Government of **Western Australia**
North Metropolitan **TAFE**

UEE 11 Training Package Support Material

(Non-Endorsed Component)

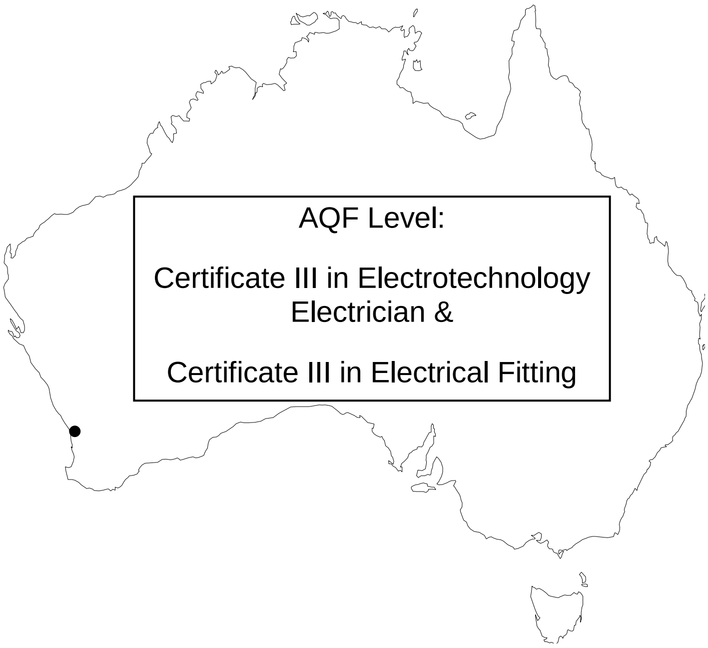
Based on:

National Electrotechnology Industry Standards

Resource Book

UEENEEG102A

Solve problems in low voltage a.c. circuits.



AQF Level:

Certificate III in Electrotechnology Electrician &

Certificate III in Electrical Fitting

North Metropolitan TAFE

Edited by J. Waswo / John Dickie

August 2018

Version 7– 08/2018

Acknowledgements

This Unit Guide has been prepared by North Metropolitan TAFE Lecturers.

It is intended for North Metropolitan TAFE students only.

Manager Publications and Distributions

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UEENEEG102A – Solve problems in low voltage a.c. circuits.

C O N T E N T S

Competency Standard Unit Elements and Performance Criteria UEENEEG102A

Work Performance Tasks for On-the-Job profiling (Q-tracker)

Learning and Assessment Plan

Assessment Strategy

Laboratory and Workshop Safety Instructions

Training Achievement Record

Name:	Student No:	App No
Employer:		College:

Activity	Topic	Date	Lecturer
Section 1 Work Sheet	Trigonometry and Pythagoras' Theorem		
Section 1 Additional	Basic Trigonometry		
Section 2 Work Sheet	The A.C. Waveform and Phasors		
Section 3 Work Sheet	The Oscilloscope		
Section 3 Project	RMS Value of A.C.		

Section 4 Work Sheet	Single Element A.C. Circuits		
Section 4 Project	Resistance in an A.C. Circuit		
Section 5 Work Sheet	R, L and C in Parallel		
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Section 5 Project 2	Resistance, Inductance and Capacitance in Parallel		
Section 5 Project 3	Varying Capacitance in a Parallel RLC Circuit		
Section 6 Work Sheet	R, L and C in Series		
Section 6 Project 1	An Inductor on A.C.		
Section 6 Project 2	Resistance, Inductance and Capacitance in Series		
Section 7 Work Sheet	Power Factor Improvement		
Section 7 Project	Power Factor in a Single 36 W Fluorescent Circuit		
Section 8 Work Sheet	Three phase Circuits		
Section 8 Project 1	Three Phase Star and Delta Circuits		
Section 8 Project 2	Out-of-balance Current in the Neutral		
Section 9 Work Sheet	Three Phase Power and Energy Measurement		
Section 9 Project	Three Phase Power Measurement		
Section 10 Work Sheet	Voltage Drop and Earth Fault-loop Impedance		
Section 10 Activity	Earth Fault-loop Impedance Measurement		

Competency Standard Units

UEENEEG102A – Solve problems in low voltage a.c. circuits.

Prerequisite Units

Granting competency in this unit shall be made only after competency in the following units have been confirmed:

UEENEEE101A – Apply occupational health and safety regulations, codes and practices in the workplace.

UEENEEE104A – Solve problems in D.C. circuits.

UEENEEG101A – Solve problems in electromagnetic devices and related circuits.

ELEMENT		**PERFORMANCE CRITERIA**	
1	Prepare to solve low voltage a.c. circuit problems.	1.1	OHS procedures for a given work area are identified, obtained and understood.
		1.2	Established OHS risk control measures and procedures in preparation for the work are followed.
		1.3	Safety hazards, which have not previously been identified, are noted and established risk control measures are implemented.
		1.4	The nature of the circuit(s) problem is obtained from documentation or from work supervisor to establish the scope of work to be undertaken.
		1.5	Advice is sought from the work supervisor to ensure the work is coordinated effectively with others.
		1.6	Sources of materials that may be required for the work are established in accordance with established procedures.
		1.7	Tools, equipment and testing devices needed to carry out the work are obtained and checked for correct operation and safety.

ELEMENT		PERFORMANCE CRITERIA	
2	Solve low voltage a.c. circuit problems.	2.1	OHS risk control measures and procedures for carrying out the work are followed.
		2.2	The need to test or measure live is determined in strict accordance with OHS requirements and when necessary conducted within established safety procedures.
		2.3	Circuits/machines/plant are checked as being isolated where necessary in strict accordance OHS requirements and procedures.
		2.4	Established methods are used to solve circuit problems from measure and calculated values as they apply to single and three-phase low voltage circuit.
		2.5	Unexpected situations are dealt with safely and with the approval of an authorised person.
		2.6	Problems are solved without damage to apparatus, circuits, the surrounding environment or services and using sustainable energy practices.
3	Complete work and document problem solving activities.	3.1	OHS work completion risk control measures and procedures are followed.
		3.2	Work site is cleaned and made safe in accordance with established procedures.
		3.3	Justification for solutions used to solve circuit problems is documented.
		3.4	Work completion is documented and an appropriate person or persons notified in accordance with established procedures.

