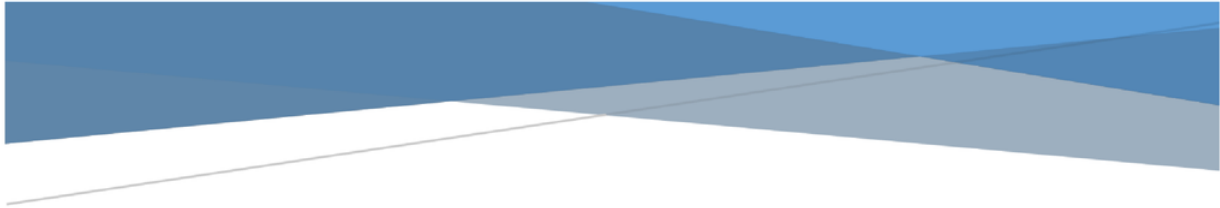


PSDE 4001 Assignment 2

by Jac Williams

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HNC ELECTRICAL AND ELECTRONIC ENGINEERING PSDE 4001

Three Phase Circuits

Jac Williams
Tata Steel

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Task 1:

Initially the ELT 171A (Three phase supply unit) was set up in a star configuration, connected to the ELT 171C (Load unit) also in a star configuration as a balanced inductive load featuring 70Ω of resistance in each coil, forming a star-star system. This setup can be seen in Figure 1, and a diagram of the system illustrated in Figure 2. This was achieved by setting the variable resistors (R_a , R_B , and R_C) to 70Ω , selecting L (Inductive Load) on the L/C selector switch, and setting the value of inductance to 200mh, as laid out in the brief.



Figure 1: Star-Star Balance Load Practical

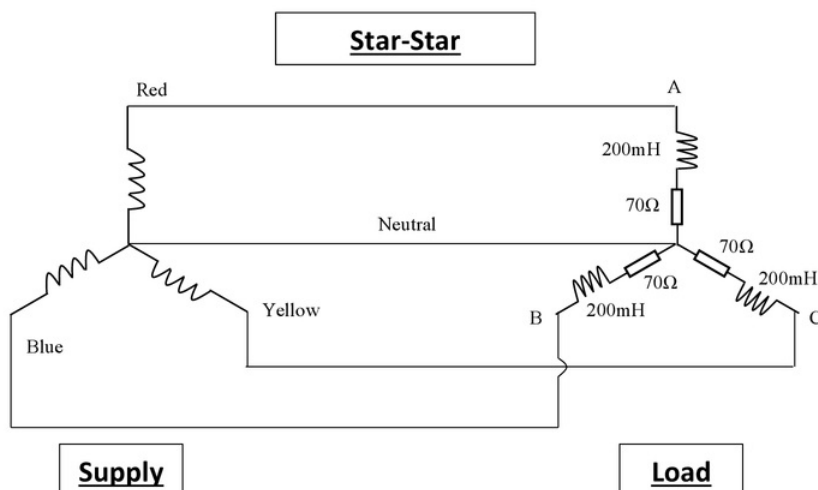


Figure 2: Stat-Star balanced load diagram

In order to attain the readings for the voltages, currents, and power factor of the system a NANOVIP was used. The NANOVIP (electronic wattmeter) is a measurement device that is capable of

measuring the voltage, current, and works out the power factor of a circuit. The voltages were attained by two leads from the NANOVIP connected onto the load as required (i.e. at points A and B for the VAB reading), and a clamp meter was then put onto a cable of the phase not having its voltage measured (i.e. for the VAB reading IC had a current the current clamp) in order to measure the current. An example of how the connections are made can be seen in Figure 3. From these reading the NANOVIP could then calculate the Real, Apparent, and Reactive power of the circuit. These results were then tabulated as displayed in Table 1.

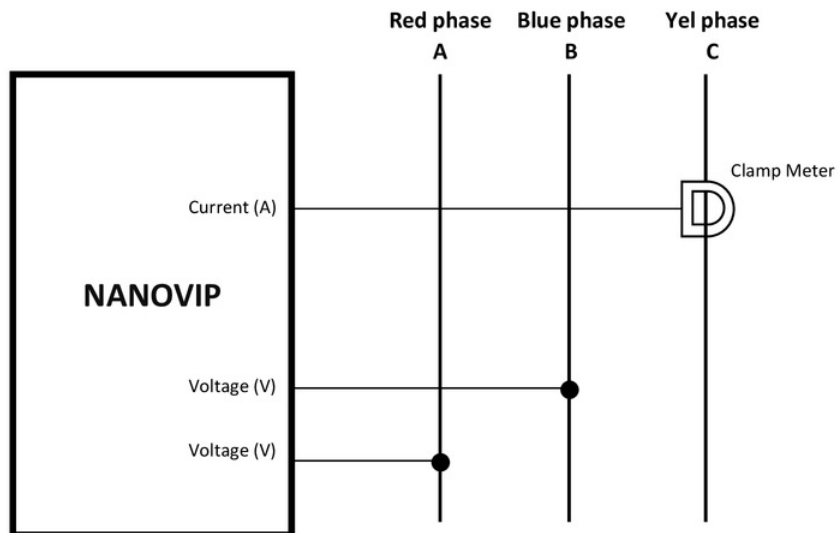


Figure 3: NANOVIP Connection Diagram

The circuit was then isolated, and the load configured into a delta formation as depicted in Figure 4, and the diagram in Figure 5, and the same steps taken for the star load repeated for this configuration and the results tabulated.

