z} =$</td></tr>
<tr><td>$V_{BN} =$</td><td>$V_{BC} =$</td><td>$I_B =$</td></tr>
<tr><td>$V_{CN} =$</td><td>$V_{CA} =$</td><td>$I_C =$</td></tr>
<tr><td colspan="3"><u>Note</u>: Give I, V, and Z in polar form.</td></tr>
<tr><td colspan="3">$P_A = |V_{AB}||I_A|\cos(\angle V_{AB} - \angle I_A) =$</td></tr>
<tr><td colspan="3">$P_C =$</td></tr>
<tr><td colspan="3">Total average power $= P = P_A + P_C =$</td></tr>
<tr><td colspan="3">Total reactive power $= Q = \sqrt{3}(P_C - P_A) =$</td></tr>
<tr><td colspan="3">Load power factor $= \cos\theta_Z =$</td></tr>
<tr><td>$P_{RA} = \dfrac{|V_{AN}|^2}{R} =$</td><td>$P_{RB} =$</td><td>$P_{RC} =$</td></tr>
<tr><td colspan="3">Total average power $= P = P_{RA} + P_{RB} + P_{RC} =$</td></tr>
</table>

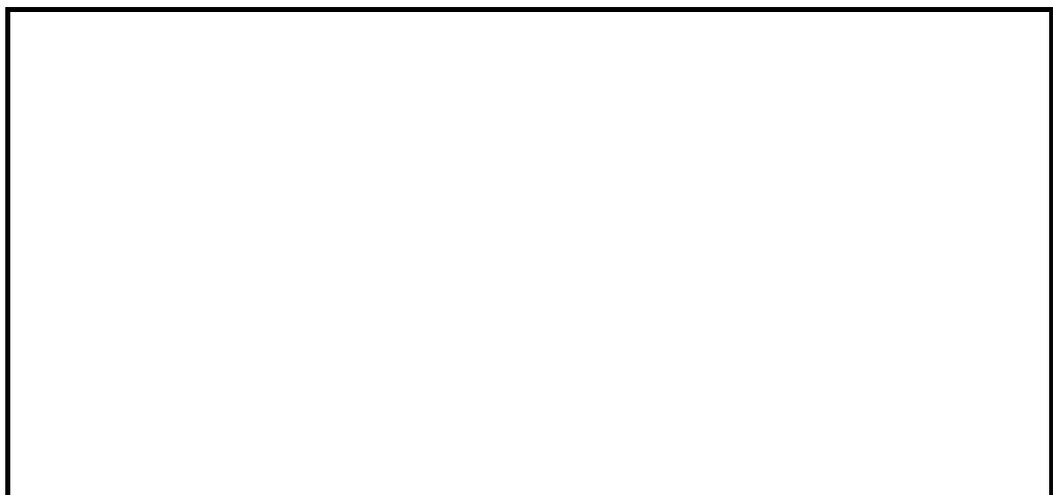1.2 Draw the phasor diagram of the voltages and currents in the circuit:

Figure 2.2 – Phasor diagram of balanced three-phase circuit

2. Balanced Load, Unity Power Factor

1.1 Calculate the value of capacitance C which has to be connected in parallel with every phase of the load to bring the load power factor to unity in the circuit of Figure 2.1. Calculate $|I_A|$, P_A, P_C and the total average power, as well as the total reactive power in the modified circuit. Record the results in Table 2.2.

Table 2.2	
$C = \dfrac{1}{\omega^2 L} =$	$|I_A| = \dfrac{|V_{AN}|}{R} =$
$P_A = \dfrac{|V_{AB}|^2}{R_A + R_B} =$	$P_C = \dfrac{|V_{BC}|^2}{R_B + R_C} =$
$P = P_A + P_C =$	$Q = \sqrt{3}\left(P_C - P_A\right) =$

2.2 Explain whether or not power factor improvement can be achieved by a delta connection of capacitors:

L2.6

3. Balanced Load, Leading Power Factor

3.1 Exchange the inductors L with $60\,\mu\text{F}$ capacitors in the circuit of Figure 2.1. Fill in Table 2.3 for this modified circuit.