Required Skills and Knowledge

This describes the essential skills and knowledge and their level, required for this unit.**KS01-EG102A Alternating current power circuits**

Evidence shall show an understanding of alternating currents power circuits to an extent indicated by the following aspects:

T1 Alternating Current Quantities encompassing:

- sine, cosine and tangent ratios of a right angle triangle
- Pythagoras Theorem to a right angle triangle.
- use of the CRO to measure d.c. and a.c. voltage levels
- sinusoidal voltage generated by a single turn coil rotated in a uniform magnetic fields
- terms 'period', 'maximum value', 'peak-to-peak value', 'instantaneous value', 'average value', 'root-mean-square (r.m.s.) value', in relation to a sinusoidal waveform.
- calculation of the instantaneous value of induced voltage of a generated sinusoidal waveform.
- measurement of instantaneous, peak, peak-to-peak values and the period of a sinusoidal waveform.
- calculation of root-mean-square (r.m.s.) value and frequency of a sinusoidal waveform from values of peak voltage and period.

T2 Phasors Diagrams encompassing:

- purpose of phasor diagrams
- 'in-phase', 'out-of-phase', 'phase angle'' lead' and 'lag'.
- phase angle between two or more alternating quantities from a given sinusoidal waveform diagram.
- convention for representing voltage, current and the reference quantity in a phasor diagram.
- drawing phasor diagrams to show the relationship between two or more a.c. values of voltage and/or current.
- determination of phase relationship between two or more sinusoidal waveforms from a given diagram and measurements.

T3 Single Element a.c. circuits encompassing:

- setting up and connect a single-source resistive a.c. circuit and take voltage and current measurements to determine the resistance
- determining the voltage, current resistances from measure of given values of any tow of these qualities.
- relationship between voltage drops and current in resistive a.c. circuit
- applications of resistive a.c. circuits
- defining ‘inductive reactance’.
- calculation of inductive reactance for a given inductor and the relationship between inductive reactance and frequency.
- applying Ohm’s Law to determine voltage, current of inductive reactance in a purely inductive a.c. circuit given any two to these quantities.
- applications of inductive a.c circuits.
- calculation of capacitive reactance
- applying Ohm’s Law to determine voltage, current or capacitive reactance in a purely capacitive a.c circuit given any two of the quantities.
- applications of capacitive a.c circuits

T4 RC and RL Series a.c. circuits encompassing:

- impedance and impedance triangle.
- determining the impedance, current and voltages for a series RC circuit given the resistance, capacitance and supply voltage.
- drawing and labelling the impedance triangle for a series RC circuit
- drawing phasor diagrams for a series RC circuit
- AS/NZS 3000 requirements for the installation of capacitors.
- examples of capacitive components in power circuits and systems and the effect on the phase relationship between voltage and current.

- determining the impedance, current and voltages for a series RL circuit given the resistance, inductance and supply voltage.
- drawing and labelling the impedance triangle for a series RL circuit
- drawing the equivalent circuit of a practical inductor
- Draw phasor diagrams for a series RL circuit.
- examples of inductive components in power circuits and systems and describe their effect on the phase relationship between voltage and current

T5 RLC Series a.c. circuits encompassing:

- measuring component voltages in a series RLC circuit and using a phasor diagram to determine the supply voltage and phase angle between circuit voltage and circuit current.
- determining the impedance, current and voltages for a series RLC circuit given resistance, inductance, capacitance and supply voltage.
- drawing and labelling the impedance triangle for a series RLC circuit.
- calculation of total impedance for a series RLC circuit.
- calculation of voltage drop for cables using the values for reactance and a.c. resistance from AS/NZS 3008.
- comparison of current limiting characteristics of inductors and resistors.
- practical examples of RLC series circuits

T6 Parallel a.c. Circuits encompassing:

- determining the branch currents of a parallel circuit that contain RL, RC or LC in two branches.
- using a phasor diagram to determine the total circuit current and phase angle in parallel RL, RC or LC circuits.
- determining the total circuit impedance of parallel RL, RC or LC circuits.
- measuring the branch currents in a parallel RLC circuit and use a phasor diagram to determine the total current and phase angle between circuit voltage and circuit current.
- determining the branch impedances, branch currents and phase angles voltages for a parallel RLC circuit given resistance, inductance, capacitance and supply voltage.
- calculation of impedance for a parallel RLC circuit.
- practical examples of parallel circuits.

T7 Power in an a.c. circuit encompassing:

- difference between true power, apparent power and reactive power and the units in which these quantities are measured.
- drawing the power triangle to show the relationships between true power, apparent power and reactive power
- defining the term "power factor" and phase angle.
- methods used to measure single phase power, energy and demand.

T8 Power Factor Improvement encompassing:

- effects of low power factor.
- requirements for power factor improvement.
- methods used to improve low power factor of an installation.
- local supply authority and AS/NZS 3000 wiring rules requirements regarding the power factor of an installation and power factor improvement equipment.
- methods used to measure single phase power factor.
- using manufacturers catalogues to select power factor equipment for a particular installation

T9 Harmonics and Resonance Effect in a.c. Systems encompassing:

- term "harmonic" in relation to the sinusoidal waveform of an a.c. power system.
- sources in a.c. systems that produce harmonics.
- problems that may arise in a.c. circuits as a result of harmonics and how these are overcome.
- methods and test equipment used to test for harmonics

- methods used to reduce harmonics in a.c. power system
- conditions in a series a.c. circuit that produce resonance.
- dangers of series resonance circuits
- conditions in a parallel a.c. circuit that produce resonance.
- dangers of parallel resonance circuits
- AS/NZS3000 and the local supply authority requirements concerning harmonics and resonance effect in a.c. power systems.