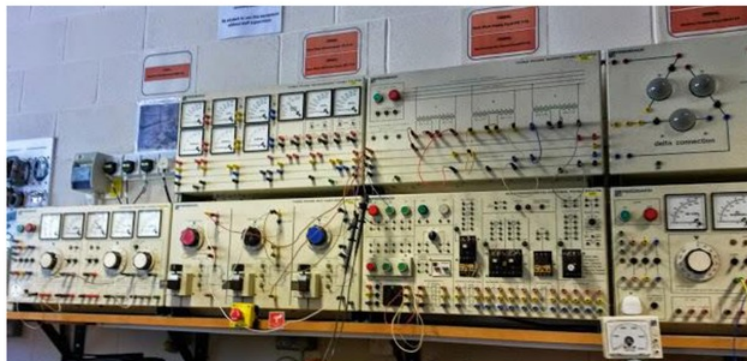


Figure 4: Star-Delta balanced load Practical

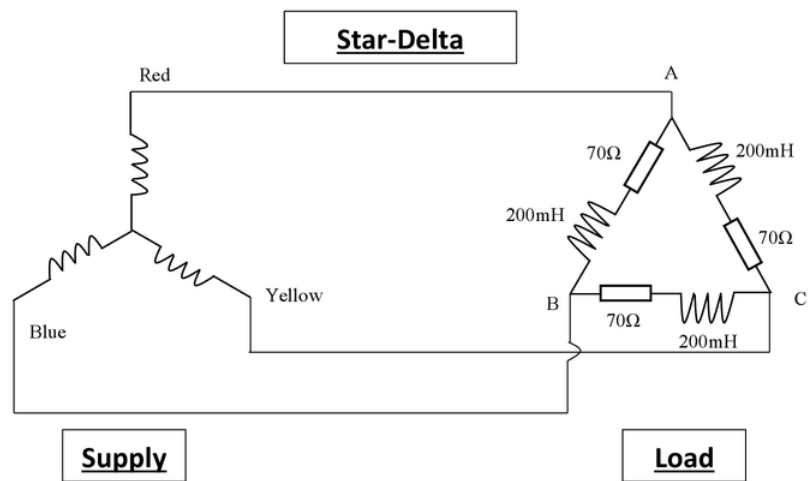


Figure 5: Star-Delta balance load diagram

Practical Results

Supply	Load	Line Voltages			Phase Voltages			I_A	I_B	I_C	PF	Real Power (W)	Apparent Power (VA)	Reactive Power VAR
		V_{AB}	V_{BC}	V_{CA}	V_{RN}	V_{YN}	V_{BN}							
Star	Star	213V	213V	213V	122V	123V	122V	1.16A	1.17A	1.21A	0.65	290W	445VA	339VAR
Star	Delta	206V	206V	206V	206V	206V	206V	3.48A	3.48A	3.48A	0.65	804	1.23KVA	980VAR

Table 1: Task 1 Practical Results

Good results and description of procedure

Analysis of results:

The line voltages for both load configurations are practically identical, this corresponds with the fact that both configurations were supplied with the same supply, and therefore should have the same line voltages. The phase voltages on the other hand vary depending on the configuration. Delta phase voltage = line voltage as you cannot practically attain a phase voltage without a neutral point, and thus only line voltage is present. Whereas in star a neutral point is present, and thus phase voltages can be attained. The phase voltage in star is governed by the formula:

$$V_{ph} = \frac{V_l}{\sqrt{3}} = \frac{213}{\sqrt{3}} = 123V$$

By plugging our recorded values into the formula we can see that they match, and are therefore the correct readings.

Most notable of disparities though is the current, where the current in delta (approx. 3.5A) is almost 3 times greater than that of star (approx. 1.2A). This is because the resistance present in delta is a lot lower than star. This is because in star the lines feature two resistances in series, whereas in delta it will feature one resistance in parallel with two series resistances. Resistances in parallel will always be less than that of series.

This can be illustrated by plugging values into the formulae, using a balanced load at 70Ω as our example

Star Resistance (Series):

$$R_t = R_1 + R_2 = 70 + 70 = 140\Omega$$

Delta Resistance (Parallel):

$$R_t = \frac{R_1 \times (R_2 + R_3)}{R_1 + (R_2 + R_3)} = \frac{70 \times (70 + 70)}{70 + (70 + 70)} = \frac{70 \times 140}{70 + 140} = 46.67\Omega$$

As can be seen from the above example the resistance is approximately 3 times less in delta as it is in series, which is the inverse of the relationship of current in star and delta. This makes sense when basic ohms law is applied where:

$$V = IR$$

So when the resistance is less the current is higher (As is true in Delta) and when the current is low the resistance is higher (as is true in Star).

As a result of this increased current, the overall power (true, apparent, and reactive) of the circuit is also greatly increased.