Table 2.3
$Z = \text{load per phase} = R \parallel jX_C =$
$I_A = \dfrac{V_{AN}}{Z} = \qquad\qquad\qquad I_B = \qquad\qquad\qquad I_C =$
$P_A = \lvert V_{AB}\rvert\lvert I_A\rvert\cos(\angle V_{AB} - \angle I_A) =$
$P_C =$
$\text{Total average power} = P = P_A + P_C =$
$\text{Total reactive power} = Q = \sqrt{3}\left(P_C - P_A\right) =$
$\text{Load power factor} = \cos\theta_Z =$

4. Unbalanced Three-Wire Circuit

Consider the three-phase circuit given below:
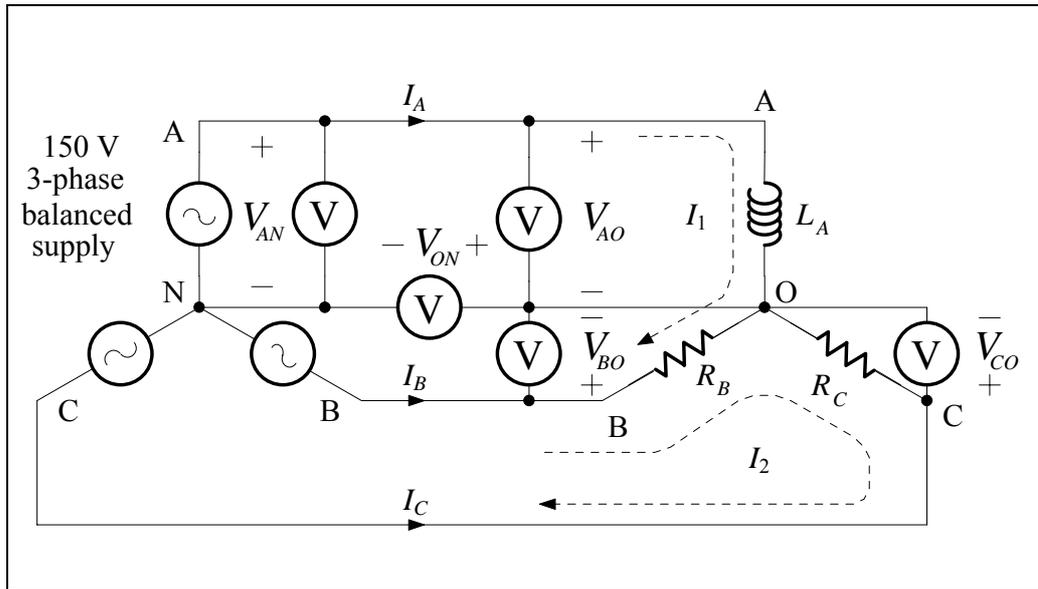

Figure 2.3 – Unbalanced three-phase circuit

The circuit has:

- positive phase sequence *abc*

- $f = 50\,\mathrm{Hz}$

- reference voltage $V_{AN} = 150\,\angle 0°$ volts RMS

- $R_B = R_C = 110\,\Omega$

- $L_A = 0.5\,\mathrm{H}$

L2.8

4.1 Using mesh analysis, fill in Table 2.4 for this circuit:

<div style="border: 1px solid black;">

Table 2.4

$Z_A = $ $\qquad\qquad\qquad\qquad\qquad$ $Z_B = Z_C = $

and since:

$V_{AB} = (Z_A + Z_B)I_1 - Z_B I_2$ $\qquad\qquad$ $V_{BC} = -Z_B I_1 + (Z_B + Z_C)I_2$

then:

$I_1 = $ $\qquad\qquad\qquad\qquad\qquad$ $I_2 = $

$I_A = I_1 = $ $\qquad\qquad$ $I_B = I_2 - I_1 = $ $\qquad\qquad$ $I_C = -I_2 = $

$V_{AO} = Z_A I_A = $ $\qquad\qquad$ $V_{BO} = Z_B I_B = $ $\qquad\qquad$ $V_{CO} = Z_C I_C = $

