

PSDE 4001 - Assignment 2

by Jed Davies

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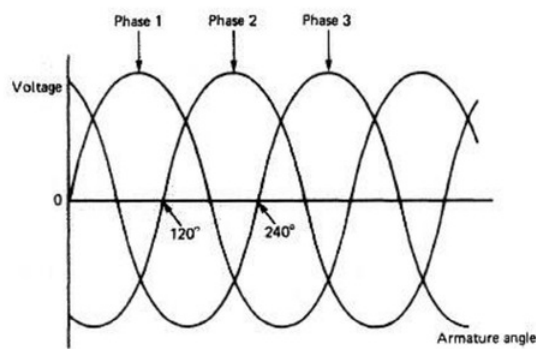
HNC Electrical & Electronic Engineering



TATA

TATA STEEL

Assignment Title: Three-Phase Circuits



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colegsirgâr

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Introduction

To achieve this brief, initially a practical test will be carried out, connecting a star and delta load on the ELT171C (Figure 1) unit which is supplied by a star load on the ELT171A unit. Readings will be taken using a NANOVIP and a table of results will be collated. Then using equations derived from scientific principles a range of calculations will be carried out and the calculated results will then be compared with those taken from the practical task. Also, relevant research will be undertaken to explore and understand the topics included within this assignment.

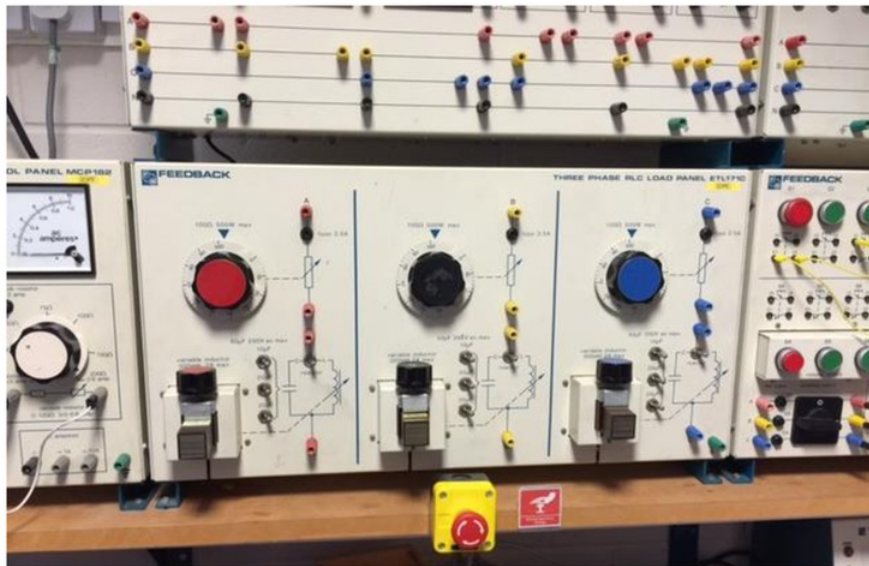


Figure 1 - ELT171C Unit

Task 1 – Star and Delta Balanced Loads (Practical Testing)

The unit was firstly set up to simulate a balanced load by setting the variable resistor values all to $70\ \Omega$ and also by including all variable inductors and setting them at a value of 200mH each. Figure 2 shows the diagrams of the balanced load in both star and delta configurations.

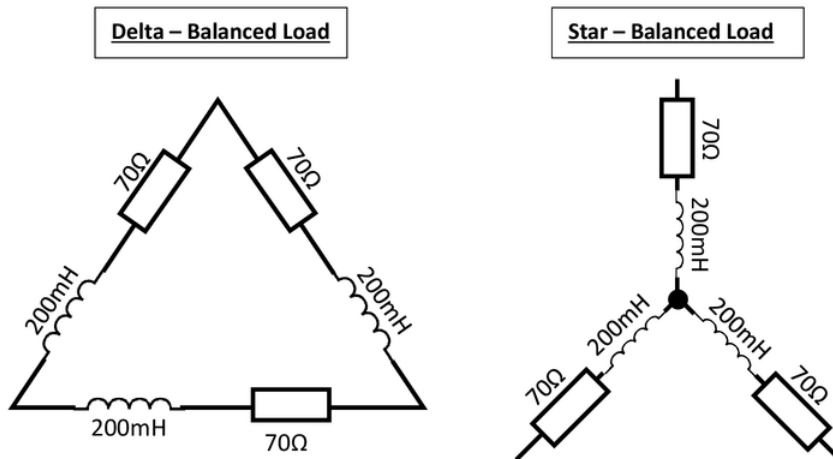


Figure 2 - Star and Delta balanced load diagrams

The load was firstly connected in a Star configuration shown in Figure 3.