The power factor (0.65) remained constant in both configuration as the same resistances and reactance was present, and the formula for PF is:

$$P.F. = \tan^{-1}\left(\frac{X_l}{R}\right)$$

Task 2:

Star Calculations:

In a star connected load the phase voltage is ascertained using the formula:

$$V_{ph} = \frac{V_L}{\sqrt{3}}$$
$$\frac{213}{\sqrt{3}} = 123V$$

The line current is then found using the formula:

$$I_{ph} = \frac{V_{ph}}{Z_{ph}}$$

In order to use this formula the phase impedance (Zph) must be calculated;

$$Z_{ph} = \sqrt{R^2 + X_L^2}$$

And consequently the inductive reactance XL has to be attained from the formula:

$$X_L = 2\pi fL$$
$$2\pi \times 50 \times 200mH = 62.8319\Omega$$

Now using the previous equation Zph can be calculated:

$$Z_{ph} = \sqrt{R^2 + X_L^2}$$
$$\sqrt{70^2 + 62.8319^2} = 94.063\Omega$$

And by subbing this value into the equation for Iph the phase current can be derived:

$$I_{ph} = \frac{V_{ph}}{Z_{ph}}$$
$$\frac{123}{94.063} = 1.308A$$

In star the line current is the same as phase current therefore:

$$I_L = I_{ph} = 1.308A$$

The phase angle is then calculated:

$$\text{Phase Angle } \theta = \tan^{-1} \left(\frac{XL}{R} \right)$$

$$\tan^{-1} \left(\frac{62.8319}{70} \right) = 41.911^\circ$$

From the phase angle we can then discern the power factor of the circuit:

$$P.F. = \cos(\theta)$$

$$\cos(41.911) = 0.744$$

Now that the power factor of the circuit is known the three types of power can be calculated;

True power:

$$\text{True Power } P = \sqrt{3} \times VL \times IL \times \cos(\theta)$$

$$\sqrt{3} \times 213 \times 1.308 \times \cos(41.911) = 359.11W$$

Reactive Power:

$$\text{Reactive Power } Q = \sqrt{3} \times VL \times IL \times \sin(\theta)$$

$$\sqrt{3} \times 213 \times 1.308 \times \sin(41.911) = 322.336VAR$$

Apparent Power:

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

$$\sqrt{359.11^2 + 322.336^2} = 482.556VA$$

Good
calcs
and
explanat
ion of
procedu
re

Delta Calculations:

The phase Voltage (V_{ph}) is equal to line voltage (V_L) as there is no neutral connection in a Delta connected Load.

Z_{ph} is the same as in the "star" connected load, therefore:

$$Z_{ph} = 94.063\Omega$$

Phase current is calculated, and Z_{ph} is known from the star calculations:

$$I_{ph} = \frac{V_{ph}}{Z_{ph}}$$

$$\frac{206}{94.063} = 2.19A$$

Unlike star, in delta the line current is not equal to phase current and can instead be calculated as follows:

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

$$\sqrt{3} \times 2.19 = 3.793A$$

The phase angle and power factor are constant between the star and delta loads, and therefore the values calculated in the star calculations can be utilised here. Because these values are known the three types of power can be calculated:

The actual power output of the circuit, true power:

$$\text{True Power } P = \sqrt{3} \times V_L \times I_L \times \cos(\theta)$$

$$\sqrt{3} \times 206 \times 3.793 \times \cos(41.911) = 1007.142W$$

The losses incurred on the system due to reactance is calculated as the reactive power:

$$\text{Reactive Power } Q = \sqrt{3} \times V_L \times I_L \times \sin(\theta)$$

$$\sqrt{3} \times 206 \times 3.793 \times \sin(41.911) = 904.005VAR$$

The potential power of the circuit is the apparent power:

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

$$\sqrt{1007.142^2 + 904.005^2} = 1353.351VA$$

Good calcs and explanation

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Power Triangles:

Star:

The power triangle for the star-star balanced load can be seen in Figure 6, drawn to scale using the ratio stated.

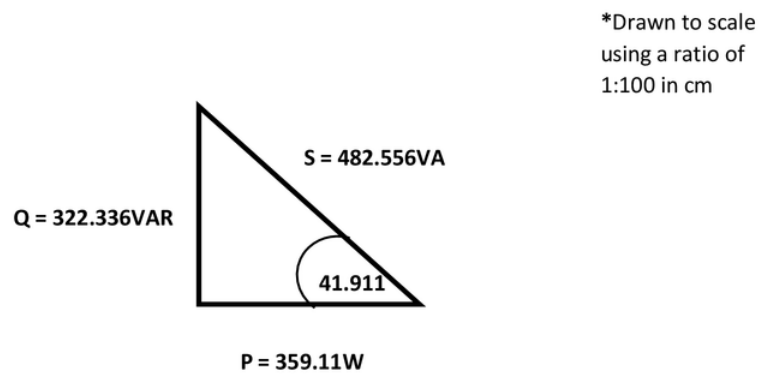


Figure 6: Star-Star balance load power triangle

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Delta:

The power triangle for the star-delta balanced load can be seen in Figure 7Figure 6, drawn to scale using the ratio stated.