$V_{ON} = V_{AN} - V_{AO} = $

</div>

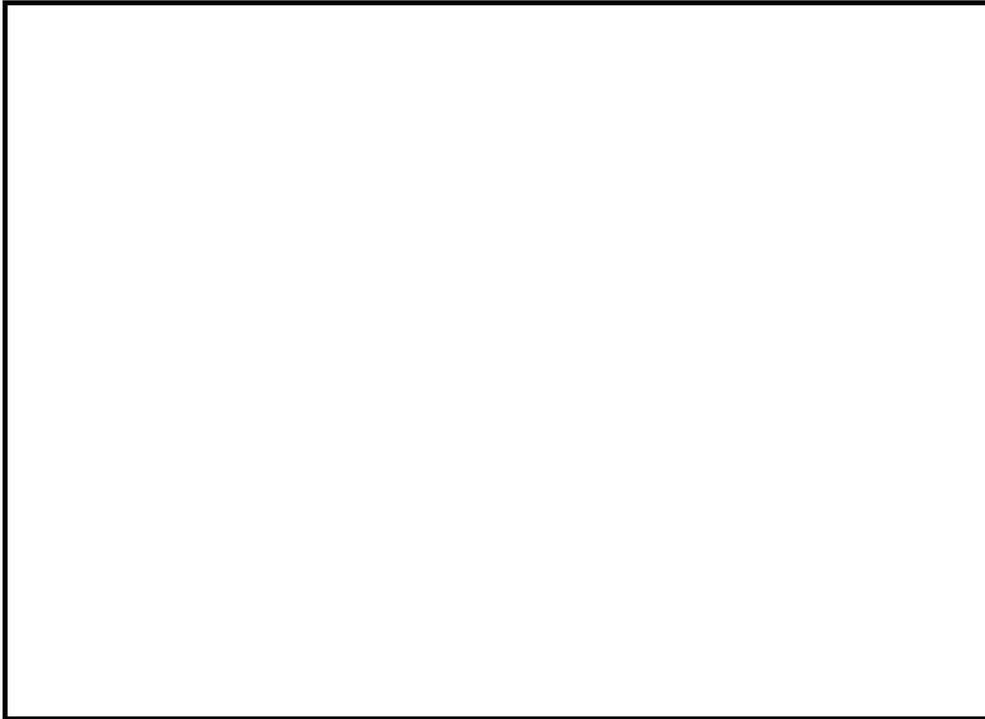4.2 Draw the voltage phasor diagram for the circuit:

Figure 2.4 – Phasor diagram of unbalanced three-phase circuit

4.3 Deduce the voltages, and relabel the phasor diagram above, for the same circuit but with the phase sequence *a'c'b'*:

$V_{A'O} =$ $V_{B'O} =$ $V_{C'O} =$ $V_{O'N} =$

4.4 Explain from these results how you might build a phase sequence tester:

L2.10

Lab Work

Phase Sequence

1. **<u>Do not connect the supply or turn on the power until circuit connections are checked by a lab tutor.</u>**

2. Connect the Phase Rotation Indicator to the red, yellow and blue terminals of the three-phase Variac (primary side), as shown below:

The Phase Rotation Indicator must be connected as shown, otherwise an incorrect phase sequence will be obtained
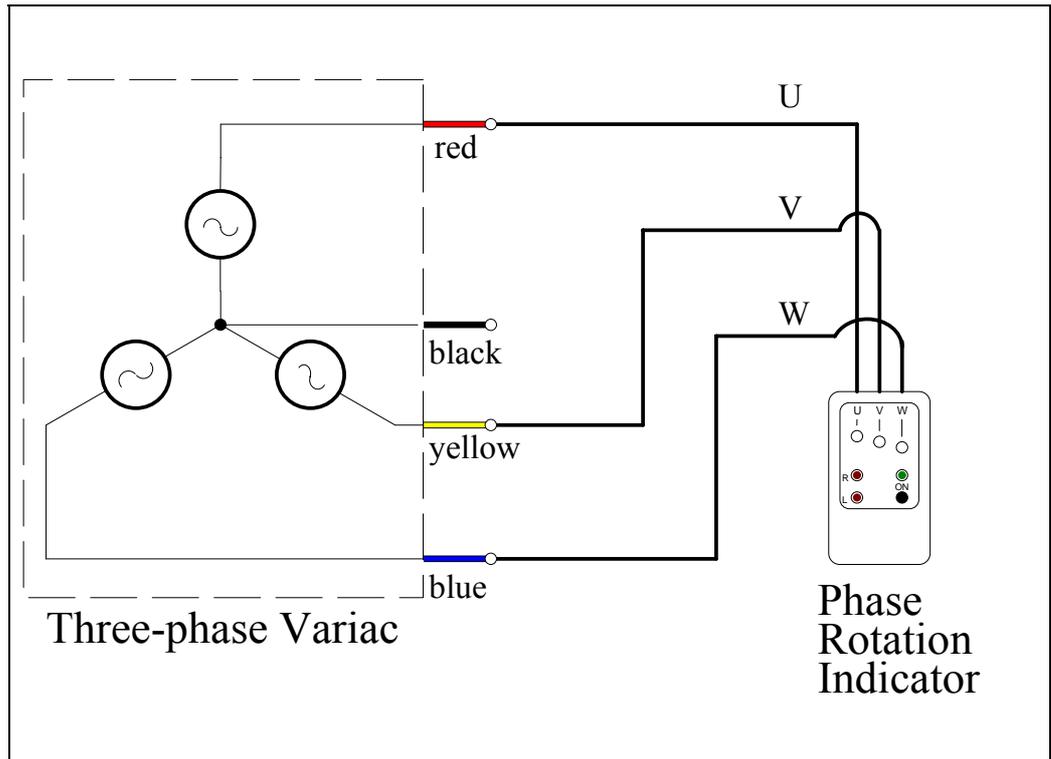

Figure 2.5 – Circuit used to measure phase sequence

3. Plug in and turn on the Variac at the three-phase wall outlet.

4. On the Phase Rotation Indicator, press the ON button. The green LED will illuminate to show that the instrument is testing.

5. The Phase Rotation Indicator will show "R" if the sequence is RYB and "L" if the sequence is RBY. Hence label the terminals:
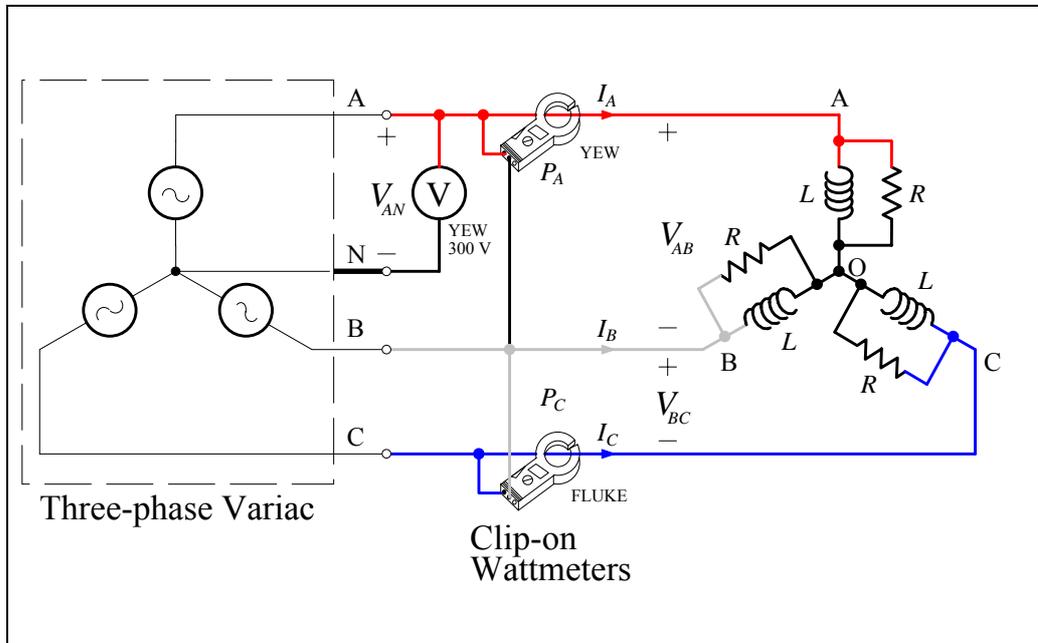
"R" (positive phase sequence)	"L" (negative phase sequence)
red = A yellow = B blue = C	red = A yellow = C blue = B