Star – Star Setup (Balanced Load)

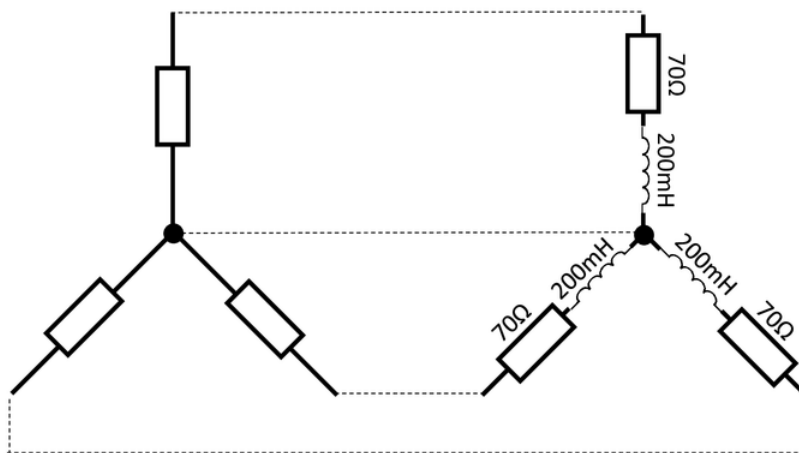


Figure 3 - Star Supply - Star Load Configuration

As previously explained a NANOVIP (shown in Figure 4) was then connected and used to record the results. The connections are shown in a diagram below (Figure 5).



Figure 4 - NANOVIP

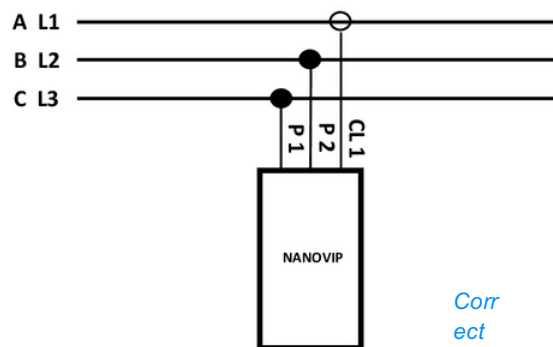


Figure 5 - NANOVIP Connection Diagram

Results were taken and noted within a results table. The unit was then safely isolated to alter the load configuration to delta. Shown in Figure 6 below.

Star – Delta Setup (Balanced Load)

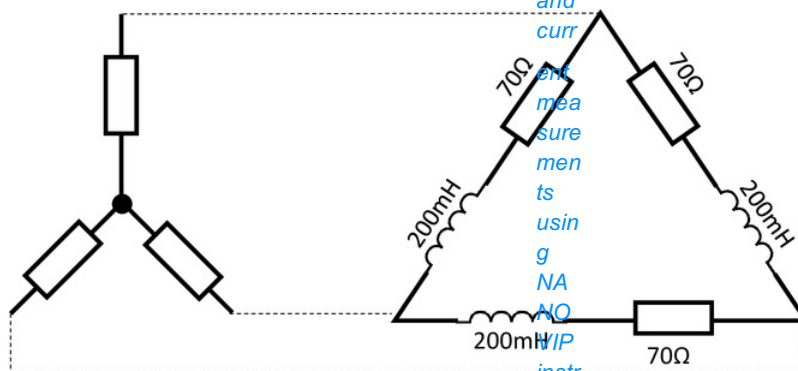


Figure 6 - Star Supply - Delta Load Configuration

Correct arrangement for phase, line and current measurements using NANOVIP instrument. This is a good example. Good illustration.

Again, results were measured using the NANOVIP connected as shown in Figure 5 and recorded in a results table.

Practical Results

Supply	Load	Line Voltages			Phase Voltages			I _A	I _B	I _C	PF	True Power (W)	Apparent Power (VA)	Reactive Power (VAR)
		V _{AB}	V _{BC}	V _{CA}	V _{RN}	V _{YN}	V _{BN}							
Star	Star	212	212	213	122	122	123	1.16	1.17	1.2	0.65	287	442	336
Star	Delta	206	206	207	206	206	206	3.45	3.42	3.47	0.65	808	1.25k	946

It can be seen from the results table above that the line voltages are virtually equal in both star and delta loads, however the phase voltage in a star configured load is considerably different to the phase voltage in a delta load configuration. This is because in star:

$$V_{ph} = \frac{V_{line}}{\sqrt{3}}$$

whereas, in Delta the phase voltage is equal to the line voltage because there is no neutral.

The current in the star configured load are all equal at approximately 1.2 A. However, this is approximately $\frac{1}{3}$ of the current measured from the delta load. This is because in star the resistance is equal to the resistance of one phase. Whereas, in delta the resistance is equal to the resistance of one phase with the two other phases also in parallel.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

This gives a lower total resistance, therefore when the resistance is lower the current is higher.

Task 2 – Balanced Load (Star and Delta) Calculations

Calculations will now be carried out to verify the phase & line voltages, phase and line currents and power factor.

Star Load

Line Voltage (V_{line}) = 212 V

Phase Voltage

Equation:

$$\text{Phase Voltage } (V_{ph}) = \frac{V_{line}}{\sqrt{3}}$$

$$\begin{aligned} V_{ph} &= \frac{212}{\sqrt{3}} \\ &= 122.398 \text{ V} \\ &= 122.4 \text{ V} \end{aligned}$$

Phase Current

Equation:

$$\text{Phase Current } (I_{ph}) = \frac{V_{ph}}{Z_{ph}}$$

Phase Impedance (Z_{ph}) is currently unknown therefore must be calculated before this calculation can be completed.