$$\sqrt{1007.142^2 + 904.005^2} = 1353.351VA$$

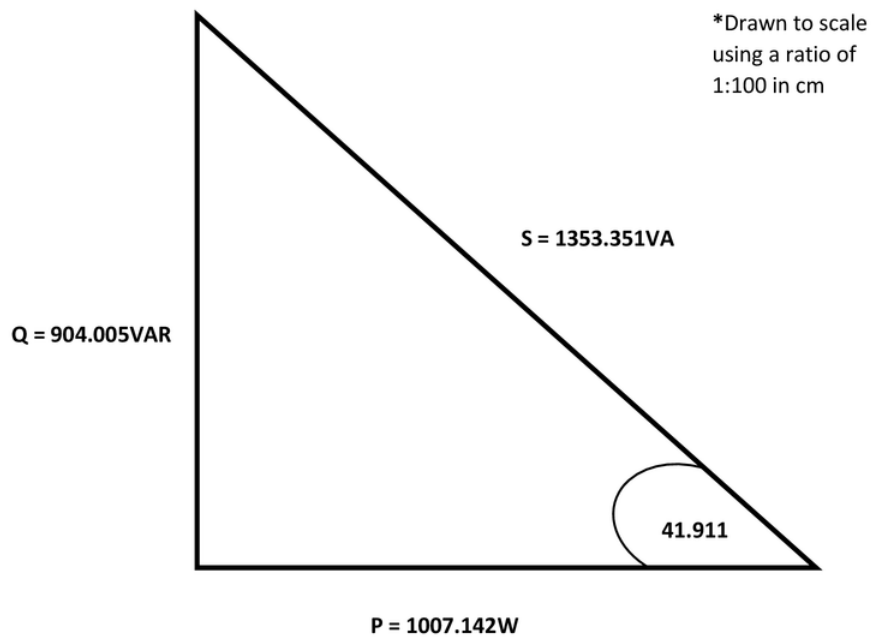


Figure 7: Star-Delta balanced load power triangle

*Good use
of power
triangles
derived
from
results.*

Analysis:

Method of results	Load	Voltage (V)		Current (I)		Power Factor	True Power (W)	Apparent Power (VA)	Reactive Power (VAR)
		Line	Phase	Line	Phase				
Calculated	Star	213	123	1.308	1.308	0.744	359.11	482.556	322.336
	Delta	206	206	3.793	2.19	0.744	1007.142	1353.351	904.005
Measured	Star	213	122	1.19	1.19	0.65	290	445	339
	Delta	206	206	3.48	N/A	0.65	804	1230	980

Table 2: Comparison of Measured and Calculated Results for balanced loads

**for the sake of clarity the measured results have been taken as averages of the readings*

When comparing the measured and calculated values displayed in Table 2: Comparison of Measured and Calculated Results for balanced loads, a disparity can be seen between the results obtained from the two methods.

A major factor in these differences is the test instrument, primarily the clamp meter. The clamp meter is an indirect current measurement device, and could likely account for a lot of the variance between the practical and calculated results. The clamp meter does not provide a “true” current reading, and it was made evident during the practical where moving the clamp meter along the cable yielded a varying reading when it should have been constant.

The calculated results are also theoretical, as they do not account for real life factors such as; losses due to wire resistance, tolerances in components and so forth.

These two factors point to being the predominant reasons for the discrepancies, as the current (and therefore the power factor and powers due to them being calculated from the current readings) is where the biggest differences lie, whilst the voltages are fairly consistent between the measured and calculated results with only negligible differences.

Similarly the NANOVIP could have been slightly out of calibration, as it might not have been sent away for calibration for a lengthy period.

Human error may have also played a part, along with rounding errors during the calculations.

Another consideration is that values from the practical were used as our jumping off point to begin the calculations, if these original practical values were out then the whole calculation is thrown off as it originates with that.

Very good arguments for differences

Task 3:

For this task a purely resistive imbalanced star connected load is set up on the ELT 171C, as displayed in Figure 8. The variable resistors were set up according to the brief, and the load made to be purely resistive by connecting the loading solely across the resistors.

The results were then tabulated in Table 3.

Load	VAB (V)	VBC (V)	VCA (V)	Vrn (V)	Vyn (V)	Vbn (V)	Ia (A)	Ib (A)	Ic (A)	PF
Star	206	208	210	118	118	122	3.37	2.72	1.93	1

Table 3: Imbalanced Resistive Star Load Results

The NANOVIP also provided the true power for the following configurations:

VAB = 688w

VBC = 1.22Kw

VCA = 981W

Apparent power is the same as true power as the PF is 1, meaning that the reactive power is 0. This is because it is a purely resistive load and thus there is no reactance (capacitive or inductive) causing a loss of power factor.