T10 Three Phase Systems encompassing:

- features of a multiphase system.
- comparison of voltages generated by single and multiphase alternators.
- reasons for the adoption of three phases for power systems.
- how three phases is generated in a single alternator.
- Calculation of r.m.s. value of voltage generated in each phase given the maximum value.
- relationship between the phase voltages generated in a three phase alternator and the conventions for identifying each.
- term "phase sequence" (also, referred to as "phase rotation").
- determining the phase sequence of a three phase supply

T11 Three phase star-connections encompassing:

- connecting a three phase star-connection load.
- phase relationship between line and phase voltages and line and phase currents of a star-connected system.
- determining the r.m.s. value of line and phase voltage given any one of these quantities.
- determining the r.m.s. value of line and phase current given any one of these quantities.
- terms "balanced load" and "unbalanced load".
- effect of a reversed phase winding of a star connected alternator.
- example of balanced and unbalanced loads in typical power systems.

T12 Three phase four wire systems encompassing:

- purpose of the neutral conductor in a three phase four wire systems.
- determining the effects of an high impedance in the neutral conductor of a three phase four wire system supplying an unbalanced load where MEN earthing is employed.
- determining the value and phase relationship of neutral current in an unbalanced three phase four wire systems given line currents and power factors.
- AS/NZS 3000 requirements regarding neutral conductors.
- AS/NZS 3008.1.1 method for determining voltage drop in unbalanced three phase circuits

T13 Three phase delta-connections and Interconnected systems encompassing:

- connecting three phase delta loads.
- phase relationship between line and phase voltages and line and phase currents of a delta-connected system.
- determining the r.m.s. value of line and phase voltage given any one of these quantities.
- determining the r.m.s. value of line and phase current given any one of these quantities.
- limitations and uses of open delta connections
- effect of a reversed phase winding of a delta connected transformer
- example of loads in typical power systems.
- drawing the typical combinations of three phase interconnected systems using star-connections and a delta-connection.
- relationship between line and phase voltages and line and phase currents in the typical interconnected systems using star-connections and delta-connections.

T14 Energy and power requirements of a.c. systems encompassing:

- purposes for measuring power, energy, power factor and maximum demand of a.c. power systems and loads.

- difference between true power, apparent power and reactive power and the units in which these quantities are measured in a three phase system.
- drawing the power triangle to show the relationships between true power, apparent power and reactive power in a three phase system.
- methods used to measure three phase power , energy, power factor and demand.
- determining how the power factor of a three phase installation can be improved.
- using manufacturers catalogues to select measurement equipment for a particular installation

T15 Fault Loop Impedance encompassing:

- term fault loop impedance of a a.c. power system
- determining fault loop impedance using resistance and reactance values from AS/NZS 3008.1.1
- measuring fault loop impedance of typical circuits
- procedures for testing fault loop impedance

G102A Work Performance Tasks – (Q Tracker tasks):

20 hours of on-the-job training

UEENEEG102A – Solve problems in a.c. circuits

1. Performance requirements:

1a. Related to the following elements:

1. Prepare to solve low voltage a.c. circuit problems.
2. Solve low voltage a.c. circuit problems.
3. Complete work and document problem solving activities.

1b. For each element demonstrate performance:

− across a representative body of performance criteria,

− on at least 2 occasions,

− autonomously and to requirements,

− within the timeframes typically expected of the discipline, work function and industrial environment.

2. Representative range includes the following:

All listed tasks related to performance across a representative range of contexts from the prescribed items below:

The minimum number of items on which skill is to be demonstrated		**Item List**
Group No		
A.	At least two of the following:	**Problem solving on AC circuits**
		• Determining the operation parameters of existing circuits.
		• Altering an existing circuit to comply with specified operating parameters.

		• Determine the cause of low power factor in an existing circuit. • Determining conditions causing an existing circuit to be unsafe includes electric shock hazard from indirect contact with conductive parts, insufficient low impedance of a fault current path and inadequate fault protection.
B.	All of the following: **Single phase circuits**	
		• Connecting single-phase circuits • Choosing correct instruments • Taking measurements correctly and accurately.
C.	All of the following: **Three-phase circuits**	
		• Connecting three-phase circuits • Choosing correct instruments • Taking measurements correctly and accurately.
D.	And at least four of the following: **Applications**	
		• Series ac circuits • Parallel ac circuits • Series / parallel ac circuits • Single phase motors / controls • Three phase motors / controls • Synchronous machines • Transformers / Auxiliary components • Star connected circuits • Delta connected circuits • Star-Delta interconnected circuits • Open Delta circuits

Workplace Rules:

Rule 1	Follow the instructions
Rule 2	Tolerate ambiguity
Rule 3	Meet your obligations

Note: This information and current details of critical aspects for each competency standard unit (CSU) in this qualification can be found at the Australian Training Standards website www.training.gov.au.

UEENEEG102A – Solve problems in a.c. circuits.

Learning and Assessment Plan

Name of Lecturer: ____

Contact Details: ____

Delivery Mode/s: □ Face to Face □ On-Line □ Blended Delivery □ Other

Using:

Session	Nominal Duration	**Program of Work (Topics to be covered)**	**Primary Reference**
1	1 hour	Introduction to UEENEEG102A Recognition of Prior Learning of CSU	Resource Book
2	3 hours	Trigonometrical functions Trig Ratios, inverse Trig functions, Pythagoras' theorem, special triangles	Resource Book
3	4 hours	AC Wave forms and Phasors	Resource Book
4	2 hours	Oscilloscope	Resource Book
5	6 hours	Single Element a.c. Circuits	Resource Book
6	8 hours	Parallel a.c. Circuits	Resource Book
7	8 hours	Series a.c. Circuits	Resource Book
8	4 hours	Revision	Resource Book
9	4 hours	**PART A Written Assessment and Observed Practical Assessment**	KS01-EG102A Alternating current power circuits
10	4 hours	Power Factor Improvement	Resource Book
11	16 hours	Three Phase Systems	Resource Book
12	4 hours	Three Phase Power and Energy Measurement	Resource Book
13	4 hours	Using AS/NZS 3008.1.1 to calculate voltage drop and fault loop impedance	Resource Book
14	4 hours	**PART B Written Assessment and Observed Practical Assessment**	KS01-EG102A Alternating current power circuits

<table>
<tr><td colspan="3">I acknowledge that I have received and read this Learning and Assessment Plan

Student Name:______________________ Signature: ____________________
Date: _________</td></tr>
<tr><td>Lecturer Name</td><td>Lecturer Signature</td><td>Date</td></tr>
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Assessment Strategy

Conditions of Assessment:

Normally learning and assessment will take place in an integrated classroom/ laboratory environment.