Equation:

$$Z = \sqrt{R^2 + X_L^2}$$

To calculate the impedance the inductive reactance (X_L) must be calculated.

Equation:

$$\begin{aligned} X_L &= 2\pi f l \\ X_L &= 2 \times \pi \times 50 \times 200\text{mH} \\ &= 62.83 \Omega \end{aligned}$$

With the inductive reactance then known the impedance can be calculated.

$$Z = \sqrt{R^2 + X_L^2}$$

$$Z = \sqrt{70^2 + 62.83^2}$$

$$Z = 94.06\Omega$$

The phase current can now be calculated.

Equation:

$$\text{Phase Current } (I_{ph}) = \frac{V_{ph}}{Z_{ph}}$$

$$I_{ph} = \frac{122.4}{94.06} = 1.301 \text{ A}$$

Line Current

With a star configured load the load current is equal to the phase current, therefore;

$$I_{line} = 1.301 \text{ A}$$

Power Factor

Firstly the phase angle needs to be calculated before the power factor can be calculated.

$$\text{Phase Angle } (\phi) = \tan^{-1} \left[\frac{X_L}{R} \right]$$

$$\text{Phase Angle } (\phi) = \tan^{-1} \left[\frac{62.8}{70} \right]$$

$$\text{Phase Angle } (\phi) = 41.89^\circ$$

Using the phase angle, the power factor can be calculated.

Equation:

$$\text{Power Factor} = \cos (41.89)$$

$$\text{Power Factor} = 0.744$$

True Power, Reactive Power and Apparent Power can then be calculated knowing the phase angle and power factor.

$$\text{True Power (P)} = (\sqrt{3})(Vl)(Il)(\cos \phi)$$

$$P = (\sqrt{3})(212)(1.301)(\cos(41.89))$$

$$P = 357.54 \text{ W}$$

$$\text{Reactive Power (Q)} = (\sqrt{3})(Vl)(Il)(\sin \phi)$$

$$Q = (\sqrt{3})(212)(1.301)(\sin(41.89))$$

$$Q = 318.98 \text{ VAR}$$

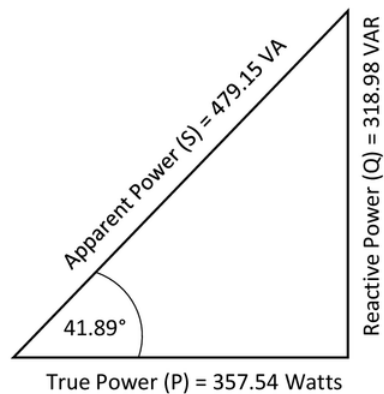
$$\text{Apparent Power (S)} = \sqrt{P^2 + Q^2}$$

$$S = \sqrt{357.54^2 + 318.98^2}$$

$$S = 479.15 \text{ VA}$$

Power Triangle

The power triangle can now be created using the values calculated above.



Good calculation which are explained well and enable the derived power triangle. This is a good finishing touch.

Delta Load

Line Voltage (V_{line}) = 206 V

Phase Voltage

When a load is connected in delta there is no neutral therefore the phase voltage is equal to the line voltage.

$$\text{Phase Voltage} = \text{Line Voltage} = 206 \text{ V}$$

Phase Current

The phase impedance is the equivalent to the phase impedance of the star load as the load conditions have not changed.

Equation:

$$\text{Phase Current } (I_{ph}) = \frac{V_{ph}}{Z_{ph}}$$

$$I_{ph} = \frac{206}{94.06} = 2.19 \text{ A}$$

Line Current

Equation:

$$I_{line} = \sqrt{3} \times I_{ph}$$

$$I_{line} = \sqrt{3} \times 2.19$$

$$I_{line} = 3.79 \text{ A}$$

Power Factor

The phase angle and power factor stay the same for a star and delta load. Therefore;

$$\text{Phase Angle } (\phi) = 41.89^\circ$$

$$\text{Power Factor} = 0.744$$

True Power, Reactive Power and Apparent Power can then be calculated knowing the above values.

$$\text{True Power (P)} = (\sqrt{3})(Vl)(Il)(\cos \phi)$$

$$P = (\sqrt{3})(206)(3.79)(\cos(41.89))$$

$$P = 1006.68 \text{ W}$$

$$\text{Reactive Power (Q)} = (\sqrt{3})(Vl)(Il)(\sin \phi)$$

$$Q = (\sqrt{3})(206)(3.79)(\sin(41.89))$$

$$Q = 902.92 \text{ VAR}$$

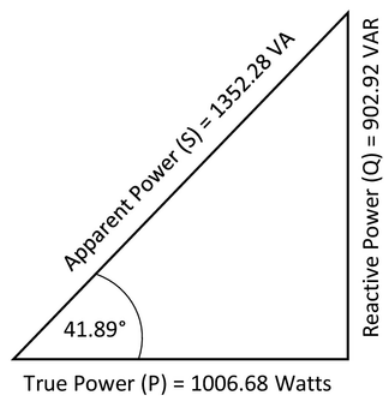
$$\text{Apparent Power (S)} = \sqrt{P^2 + Q^2}$$

$$S = \sqrt{1006.68^2 + 902.92^2}$$

$$S = 1352.28 \text{ VA}$$

Power Triangle

The power triangle can now be created using the values calculated above.