Good explanation of power factor characteristic

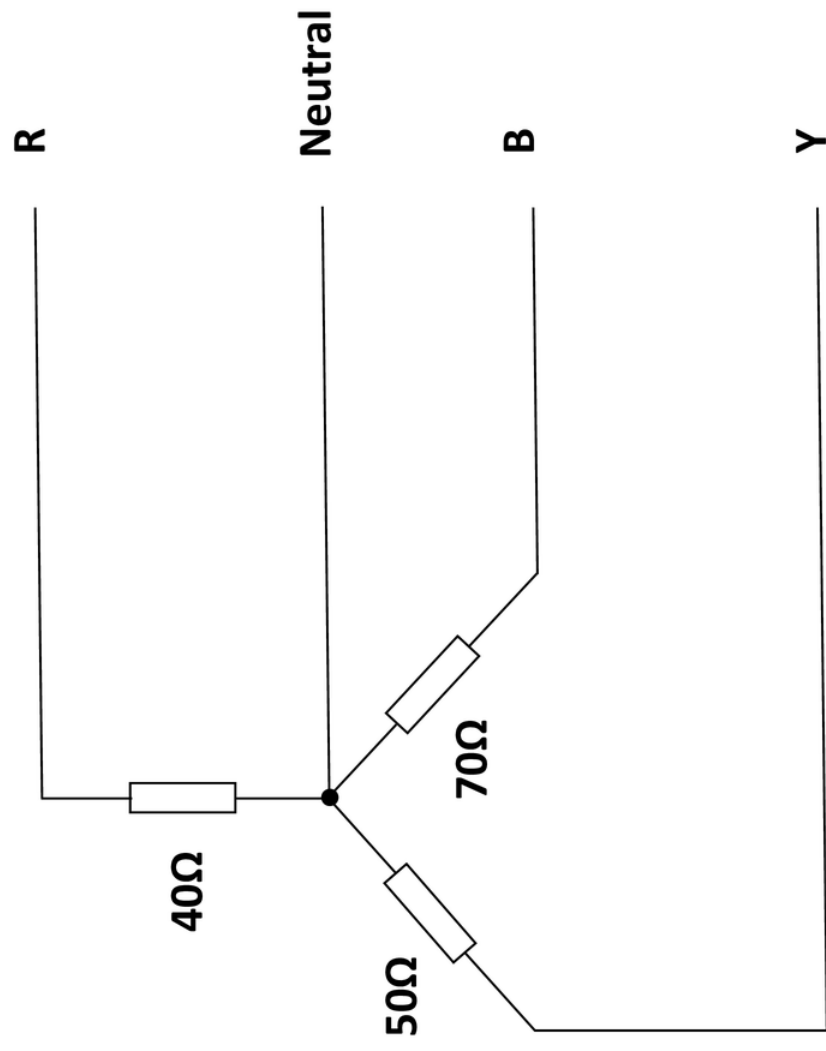


Figure 8: Unbalanced Resistive Star Load diagram

Calculations:

Line Voltage = 208V

$$\text{Calculated phase voltage} = \frac{V_{line}}{\sqrt{3}} = \frac{208}{\sqrt{3}} = 120.09V$$

$$\text{Average of Measured phase voltages} = (118 + 118 + 120)/3 = 118.667V$$

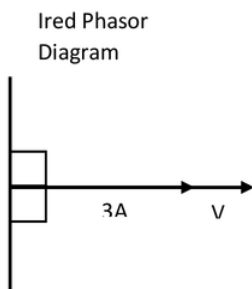
This proves that our voltages are correct as our practical and calculated results coincide with each other, with only a negligible approximate 2V difference.

Phase Currents:

$$I_{red} = \frac{V_{ph}}{R_{ph}} = \frac{120.09V}{40\Omega} = 3A$$

$$I_{yellow} = \frac{V_{ph}}{R_{ph}} = \frac{120.09V}{50\Omega} = 2.402A$$

$$I_{blue} = \frac{V_{ph}}{R_{ph}} = \frac{120.09V}{70\Omega} = 1.716A$$



Phase	Measured Current (A)	Calculated Current (A)
Red	3.37	3
Yellow	2.72	2.402
Blue	1.93	1.716

Table 4: Imbalanced Star Load Comparison of results

As the load is purely resistive and features no inductive or capacitive loading, the current is in phase with the voltage, as no reactance is present.

It is evident from Table 4 that the results attained from both methods are fairly similar, with the largest being a deviation of around 0.4A on the red phase, which is just above 10%. The reasons for the discrepancies are the same as those stated at the end of task 2.

Good work with analysis

Vector Calculations:

By converting the currents into their horizontal and vertical parts and using Pythagoras theorem a scaled phasor diagram can be created in order to find out the neutral current.

Red Phase:

The red phase is used as a reference as shown in figure 9.

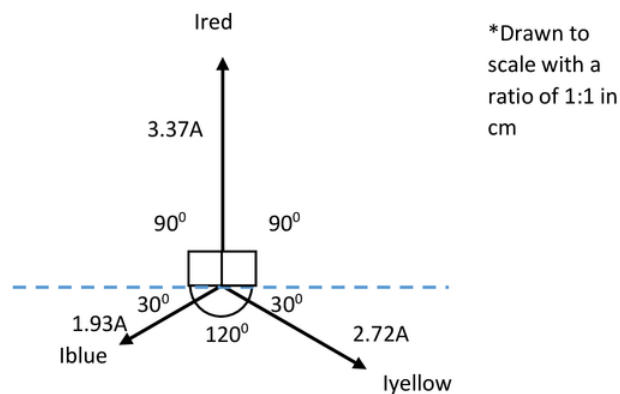


Figure 9: Vector diagram for Measured Results

Because the red phase is used as reference it has zero horizontal value, and the vertical value is its full magnitude which is 3.37A.

Using trig and the above diagram we can calculate the horizontal and vertical parts of the other two phase currents.

The Vertical component is the opposite side, and is calculated through:

$$\text{Opposite} = \sin(\text{angle}) \times \text{hypotenuse}$$

Whilst the Horizontal component is the adjacent side and is calculated as follows:

$$\text{Adjacent} = \cos(\text{angle}) \times \text{hypotenuse}$$

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Yellow Phase:

For the vertical value of the yellow phase the “adjacent” side must be discerned using trigonometry

$$\text{Opposite} = \sin(30) \times 2.72A = 1.36$$

And the horizontal is:

$$\text{Adjacent} = \cos(30) \times 2.72 = 2.36$$

In order to better illustrate this the diagram in figure 10 was created.