6. Disconnect the Phase Rotation Indicator.

7. **<u>Turn the Variac off at the wall outlet.</u>**

Balanced Load, Lagging Power Factor

1. **Do not connect the supply or turn on the power until circuit connections are checked by a lab tutor.**

2. Wire up the circuit shown below:

Note the use of coloured leads

$|V_{AN}|$ is measured using an analog YEW meter

$|V_{AB}|$, $|V_{BC}|$ and all currents are measured using the clip-on wattmeters

Remember to connect the earth!

Figure 2.6 - Balanced three-phase circuit with lagging power factor

3. After the circuit has been checked, turn on the Variac and bring up the voltages until the phase voltage $|V_{AN}| = 150\,\text{V}$ RMS. Tabulate readings below.

Table 2.5		
$|V_{AN}| =$	$|I_A| =$	$P_A =$
$|V_{AB}| =$	$|I_B| =$	$P_C =$
$|V_{BC}| =$	$|I_C| =$	$P = P_A + P_C =$
		$Q = \sqrt{3}(P_C - P_A) =$

4. **Wind down and switch off the Variac.**

5. Compare your results in Table 2.1 and Table 2.5 and give your comments.

L2.12

Balanced Load, Unity Power Factor

1. **Ensure that the Variac is wound down and switched off.**

2. Connect parallel capacitances across each phase load to obtain as near as possible the unity power factor condition.

3. Turn on the Variac and bring up the voltage to $|V_{AN}| = 150\,\text{V}$ RMS. Records the readings and results listed below.

<table>
<tr><td colspan="3" align="center">Table 2.6</td></tr>
<tr><td>$|I_A| =$</td><td>$P_A =$</td><td>$P = P_A + P_C =$</td></tr>
<tr><td>$|I_B| =$</td><td>$P_C =$</td><td>$Q = \sqrt{3}(P_C - P_A) =$</td></tr>
<tr><td>$|I_C| =$</td><td></td><td></td></tr>
<tr><td>$\tan\theta = \dfrac{Q}{P} =$</td><td>$\theta =$</td><td>p.f. $= \cos\theta =$</td></tr>
</table>

4. **Wind down and switch off the Variac.**

5. How do line current magnitudes compare with those for the lagging power factor case? Why is the unity power factor condition desirable?

6. Compare your results in Table 2.2 and Table 2.6 and give your comments.

Balanced Load, Leading Power Factor

1. **<u>Ensure that the Variac is wound down and switched off.</u>**

2. Exchange the inductors L with $60\,\mu F$ capacitors in the circuit of Figure 2.6.

3. Turn on the Variac and bring up the voltage to $|V_{AN}| = 150\,\text{V}$ RMS. Records the readings and results listed below.

<table>
<tr><td colspan="3" align="center">**Table 2.7**</td></tr>
<tr><td>$|I_A| =$</td><td>$P_A =$</td><td>$P = P_A + P_C =$</td></tr>
<tr><td>$|I_B| =$</td><td>$P_C =$</td><td>$Q = \sqrt{3}(P_C - P_A) =$</td></tr>
<tr><td>$|I_C| =$</td><td></td><td></td></tr>
<tr><td>$\tan\theta = \dfrac{Q}{P} =$</td><td>$\theta =$</td><td>$\text{p.f.} = \cos\theta =$</td></tr>
</table>

4. **<u>Wind down and switch off the Variac.</u>**

5. Compare your results with those obtained for the lagging and unity power factor loads? Give your comments.

L2.14

Unbalanced Three-Wire Circuit

1. **Ensure that the Variac is wound down and switched off.**

2. Wire up the circuit shown below. **You will not be able to measure all voltages at once**. In particular, $|V_{AO}|$, $|V_{BO}|$ and $|V_{CO}|$ will need to be measured on separate, wind down - change circuit - wind up "routines".