*Same for the
Delta
calculations. A
good finishing
touch with the
derived power
triangle.*

Below is a table displaying the calculated and measured results of balanced star and delta loads.

Calculated Values									
Supply	Load	Current		Voltage		PF	True Power (W)	Apparent Power (VA)	Reactive Power (VAR)
		Line (mA)	Phase (mA)	Line (V)	Phase (V)				
Star	Star	1.301	1.301	212	122.4	0.744	357.54	479.15	318.98
Star	Delta	3.79	2.19	206	206	0.744	1006.68	1352.28	902.92
Measured Values									
Star	Star	1.16	1.16	212	122	0.65	287	442	336
Star	Delta	3.45	N/A	206	206	0.65	808	1250	946

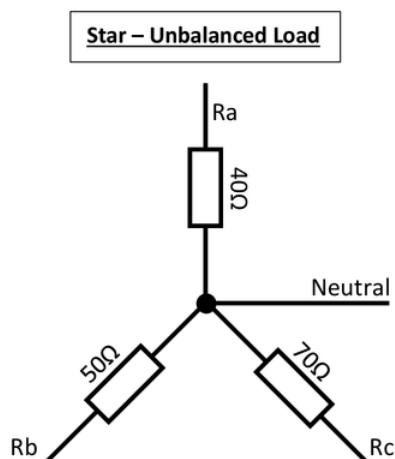
Figure 7 - Comparison of measured and calculated results

It can be seen from the comparison table above that all calculated and measured values follow the same trends. However, there are some noticeable differences in the values and there are a number of reasons for this. For example, there could have been fluctuations in the supply while carrying out the practical, the calibration of the test equipment could be inaccurate, losses through wire resistances which will not be considered in theoretical calculations and also a current clamp is not the most accurate form of measuring equipment.

Good arguments presented here for the differentials. Good set of results.

Task 3 – Star Unbalanced Load (Practical Testing)

The set-up used in the practical of Task 1 will now be isolated and modified to represent an unbalanced star load. The unbalanced set-up will be configured as shown in the diagram below, with three resistors of different values and as can be seen this load will be purely resistive, the inductors will be removed. The results will be recorded and then presented in a table.



Practical Results

Figure 8 shows the table of results recorded from the practical task.

Supply	Load	Line Voltages			Phase Voltages			I _A	I _B	I _C	PF
		V _{AB}	V _{BC}	V _{CA}	V _{RN}	V _{YN}	V _{BN}				
Star	Star	206	208	210	118	118	122	3.37	2.72	1.93	1.0

Figure 8 - Unbalanced Star Load Practical Results

Line Voltage

Line Voltage = 208V

Phase Voltage

$$\text{Phase Voltage } (V_{ph}) = \frac{V_{line}}{\sqrt{3}}$$

$$\text{Phase Voltage } (V_{ph}) = \frac{208}{\sqrt{3}}$$

$$V_{ph} = 120.09 \text{ V}$$

Phase Current

$$I_{AN} = \frac{V_{ph}}{R_a} = \frac{120.09}{40} = 3 \text{ A}$$

$$I_{BN} = \frac{V_{ph}}{R_b} = \frac{120.09}{50} = 2.4 \text{ A}$$

$$I_{CN} = \frac{V_{ph}}{R_c} = \frac{120.09}{70} = 1.7 \text{ A}$$

Line Current

With a star configured load the line current is equal to the phase current.

Power Factor

VAB

True Power = 688 W

Apparent Power = 688 VA

Reactive Power = 0 VAR

VBC

True Power = 1.22 kW

Apparent Power = 1.22 VA

Reactive Power = 0 VAR

VAC

True Power = 981 W

Apparent Power = 981 VA

Reactive Power = 0 VAR

The Power factor is equal to 1 because it is a purely resistive circuit. Hence, there is no reactive power because there is no capacitive (Xc) or inductive (XL) reactance.

*Good reasoning
using the logic
13 that the circuits
are resistive only
and will have no
reactive power.*

Below shows a table displaying both the measured and calculated values.

Supply	Load	Line Voltages			Phase Voltages			I _A	I _B	I _C	PF
		V _{AB}	V _{BC}	V _{CA}	V _{RN}	V _{YN}	V _{BN}				
Measured											
Star	Star	206	208	210	118	118	122	3.37	2.72	1.93	1.0
Calculated											
Star	Star	208	208	208	120	120	120	3	2.4	1.7	1

It can be seen from the results that there are only very minor differences between both sets of results. The potential reasons for discrepancies are the same as those mentioned in Task 1.

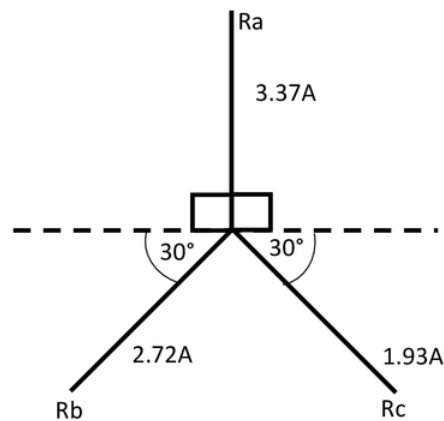
Using the measured values, the phasor diagrams can now be produced.