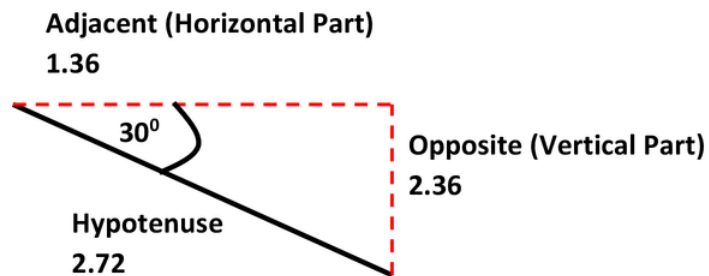


Figure 10: Yellow Phase Horizontal and Vertical Example

Blue Phase:

The same process used for calculating the yellow phase horizontal and verticals is repeated with the blue phase values substituted in.

Vertical:

$$\text{Opposite} = \sin(30) \times 1.93A = 0.965$$

Horizontal:

$$\text{Adjacent} = \cos(30) \times 1.93 = 1.67$$

Neutral Current:

Phase	Vertical	Horizontal
Red	3.37	0
Yellow	1.36	2.36
Blue	0.965	1.67

Table 5: All horizontal and vertical parts

Using the values in Table 5 the sum of the horizontals and verticals can be deduced.

Verticals:

$$3.37 - 1.36 - 0.965 = 1.045$$

Horizontals:

$$2.36 - 1.67 = 0.69$$

The formula for neutral current is:

$$I_{neutral} = \sqrt{vertical\ sum^2 + Horizontal\ sum^2}$$

$$\sqrt{1.045^2 + 0.69^2} = 1.2522A$$

In order to prove this result, a separate method was used to verify it, the scaled diagram shown in figure 11. The reason for the diagram not quite matching up is due to limitations in the resolution available when plotting the length of the lines in the software, thus all of the lines are out ever so slightly. But the diagram itself points towards the calculations being correct.

Good
explan
ations

To scale with a
ratio of 1:2 in
inches

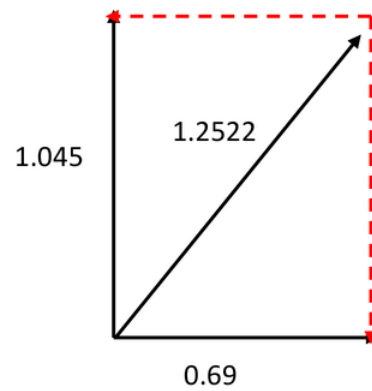


Figure 11: Scaled Phasor Diagram for neutral current

Very
good
work
with
trig
calcul
ations
.

Task 4:

Three phase power transmission is the standard worldwide due to the multitude of advantages it has over any alternative.

DC transmission is a very unappealing alternative due to its many disadvantages. The predominant disadvantage is the inability to transform DC voltages, as transformers work off of AC voltages (although means of changing DC voltages exist they are expensive and impractical). DC transmission gear is also very costly, including the switching gear. Similarly the transmission lines for DC have to feature much thicker cabling and therefore are more costly (Electrical Technology, 2014)

Single phase and two phase circuits have the negative that they do not provide constant power, which is crucial in most applications. Whereas three phase provides constant power at all times. By looking at Figure 12 and following the path of a single phase it can be plainly seen that single phase supplies would not yield constant power, whereas in three phase the multiple phases provide power when the other phases do not, overall providing continuous constant power.

Three phase is ideal as they can also be tapped to provide single phase supplies where needed, meaning that it can provide power to single phase and three phase systems easily. (Edvard, 2012)

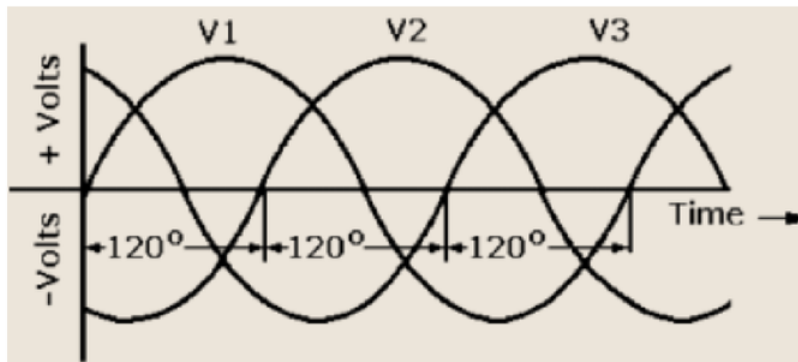


Figure 12: Three phase power sine wave (Edvard, 2012)

An important consideration in transmission is the costs of cabling, which is a major factor in why higher number polyphaser systems are not used for transmission, as more cables would be needed and this would turn out to be extremely costly.

Increasing the number of phases provides a cleaner supply, due to less losses from harmonics, but has diminishing returns past three phase. Upgrading from a single phase to two phase supply yields a 41.4% increase in the effective output of the system, and three phase yields a 50% increase. Increasing the number of phases past 3 yields only a 7% bonus in output. At this point the return on output efficiency and the cost of setting up the system is negligible. (study electrical, 2016)

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Three phase applications are prevalent in industry, which accounts for a large portion of the worlds energy usage. Three phase is ideal for supplying heavy duty motors, and other industrial equipment, whereas single phase would need heavy modification to supply them efficiently.