Note the use of coloured leads

$|V_{AN}|$ is measured using an analog YEW meter

$|V_{AB}|$, $|V_{BC}|$ and all currents are measured using the clip-on wattmeters

All other voltages are measured with DMMs
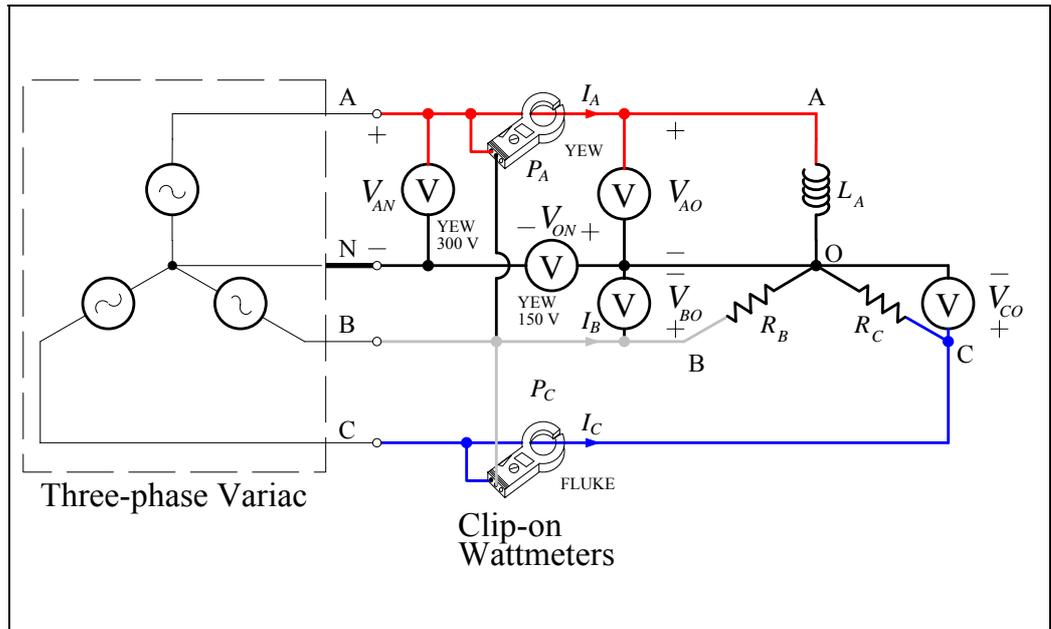
Remember to connect the earth!

Figure 2.7 - Unbalanced three-phase circuit

3. Turn on the Variac and bring up the voltage to $|V_{AN}| = 150$ V RMS. Records the readings and results listed below.

Table 2.8		
$|I_A| =$	$|V_{AO}| =$	$P_A =$
$|I_B| =$	$|V_{BO}| =$	$P_C =$
$|I_C| =$	$|V_{CO}| =$	$P = P_A + P_C =$
	$|V_{ON}| =$	$P = R_B|I_B|^2 + R_C|I_C|^2 =$

4. **Wind down and switch off the Variac.**

5. Compare the two values of real power derived in Table 2.8 and comment.

6. Use a graphical method for determining V_{AO}, V_{BO} and V_{CO} from $|V_{AO}|$, $|V_{BO}|$ and $|V_{CO}|$ and compare the results with those of Table 2.4.

   Hint: Draw the V_{AN}, V_{BN} and V_{CN} phasors (on a sheet of graph paper). Then draw three arcs centred at the tips of the phasors (labelled *A*, *B*, *C*) with radii corresponding to the magnitudes of the three voltages $|V_{AO}|$, $|V_{BO}|$ and $|V_{CO}|$ from Table 2.8. Find point *O* as an approximate intersection of the three arcs and hence the phasors V_{AO}, V_{BO} and V_{CO}.

7. Change the phase sequence by swapping B and C leads from the three-phase Variac. Record the new readings:

   $|V_{A'O}| =$ $|V_{B'O}| =$ $|V_{C'O}| =$

8. Give your comments and conclusions.

L2.16

Report

Only submit **_ONE_** report per lab group.

Complete the assignment cover sheet and attach your pre-work.

Ensure you have completed:

1. **_Pre-Work_** – hand analysis.

2. **_Lab Work_** – all tables completed.

3. **_Post-Work_** – all questions answered.

The lab report is due in exactly two (2) weeks.