It is essential to work through the worksheets and activities in this workbook and follow the guidance of your lecturer. The worksheets and practical activities will provide the required skills and knowledge outlined in this Unit and assist you in achieving competency.

Assessment Methods:

Resource Book - The satisfactory completion of all worksheets and practical activities is required.

Written Theory Assessment – based on the **REQUIRED SKILLS AND KNOWLEDGE**. You must achieve a mark of 75% or more in this assessment.

Observed Practical Assessment – based on the Elements and Performance Criteria of this Competency Unit UEENEEG102A. You must achieve a mark of 100% in this assessment.

On-Job-Training:

It is expected that the off-job component of this competency unit will be complemented by appropriate on-job development involving exposure to re-occurring workplace events and supervised experiences. (See Work Performance Tasks). You are required to log your on-the-job training in your on line 'Q-Tracker' account.

Sufficiency of Evidence:

In all instances competency is to be attributed on evidence sufficient to show that a person has the necessary skills required for the scope of work. These include:

- Task skills - performing individual tasks
- Task management skills - managing a number of different tasks
- Contingency management skills - responding to irregularities and breakdowns in routines
- Job/role environment skills - dealing with the responsibilities and expectations of the work environment including working with others.

Evidence must demonstrate that an individual can perform competently across the specified range of activities and has the essential knowledge, understanding and associated skills underpinning the competency.

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Danger Tag Procedure

Use of Danger Tags

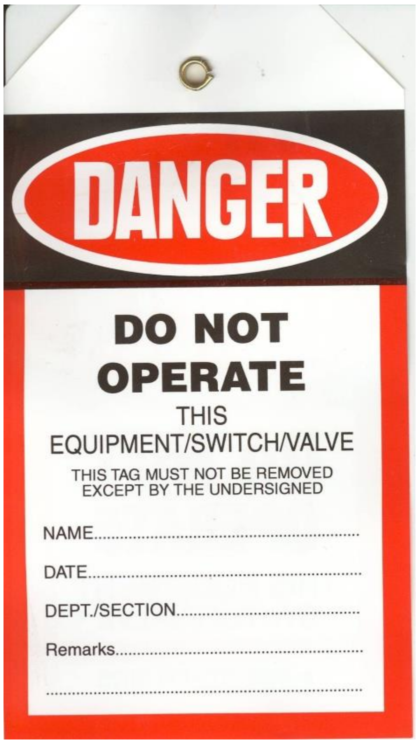
If you have a practical task to do and there is a possibility that you could be injured if someone turns on the electricity, then you **MUST** fasten a red danger tag to the machine main isolation switch, circuit-breaker or the equipment plug top.

Each danger tag you use must clearly show; your name, your section (class) and the date.

Nobody must operate the danger tagged switch or control point until the job is made safe and the danger tag has been removed.

Your lecturer will check your task before you are allowed to remove your danger tag.

Only the person, who is named on the tag and attached the tag, is allowed to remove it.



Points to Watch

Make absolutely sure the switch/circuit-breaker/plug top is the correct one to tag. If you have any doubts, ask your lecturer.

Make sure that you have switched the isolator to **OFF** position before you attach your danger tag.

Fasten the danger tag securely.

The purpose of using Danger Tags is to prevent electrical accidents from happening.

Failure to follow Danger Tag Procedures when working on practical activities and practical assessments will result in a **not yet competent** comment recorded for this Unit of Competency – UEENEEG102A

Student's Signature ___________________________ Date: __________________

LABORATORY and WORKSHOP SAFETY INSTRUCTIONS

Students working in laboratories, workshops and installation skills areas at this college do so on the condition that they agree to abide by the following safety instructions. Failure to observe the safety instructions may result in immediate suspension.

1. Personally owned eye protection must be worn AT ALL TIMES where eye protection signs are displayed. Other safety equipment including hearing protection must be worn when applicable to a particular task.
2. Loose clothing must not be worn when working on fixed or portable machines. Hairnets must be worn where applicable. Clothing must cover the upper arms and body.
3. **Safety boots or safety shoes** must be worn at all times on this campus. Thongs or sandals are not permitted.
4. Tools and safety equipment are issued from the tool store on request. It is your responsibility to ask for the correct item (Size, Type and Tool). Check to see that you have been given the correct item before using it. If in doubt ask your LECTURER, not the store person.
5. Report any broken, damaged or unserviceable equipment to your Lecturer. Do not use damaged tools or machines.
6. Clean down the machines immediately after use. All tools must be cleaned before returning them to the store.
7. Skylarking is not permitted at any time.
8. Danger Tag procedures must be followed during all practical activities of this unit.
9. Accidents resulting in cuts, abrasions or other personal injury must be reported to your Lecturer immediately - no matter how minor they may seem. A first-aid kit is available in the tool store.
10. Never leave a machine unattended when it is running. Do not allow yourself to be distracted when operating a machine.
11. Read all safety signs and notices and follow the instructions.
12. Do not use a fixed or portable machine unless you have been instructed in its proper use.
13. Read all risk assessment documentation provided (JSAs) and conduct a relevant risk assessment process before performing any task.

Student's Signature ________________________ Date: ________________

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 1 Introduction	G102A JW/JD DEC 2013

Trigonometry and Pythagoras' Theorem

Task:

To perform trigonometrical calculations related to electrical trade's a.c. theory as applied to right-angled triangles.

Why:

The study of alternating current circuits which have inductive and capacitive components, involves currents and voltages which are not occurring at the same time in a given circuit. They are said to be out of phase. Trigonometrical techniques are a convenient method of analysing the behaviour of such circuits, and calculating circuit values.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in written assessments.

2. You must satisfactorily complete the set laboratory tasks.

3. You must achieve 100% in a final practical competency assessment.

Equipment:

Scientific Calculator
300mm ruler
Drawing Protractor
5mm square graph paper

References:

- Electrical Principles for the Electrical Trades, J.R. Jenneson
- AS/NZS 3000-2018
- WAER

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 1 Study Guide	G102A JW/JD DEC 2013

Trigonometry and the A.C Waveform

Suggested Self Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades

Section 1.6 Trigonometry

2. Read the Summary and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.
3. Answer the questions given on the Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.
4. Complete the projects in this manual.
5. Submit your answers on the Work Sheet to your Lecturer for discussion and assessment.