When comparing as a group it became evident that three phase was the clear choice for transmission due to its myriad of advantages. Its more economical than the alternatives due to installation and maintenance costs, and increasing the number of phases past three provides negligible returns for large costs. It can also supply single and two phase systems easily, which is ideal for domestic applications, whilst still providing the three phase needed for industry. Provides a cleaner supply, leading to increased life of equipment. The infrastructure for three phase transmission has been in place for a long time, and changing to a different polyphaser transmission system would cost an incredible amount of money, far more than could ever be saved by converting.

Good research

Task 5:

At its core power factor is the efficiency of an electrical engineering system, and is vitally important for a multitude of reasons. It is the ratio of the power put into the system (Apparent power) to the output power (true power) of a system, with the losses incurred through reactance (reactive power). The relationship of these three types of power is displayed in the power triangle, seen in Figure 13. In purely resistive loading there is no reactive power and therefore apparent power is equal to true power.

Whereas inductive and capacitive loads cause reactance in a system, with inductive loading causing a lagging current, and a capacitive causing a leading current. Therefore the two types of reactance oppose each other, which is a critical fact in power factor correction.

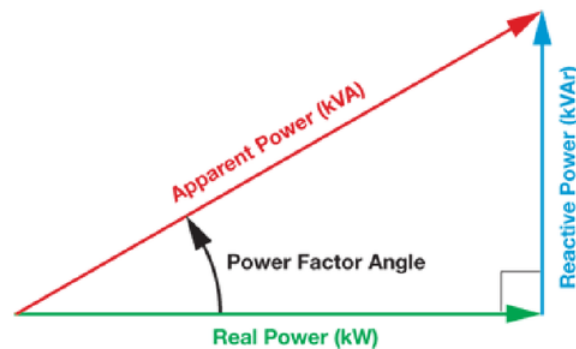


Figure 13: Power triangle (Trical Doubts, 2015)

Electrical companies also impose a tariff on customers with low power factor loading, and so from an industry standpoint it is vital to have a good power factor for the sake of efficiency and for profit.

Power factor correction is where an opposing reactive power is implemented in the system (typically capacitors added to an already inductive load such as motors) in order to bring the current back into phase and reduce reactive power, and therefore the losses in power. The goal of power factor correction is to make the apparent power as close to true power as possible (although a power factor of 1 is only theoretical and cannot be practically achieved).

Power factor correction can either be passive (as seen in Figure 14) or active (as seen in Figure 15). Passive PFC constantly filters the system, and requires larger inductors/capacitors. Whereas active PFC is capable of achieving a PF of up to 0.99 if properly utilised. (Ananthampalayam, 2013)

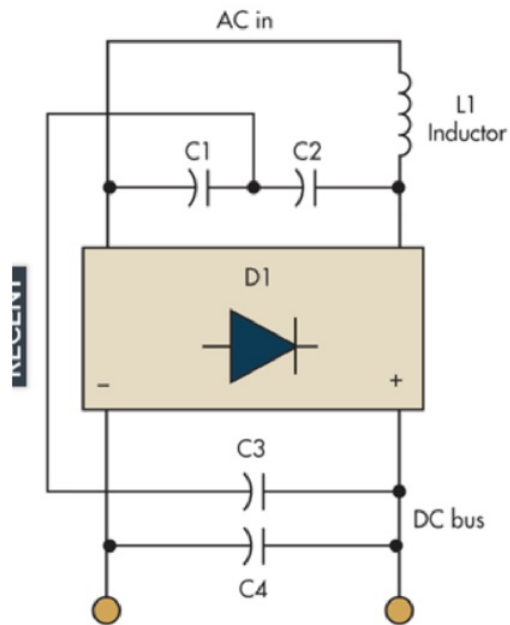


Figure 14: Passive power factor correction (Ananthampalayam, 2013)

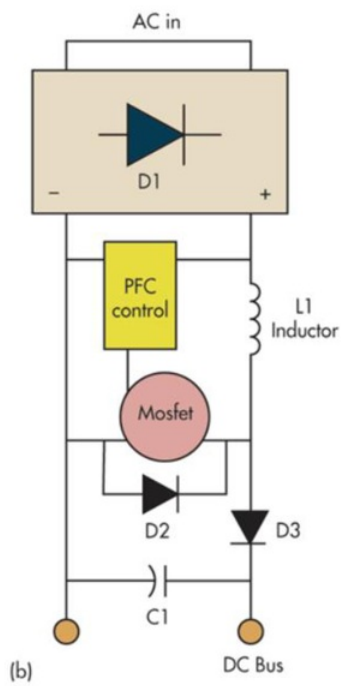


Figure 15: Active power factor correction (Ananthampalayam, 2013)

Task 6:

There are four configurations of star and delta for transformer applications, and are specifically used for certain applications depending on their properties.

Star-Star:

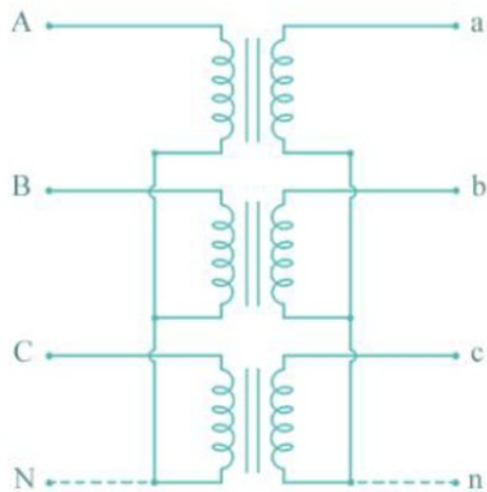


Figure 16: Star-Star transformer connections (Daware, 2018)

This configuration is typically employed in smaller high-voltage transformers. A reduced number of turns per phase is required due to the phase voltage being less than line voltage ($V_{ph} = V_L \times \sqrt{3}$), and due to this decreased phase voltage less insulation is required on the cabling making it ideal for more compact applications.