Good valid point.

Phasor Diagrams

Red Phase (a)

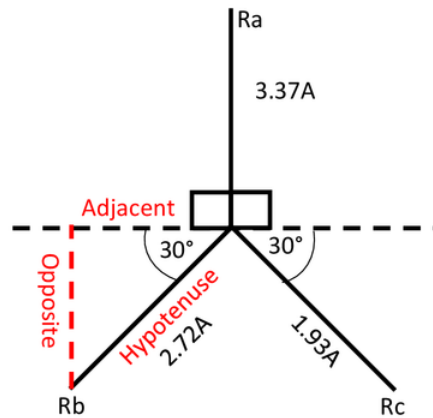
The selected reference phase was the red phase meaning the horizontal value will be equal to 0. As this phase has been selected as the reference the vertical value is the full current range because it is at the phase's sine waves maximum point of 90° .



Blue Phase (b)

Using trigonometry, the vertical and horizontal factors of the vector can be calculated.

Vertical



Vertical = Opposite Side

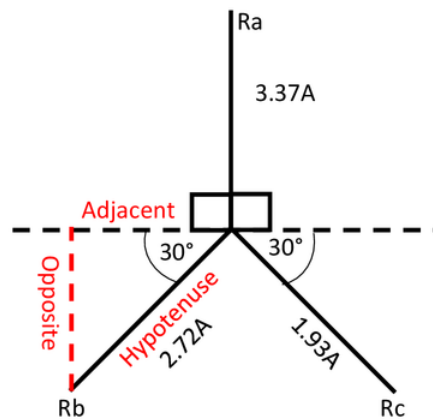
As the hypotenuse and the opposite angle are known the Sin rule must be used.

$$\sin \theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$2.72 \times \sin 30^\circ = \text{Opposite}$$

$$\text{Vertical (Opposite)} = 1.36 \text{ A}$$

Horizontal



Horizontal = Adjacent Side

As the hypotenuse and the opposite angle are known the Cos rule must be used.

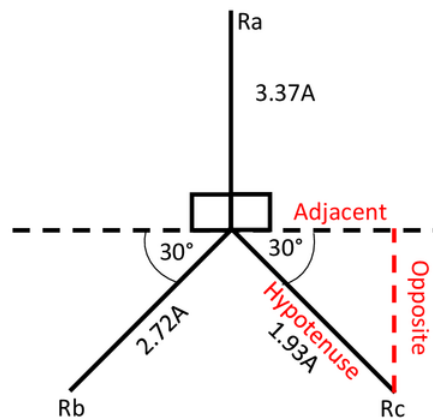
$$\cos \theta = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$

$$2.72 \times \cos 30^\circ = \text{Adjacent}$$

$$\text{Horizontal (Adjacent)} = 2.36 \text{ A}$$

Yellow Phase (c)

Vertical



Vertical = Opposite Side

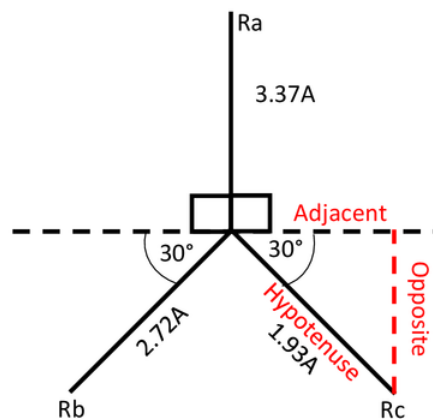
As the hypotenuse and the opposite angle are known the Sin rule must be used.

$$\sin \theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$1.93 \times \sin 30^\circ = \text{Opposite}$$

$$\text{Vertical (Opposite)} = 0.97 \text{ A}$$

Horizontal



Horizontal = Adjacent Side

As the hypotenuse and the opposite angle are known the Cos rule must be used.

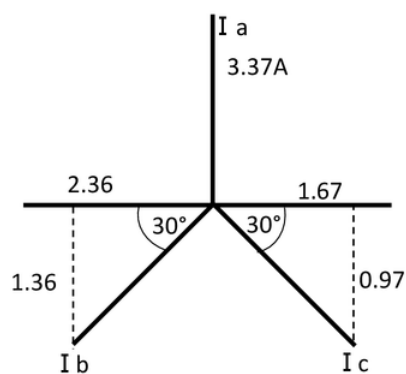
$$\cos \theta = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$

$$1.93 \times \cos 30^\circ = \text{Adjacent}$$

$$\text{Horizontal (Adjacent)} = 1.67 \text{ A}$$

The results of the above calculations were then put into a table and a phasor diagram drawn with all values included.