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 1 Summary	G102A JW/JD DEC 2013

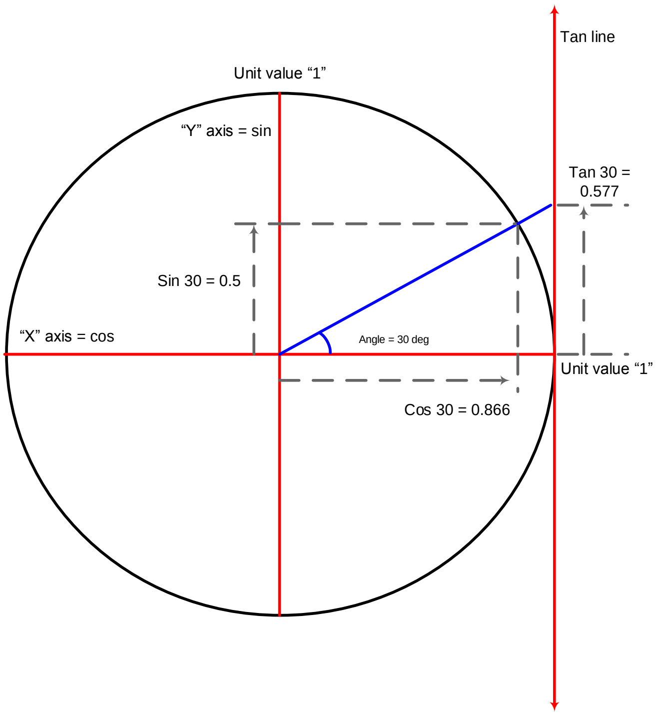
Trigonometry and Pythagoras' Theorem

1. Trigonometry is a branch of mathematics which deals with the relationships which exist between the sides and angles of triangles. In alternating current circuits, currents and voltages are out of phase with each other, so Trigonometry is often used as a means of analysing such circuits.

2. Most of the Trigonometry used for electrical trades purposes involves triangles which have a right angle (90°) as one of the internal (or 'included') angles – these triangles are known as 'right-angled triangles' or 'right triangles'.

Definitions

3. ***Sin***: Defines the value of an angle on the "y" or vertical axis. We use the ***sin*** function to define the output voltage of an alternator at any given point in time by the equation $\boldsymbol{V_{ins} = V_{peak}\, sin\theta}$. We view the vector as starting at zero degrees and rotating counter clockwise as the alternator turns through its 360^0 rotation. By multiplying the sin of the angle by the peak output we can calculate the voltage output at any point in time throughout the whole 360^0 cycle.
4. ***Cos***: Defines the value of an angle on the "x" axis. We use the ***cos*** function to define the true power when calculating power factor and other power related functions. By multiplying the cos of the angle by the apparent power we can calculate the true or real power because this is the resistive part of the load which appears on the "x" axis. So by defining the value of the apparent power at a certain phase angle using the ***cos*** function we are able to define true power. Equation as follows.
$\boldsymbol{Power_{true} = V\ x\ I\ cos\theta}$
5. **Tan**: Defines the value of an angle on a line that intersects with the circumference of the circle and runs parallel to the "y" axis. Hence ***tan*** can have a value greater than one as it is outside the unit circle. The ***tan*** of 90^0 cannot be calculated because that angle is parallel to the ***tan*** line outside the circle and as such they can never intersect.



Angles

6. An angle is generated by rotating a line about its end point from some initial point. The customary unit of angular rotation for electrical trade's purposes is the degree. If the line OA is rotated about its end point for one complete revolution, the generated angle is 360°, and point A generates a circle.

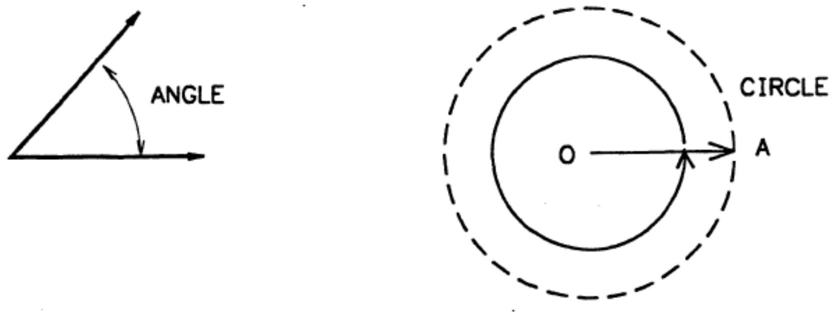


Figure 1 – Angle and Circle

7. If the direction of rotation is anti-clockwise, a positive angle is generated; if the direction of rotation is clockwise, a negative angle is generated.

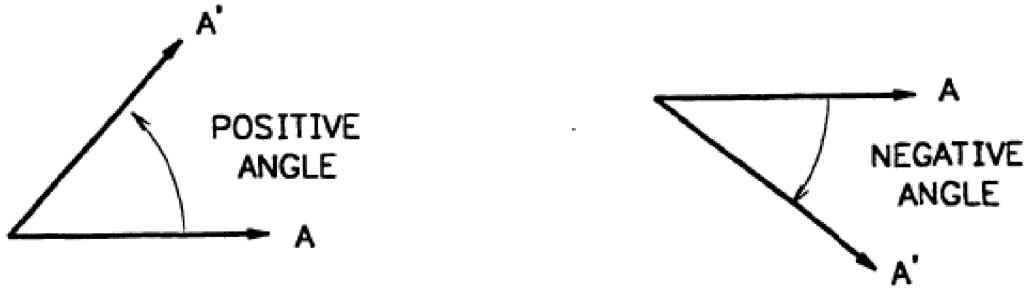


Figure 2 – Positive and Negative angles

Triangles

8. A typical right triangle is produced by rotating a horizontal line (OA) about its end point for a given number of degrees, then drawing a vertical line from A to the initial horizontal axis. It is often useful to show the triangle in relation to a circle divided into four quadrants on a Cartesian Plane, with the centre of rotation at the junction of the X and Y axes (the origin), and a radius equal to the length of the line OA – as shown below.