Star-Delta:

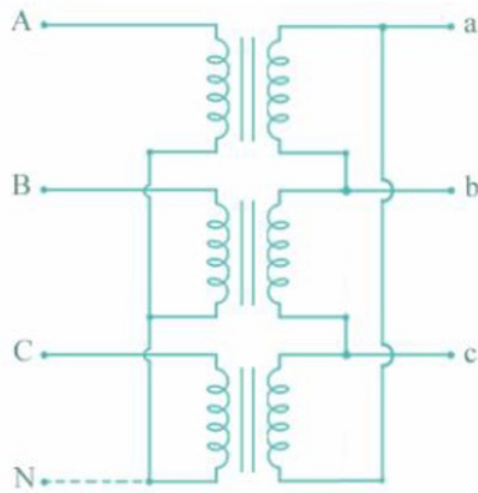


Figure 17: Star-Delta transformer connections (Daware, 2018)

Typically found utilised as step down transformers in substations on the transmission line.

Delta-Star:

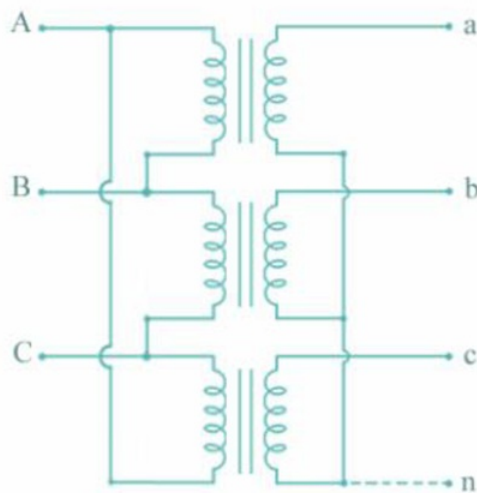


Figure 18: Delta-Star transformer connections (Daware, 2018)

The configuration preferred at the beginning of transmission for step up transformers, the opposite application to star-delta as they essentially have reversed properties due to them being the reverse of each other.

Delta-Delta:

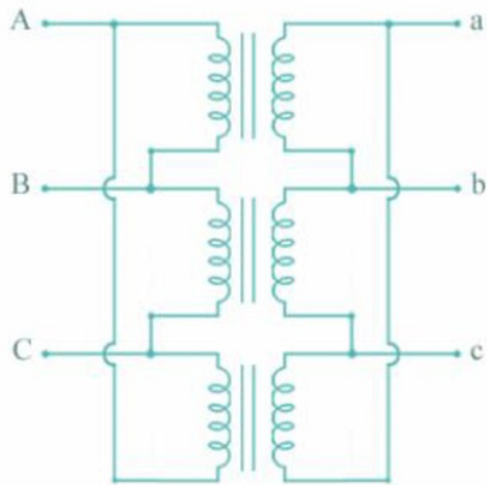


Figure 19: Delta-Delta transformer connections (Daware, 2018)

Primarily utilised for larger low voltage transformers.

(Daware, 2018)

Could have a little more explanation but answers the question.

Works Cited

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*Good relevant
sources*

PSDE 4001 Assignment 2

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

74/100

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

Text Comment. Good results and description of procedure

PAGE 8

Text Comment. Good explanation

PAGE 9

PAGE 10

Text Comment. Good calcs and explanation of procedure

PAGE 11

Text Comment. Good calcs and explanation

PAGE 12

PAGE 13

Text Comment. Good use of power triangles derived from results.

PAGE 14

Text Comment. Very good arguments for differences

PAGE 15

Text Comment. Good explanation of power factor characteristic

PAGE 16

PAGE 17

Text Comment. Good work with analysis

PAGE 18

PAGE 19

PAGE 20

Text Comment. Good explanations

PAGE 21

Text Comment. Very good work with trig calculations.

PAGE 22

PAGE 23

Text Comment. Good research

PAGE 24

Text Comment. Good explanation but would have benefitted with a calculation example.

PAGE 25

PAGE 26

PAGE 27

PAGE 28

Text Comment. Could have a little more explanation but answers the question.

PAGE 29

Text Comment. Good relevant sources

JAC WILLIAMS

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RESEARCH-INFORMED LITERATURE



Research is good. 3.5/5 Good sources used. 3.5/5

7/10

KNOWLEDGE AND UNDERSTANDING



Intro in practical tasks only. 2.5/5 Procedures are explained well. 4/5 Discussion of results is good. 8.5/10

15/20

ANALYSIS



Testing and analysis is excellent. 26/30 Lacks a conclusion but has conclusive discussions in the report. 3/10

29/40

PRACTICAL APPLICATION AND DEP.



All procedure are explained well. 4/5 Discussion of results are good. 4/5 Quality of work is very good. 8/10

16/20

SKILLS FOR PROFESSIONAL PRAC.

Report is very good. 4/5 Team work is good. 3/5