Phase	Horizontal	Vertical
Red	0	3.4
Blue	2.36	1.36
Yellow	1.67	0.97



In order to calculate the neutral current, a sum of the vertical and horizontal values is required. This is because the equation used to calculate neutral current is:

$$\sqrt{\text{Sum of Verticals}^2 + \text{Sum of Horizontals}^2}$$

Vertical Sum:

$$3.37 - 1.36 - 0.97 = 1.04$$

Horizontal Sum:

$$2.36 - 1.67 - 0 = 0.69$$

Neutral Current

$$I_N = \sqrt{\text{Sum of Verticals}^2 + \text{Sum of Horizontals}^2}$$

$$I_N = \sqrt{1.04^2 + 0.69^2}$$

$$I_N = 1.25 \text{ A}$$

Calculations for the neutral are good.

Using this value as well as the sum of the vertical and horizontal values a vector diagram can be produced. This is shown in Figure 9.

Vector Diagram

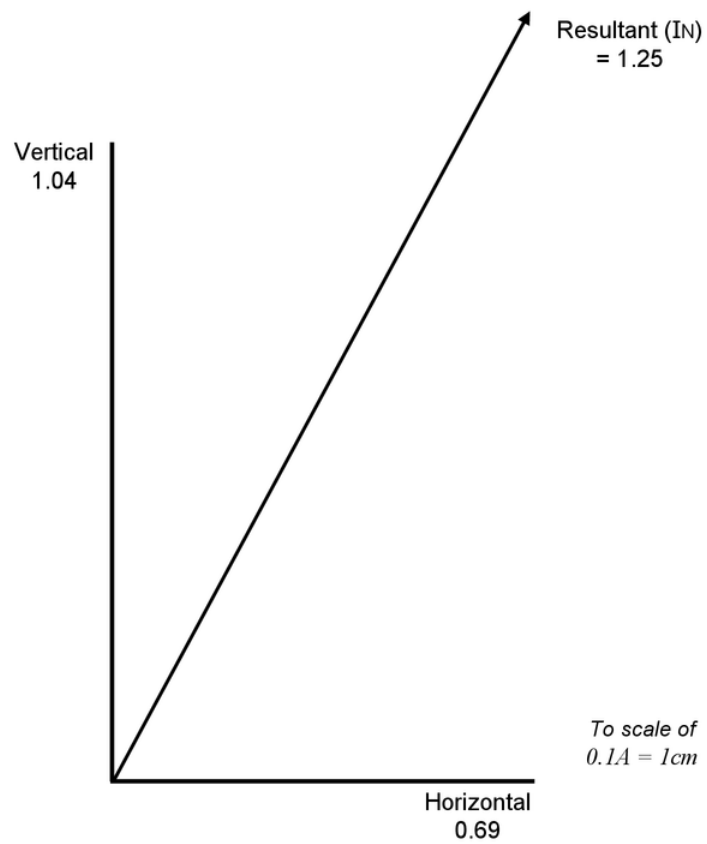


Figure 9 - Vector Diagram

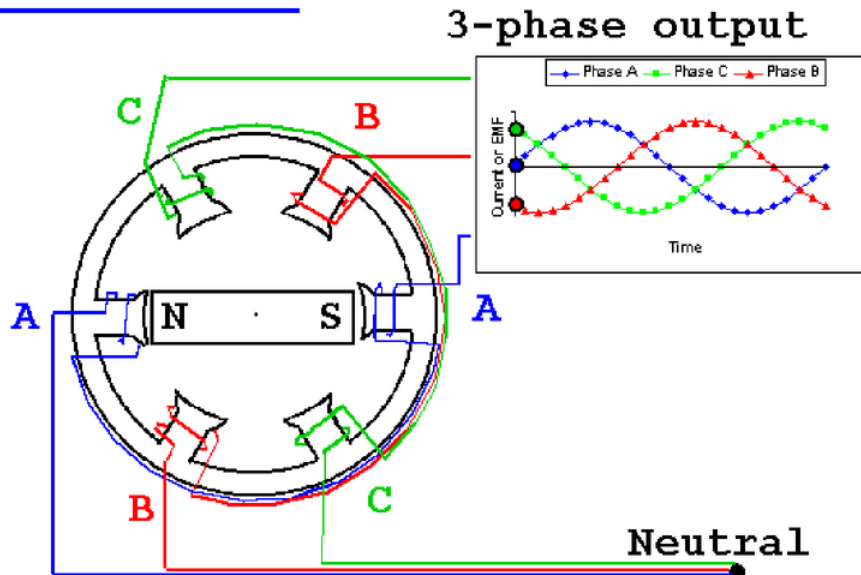
*This is
good
work.*

Task 4 – Three-Phase Transmission

Electricity is transmitted on a three-phase basis as it is the most efficient way of transporting energy. There are 120 moments per second where single phase or 2-phase sine wave is at 0 volts. However, with three-phase at any time one phase is reaching its peak. (Roos, 2018)

This is because three-phase power is created by a generator with 3 pairs of coils which are physically offset by 120° on the armature. An example of this is shown in Figure 10.

The Generator



T. Davies 2002

Figure 10 - Three-Phase Generator (Urban, 2015)

Most industrial plants will require power at three-phase whereas the majority of residential homes are run on single phase. By transmitting at three-phase with a neutral you are then able to tap of one phase and neutral when it comes to supplying houses. Whereas it is not possible to get three-phase from a single phase.

Another significant advantage of transmitting three-phase power is that you can transmit 3 times the amount of power than single phase with just one and a half times more cable. Which of course proves to be very efficient.