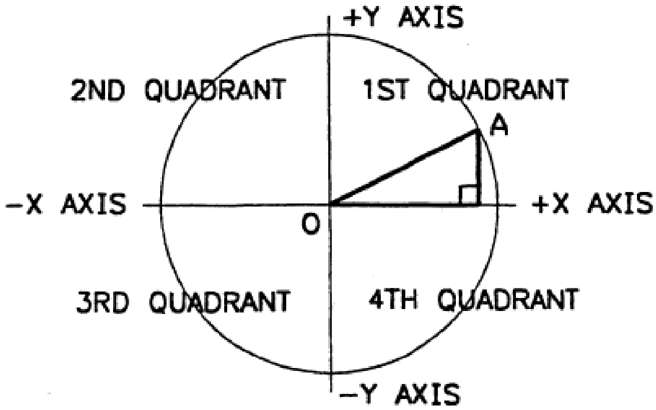


Figure 3 – Cartesian Plane

9. The sum of the internal angles of any triangle is 180°, so if one of the angles is a right angle, the sum of the other two angles must be 90°. Angles which add up to 90° are said to be 'complementary'. An angle which is less than a right angle is called an 'acute' angle. If one of the acute angles of a right triangle is 30°, the other must be 60° (the 'complement' of 30° is 60°). A right triangle must always consist of one right angle and two acute angles. The right angle is often identified by drawing two sides of a square at the right angle.

10. It is customary to name a triangle by assigning letters to each of the angles, sides or angles. Upper case letters are usually used to name the angles, and the Greek Letters Phi (Φ) and Theta (ϴ) are usually used to name the acute internal angles. The side of a triangle is named using the same letter as the angle opposite to it, but in lower case. The right triangle shown in Figure 1 has internal angles named A, B and C, sides named a, b, c, and the two internal acute angles are named Φ and ϴ.

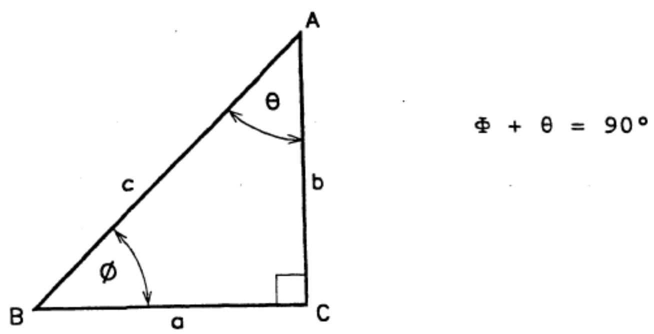


Figure 4 – Names of the parts of a right triangle

11. For trigonometrical purposes, the sides of a right triangle are given general names with respect to a specified internal reference angle. The longest side (the side opposite the right angle) is always called the HYPOTENUSE (HYP). The side opposite the reference angle is called the OPPOSITE (OPP), and the side next to the reference angle is called the ADJACENT (ADJ). Figure 5 shows the trigonometrical names of the sides with respect to the angle Φ.

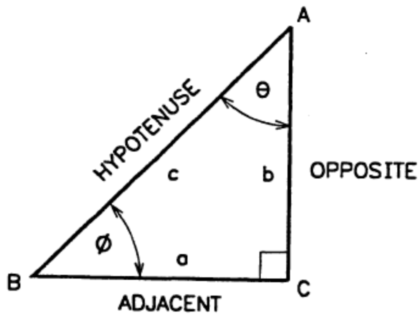


Figure 5 – The trigonometrical names of the sides of a right triangle

12. In any right triangle the ratio between any two sides is constant with respect to a given internal angle, regardless of the size of the triangle.

13. Consider the two right triangles shown in Figure 3. Draw any vertical line up from the side adjacent to Φ until it meets the hypotenuse. Measure the length of the vertical line, and the distance from the start of the angle Φ to the point on the adjacent at which the vertical line begins. Regardless of the length of the vertical (opposite) line, the ratio between the opposite side and the adjacent side (with respect to Φ) remains the same. The same effect occurs between any two sides of a given right triangle – the ratio between any two sides with respect to a nominated angle remains constant regardless of the size of the triangle.

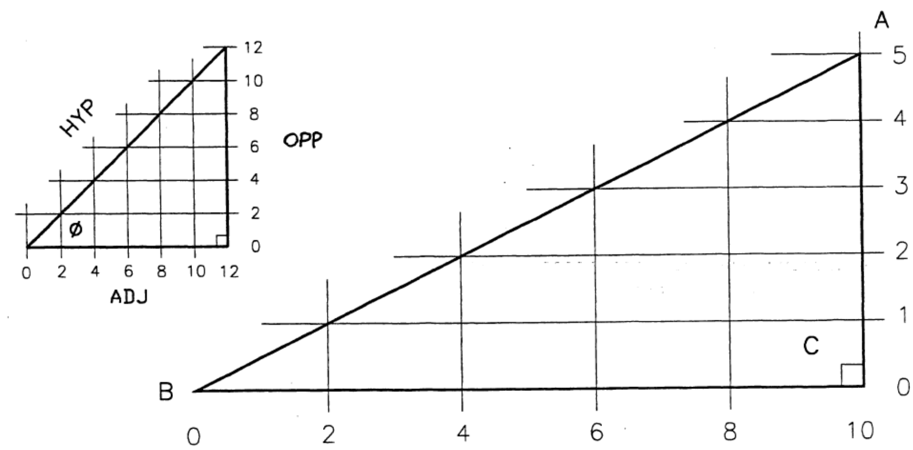


Figure 6 – Right triangles

Trigonometrical Ratios

14. Since a triangle has three sides, there are six possible combinations of sides with respect to each of the internal angles. The six possible combinations are known as the trigonometrical ratios and each one is given a special name. The name and definitions of the six trigonometrical (trig) ratios are:

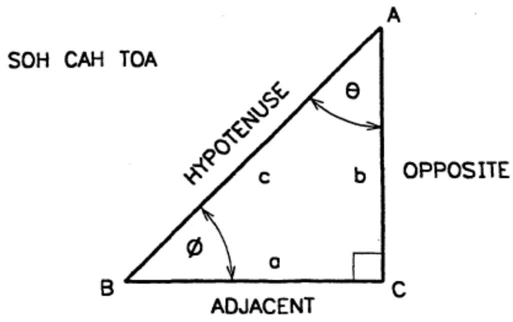


Figure 7 – Trigonometrical ratios

$$\text{Sine}\,\phi = \frac{\text{Opposite}}{\text{Hypotenuse}} \qquad \text{Cosecant}\,\phi = \frac{\text{Hypotenuse}}{\text{Adjacent}}$$

$$\text{Cosine}\,\phi = \frac{\text{Adjacent}}{\text{Hypotenuse}} \qquad \text{Secant}\,\phi = \frac{\text{Hypotenuse}}{\text{Adjacent}}$$

$$\text{Tangent}\,\phi = \frac{\text{Opposite}}{\text{Adjacent}} \qquad \text{Cotangent}\,\phi = \frac{\text{Adjacent}}{\text{Opposite}}$$

15. For electrical trades purposes it is usually only necessary to use three of these ratios – SIN, COS and TAN. You will need to memorise the ratios for SIN, COS and TAN before you can perform trigonometrical calculations relating to a.c. For the purposes of this module, all triangles are assumed to be right triangles unless otherwise stated.

16. The ratio between the sides in any right triangle in which the reference angle is known, can be found using a scientific calculator or trigonometrical tables. You need to make sure that your calculator is set to ‘degrees’ (most scientific calculators have provision for angular measure in degrees or radians).

17. **Examples**

   a. What is the ratio between the opposite side and the hypotenuse in a right triangle if the reference angle is 30°?

   Solution:

   $\text{Sin } 30° = \frac{\text{Opposite}}{\text{Hypotenuse}}$ (By definition)

   $\text{Sin } 30° = 0.5$ (Using a calculator)

   b. What is the cosine of 30º?

   Solution:

   $\text{Cos } 30° = 0.866$ (Using a calculator)

18. **Exercises**

Use a scientific calculator to determine the values indicated below. (The symbol ' means minutes, where 1 minute is 1/60th of a degree). Round your answer to two decimal places if applicable:

a. What is the sine of 25º? ____________________

b. What is the cosine of 103º? ____________________

c. What is the tangent of 25º? ____________________

d. What is the sine of 325º? ____________________

e. What is the cosine of 90º? ____________________

f. What is the tangent of 90º? ____________________

g. What is the sine of 25º 30'? ____________________

h. What is the cosine of 90º? ____________________

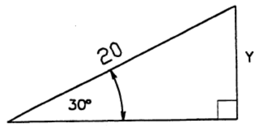
i. What is the sine of 0º? ____________________

j. What is the cosine of 0º? ____________________

19. One of the major uses of trigonometry in electrical trade's calculations, is to find the length of the sides of a right triangle when given the length of one side and an internal angle. You should not attempt to perform these calculations until you have memorised the definitions of the ratios:- sine (opp/hyp), cosine (adj/hyp) and tangent (opp/adj).

20. **Example 1**

Find the length of y in the following right triangle. (Note: You should always draw a neat freehand sketch of the problem.)



a. Express the unknown side and the known side as a fraction (ratio) with the unknown side as the denominator (on top line) if possible. $\frac{y}{20}$

b. Determine the trig ratio which is equivalent to the fraction (sine, cos or tan only). $\sin 30^{\circ}$

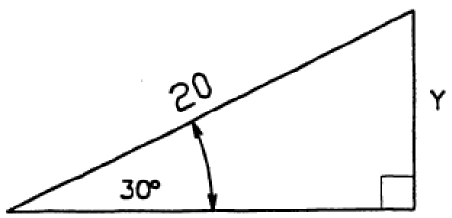
c. Express the relationship as a mathematical equation. $\sin 30^{\circ} = \frac{y}{20}$

d. Transpose the equation leaving the unknown value on the left side of the equation. $y = 20 \times \sin 30^{\circ}$

e. Use your calculator to determine the ratio applicable to the given angle. $y = 20 \times 0.5$

f. Express the answer in convenient units. $y = 10$

In practice, some of the steps above can often be done mentally, so the calculation would look like this (note that you should always draw a diagram first so that you have a visual picture of what you are trying to calculate):



$$\sin 30^{\circ} = \frac{y}{20}$$

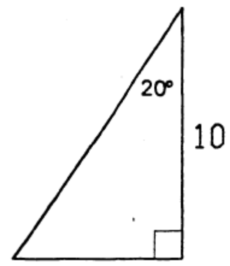
$$y = 20 \times \sin 30^{\circ}$$

$$y = 10$$

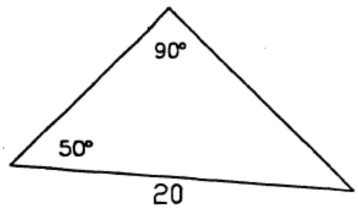
21. **Exercises**

Find the length of the two unknown sides in the following examples (using trigonometry).

a.



b.



Inverse Trigonometrical Functions

22. In many electrical calculations, two of the sides of a right triangle are known, and it is necessary to find the angle between them. In these cases it is necessary to find the numerical value of the ratio between the two sides, then find the angle which has that ratio.

23. The process of finding the angle which has a given trigonometrical ratio, is known as an inverse function, and it has a special symbol.

$\sin^{-1}$ 0.5 means 'the angle which has a sine of 0.5'

24. To find the angle which has a sine of 0.5:

    a. Enter the number 0.5

    b. Press the INVERSE SINE function on your calculator (Different brands of calculator use different symbols for this function).