Three-phase power also allows you to obtain a constant output voltage.

Task 5 – Power Factor

Power Factor is a measure of how efficient the load current is being converted into useful power. It is represented as either a value between 0 and 1 or as a percentage and is the ratio of true power (P) to apparent power (S). Where true power represents the amount of working power that is dissipated within a circuit and apparent power is the product of the voltage and current within a circuit, a combination of true power (P) and reactive (magnetising) power (R). (Wildi, 1991, p. 147)

True Power (P)

In a DC circuit **True Power (P) = V I** because there is no phase angle therefore no power factor and this is also the case for a purely resistive AC circuit. However, in any other AC circuits because of phase differences, True Power (P) = $V I \cos \theta$. The unit for true power is kilowatts (kW). (True, Reactive and Apparent Power, 2018)

Reactive Power (Q)

Reactive power is power not used through the load its generally discharged by transformers or inductive motors. The reactive power which inductive loads needs, in turn raises the amount of apparent power which decreases power factor. Reactive power is measured in Volt-Amps-Reactive (VAR)

Apparent Power (S)

Apparent power is measured in volt-amps (VA) and is calculated by multiplying the current and voltage of an AC circuit. This type of power is the vector sum of true power and reactive power.

(Active, Reactive, Apparent and Complex Power, 2018)

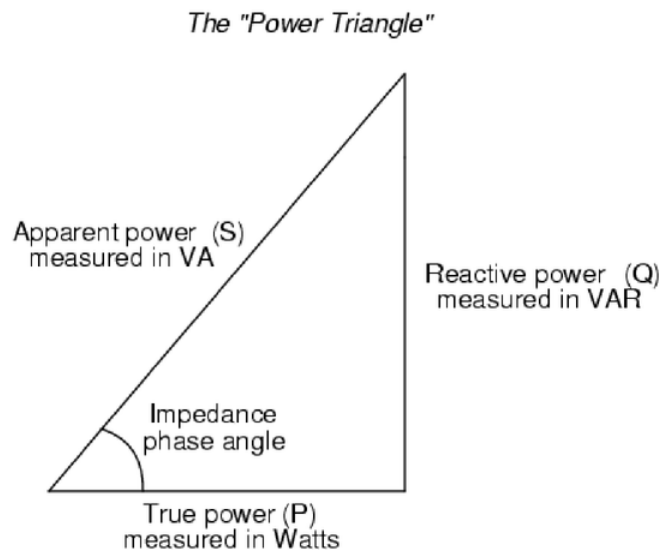


Figure 11 - Power Triangle (True, Reactive and Apparent Power, 2018)

The three powers are all related in trigonometric form, hence the 'Power Triangle'. This is shown in Figure 11 above.

The equation for Power Factor is:

$$P.F = \frac{\text{True Power (P)}}{\text{Apparent Power (S)}}$$

Due to the fact that true power can never be greater than apparent power, power factor can never exceed unity (1).

A power factor of 1 would tell you that a system is very effective and is the supply is 100% efficient. Whereas, a power factor of 0.6 for example shows that 40% of the supply power is being wasted.

In cases where the power factor is low power factor correction can be utilised to improve the power factor bringing it as close to unity as possible.

Power Factor Correction

It is the reactive power within operating power which has a negative effect on power factor, however it cannot be eliminated because it is required for producing magnetic fields. Capacitors can be utilised as reactive power generators, therefore consumers can switch in capacitors which will supply their own reactive power. This will reduce the total amount of current drawn from the suppliers which subsequently raises the Power Factor level. (Industries, 2018)

Although it has quite a substantial initial cost to install the capacitors it has been suggested that you will earn back the cost in energy savings within 1 year.

*This could
have done
with a
calculated
example.*

Task 6 – STAR and DELTA Connection Arrangements

The windings of a three-phase transformer can be configured in different ways to meet the requirements of the application. There are four configurations that the transformers can be connected, Star – Star, Star – Delta, Delta – Delta and Delta – Star.

Star – Star

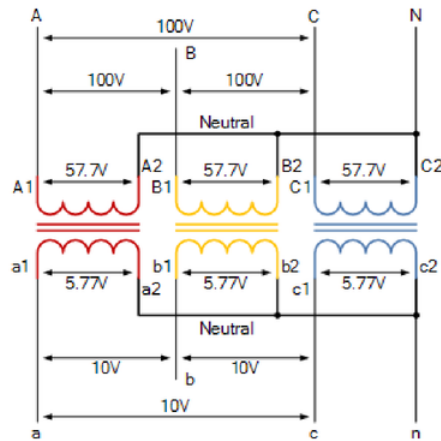


Figure 12 - Star - Star Configuration (Three Phase Transformers, 2018)

The star-star connection is used for small, high voltage transformers. This type of configuration can only be used if a balanced load is connected.

Star – Delta

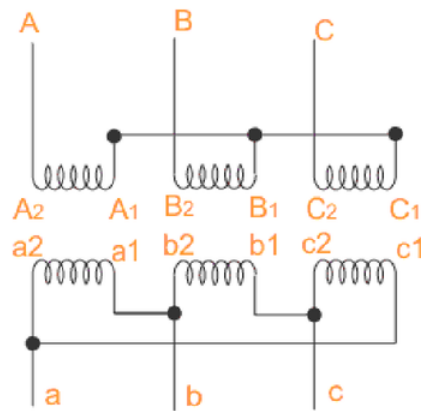


Figure 13 - Star - Delta Configuration (Single Three-Phase Transformers vs Bank of Three Single-Phase Transformers, 2018)

This type of configuration is mainly used in step-down transformers within substations after the transmission process has been carried out.

Delta – Delta

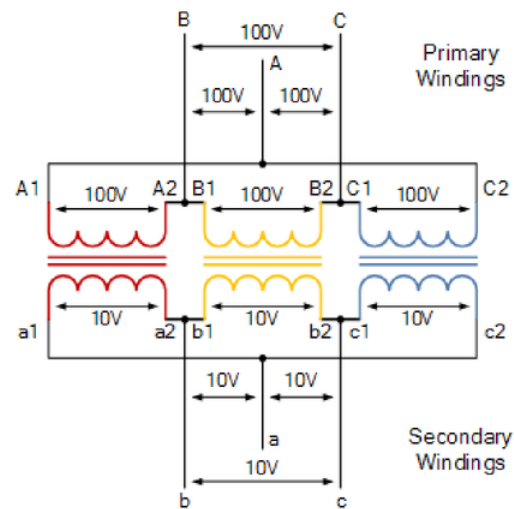


Figure 14 - Delta - Delta Configuration (Three Phase Transformers, 2018)

This is used in the opposite applications to Star-Star. For large, low voltage transformers. The number of turns is significantly larger than the star-star configuration. This connection can be used for balanced and unbalanced loads and can also operate in open delta connection if one transformer fails.

Delta – Star

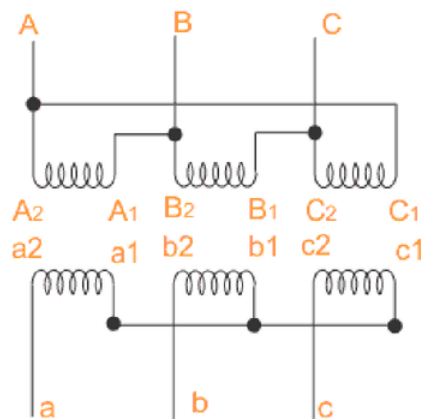


Figure 15 - Delta - Star Configuration (Single Three-Phase Transformers vs Bank of Three Single-Phase Transformers, 2018)

This configuration is generally used within the step-up transformers prior to transmission.

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Good
sources
used

PSDE 4001 - Assignment 2

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

74/100

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

Text Comment. Good illustration of the practical loading arrangement.

PAGE 5

Text Comment. Correct arrangement for phase, line and current measurements using NANOVIP instrument. This is a good example of the arrangement.

Text Comment. Good illustration.

PAGE 6

PAGE 7

PAGE 8

PAGE 9

Text Comment. Good calculation which are explained well and enable the derived power triangle. This is a good finishing touch.

PAGE 10

PAGE 11

Text Comment. Same for the Delta calculations. A good finishing touch with the derived power triangle.

PAGE 12

Text Comment. Good arguments presented here for the differentials. Good set of results.

PAGE 13

PAGE 14

Text Comment. Good reasoning using the logic that the circuits are resistive only and will have no reactive power.

PAGE 15

Text Comment. Good valid point.

PAGE 16

PAGE 17

PAGE 18

Text Comment. Good work here. Shows a good understanding.

PAGE 19

Text Comment. Calculations for the neutral are good.

PAGE 20

Text Comment. This is good work.

PAGE 21

PAGE 22

PAGE 23

Text Comment. This could have done with a calculated example.

PAGE 24

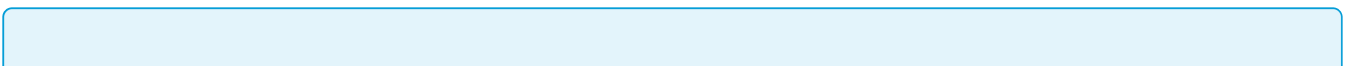
PAGE 25

Text Comment. The research covers what was required.

PAGE 26

Text Comment. Good sources used

GRADING FORM: CSG-RUBIC



JED DAVIES

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RESEARCH-INFORMED LITERATURE



Research has covered what was required. 3.5/5 The referencing is good with a number of academic relevant sources. 3.5/5

7/10

KNOWLEDGE AND UNDERSTANDING



Good introduction to the tasks. 3.5/5 Procedures are explained well with a good understanding demonstrated. 3.5/5 Discussion of results is good. 7/10

14/20

ANALYSIS



Testing and analysis is very good. 26/30 Lacks a good conclusion, but there are conclusive discussions. 4/10

30/40

PRACTICAL APPLICATION AND DEP.



All procedures are explained very well. 4/5 Discussion of results explains what the reasons for differences. 3.5/5 Quality of work is very good. 8.5/10

16/20

SKILLS FOR PROFESSIONAL PRAC.



Report is very good and good. 3.5/5 skills were demonstrated with team work for the practical work.
3.5/5

7/10