    $\sin^{-1} 0.5 = 30^\circ$

25. **Exercises**

In the following exercises it is assumed that all angles required are between 0º and 90º.

a. What angle has a cosine of 0.866? __________________

b. What angle has a tangent of 0.707? __________________

c. What angle has a sine of 0.97? __________________

d. $\sin^{-1} 0.37 =$ __________________

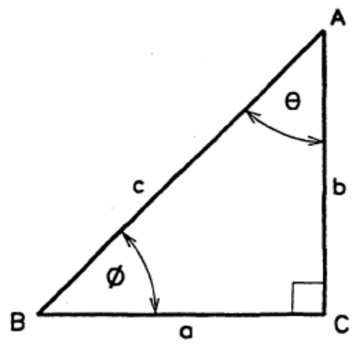
e. $\cos^{-1} 0.95 =$ __________________

f. $\tan^{-1} 2.4 =$ __________________

Pythagoras' Theorem

26. There is a definite relationship between the three sides of a right-angle triangle. This relationship is known as Pythagoras' Theorem, which states:

The square of the hypotenuse of a right angle triangle is equal to the sum of the squares of the other two sides.



$\Phi + \theta = 90°$

$c^2 = a^2 + b^2$

$c = \sqrt{a^2 + b^2}$ and

$a = \sqrt{c^2 - b^2}$ and

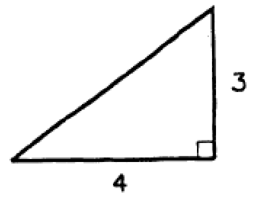
$b = \sqrt{c^2 - a^2}$

27. From this we can develop formulas which enable us to calculate any one side of a right triangle, provided the lengths of the other two sides are known.

28. **Examples**

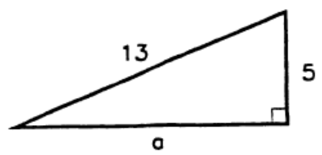
a. The two shortest sides of a right triangle are 3 units and 4 units respectively. What is the length of the hypotenuse?

$$
\begin{aligned}
c &= \sqrt{a^2 + b^2} \\
&= \sqrt{3^2 + 4^2} \\
&= \sqrt{9 + 16} \\
&= \sqrt{25} \\
c &= 5 \text{ units}
\end{aligned}
$$



b. The length of the hypotenuse of a right triangle is 13 units and the length of one other side is 5 units. What is the length of the third side?

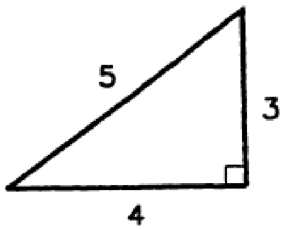
$$
\begin{aligned}
a &= \sqrt{c^2 - b^2} \\
&= \sqrt{13^2 - 5^2} \\
&= \sqrt{169 - 25} \\
&= \sqrt{144} \\
a &= 12 \text{ units}
\end{aligned}
$$



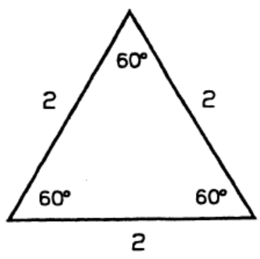
Special Triangles

29. There are several triangles which have special characteristics commonly found in electrical calculations.

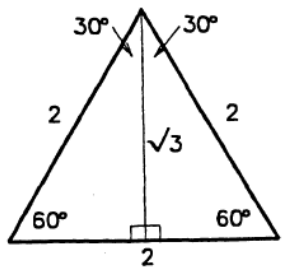
a. 3-4-5 Triangle. If the sides of the triangle are in the ratio 3:4:5, the angle opposite the longest side is a right angle.



b. Equilateral Triangle. All sides and all internal angles are equal in an equilateral triangle; all internal angles are 60º.



c. 60 – 30 Triangle. If one angle of an equilateral triangle is bisected, the bisector divides the side opposite the angle in half. Two equal right triangles are formed, each having 30º and 60º as their internal acute angles. The lengths of the sides are in the ratio 1:2:√3.



d. The diagonal of a square forms two equal triangles, each having two equal sides and two equal angles of 45º. The lengths of the hypotenuse of each triangle is √2 times the length of any other side.

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Trigonometry and Pythagoras' Theorem

1. What are the names usually given to the three sides of a right triangle?
2. How can the hypotenuse be identified in any right triangle?
3. What is the complement of 30°?
4. If a particular right triangle is named ABC, what is the usual name given to the side opposite the right angle?
5. In electrical trades calculation, what Greek Letter is usually used to name the unknown angle?
6. If a right triangle has one acute angle of 60°, how many degrees would there be in the other acute angle?
7. What is the sum of the internal angles in a triangle?
8. Define the sine of any internal angle in a right triangle.
9. Define the cosine of any internal angle in a right triangle.
10. Define the tangent of any internal angle in a right triangle.
11. What are the largest and smallest possible values for the sine of an angle?
12. What are the largest and smallest possible values for the cosine of an angle?
13. What is the value of the cosine of the complement of 60°?
14. What is the sine of 60°?
15. What is the sine of 120°?
16. What is the sine of 210°?
17. What is the sine of 300°?

18. What angle between 0° and 90°has a cosine of 0.707?

19. If the sine of an angle between 0° and 90° is 0.5, what is the cosine of the angle?

20. Refer to Diagram 1. If the value of X_L is 30Ω, and the value of R is 40Ω, what is the value of the angle Φ (phi)?

21. Refer to Diagram 1. If the value of X_L is 30Ω, and the value of R is 40Ω, what is the value of Z?

22. Refer to Diagram 2. If the value of I_{XL} is 12A, and the value of the angle Φ is 30°, what are the values of I_R and I_Z?

23. Refer to Diagram 3. If the value of P, S2 and S1 are 1000W, 1100W and 1200W respectively, what is the value of the cosine of the angle Φ2?

24. Refer to Diagram 3. If the value of P, S2 and S1 are 1000W, 1100W and 1200W respectively, what is the value of Q2?

25. Refer to Diagram 4. If the value of X_L is 90Ω, and Z is 120Ω, what is the cosine of the angle Θ (Theta)?

26. The arrows labelled R, W and B in Diagram 5 each have a length of 240mm, and there are120° between them. What is the length of a line drawn from R to W?

27. The arrows labelled R, W and B in Diagram 6 represent distances of 40, 60 and 20 units respectively, and the angle between each is 120°. What is the distance between X1 and X2?

28. The lengths of the two longest sides in a right triangle are 12 units and 13 units respectively. What is the length of the third side?

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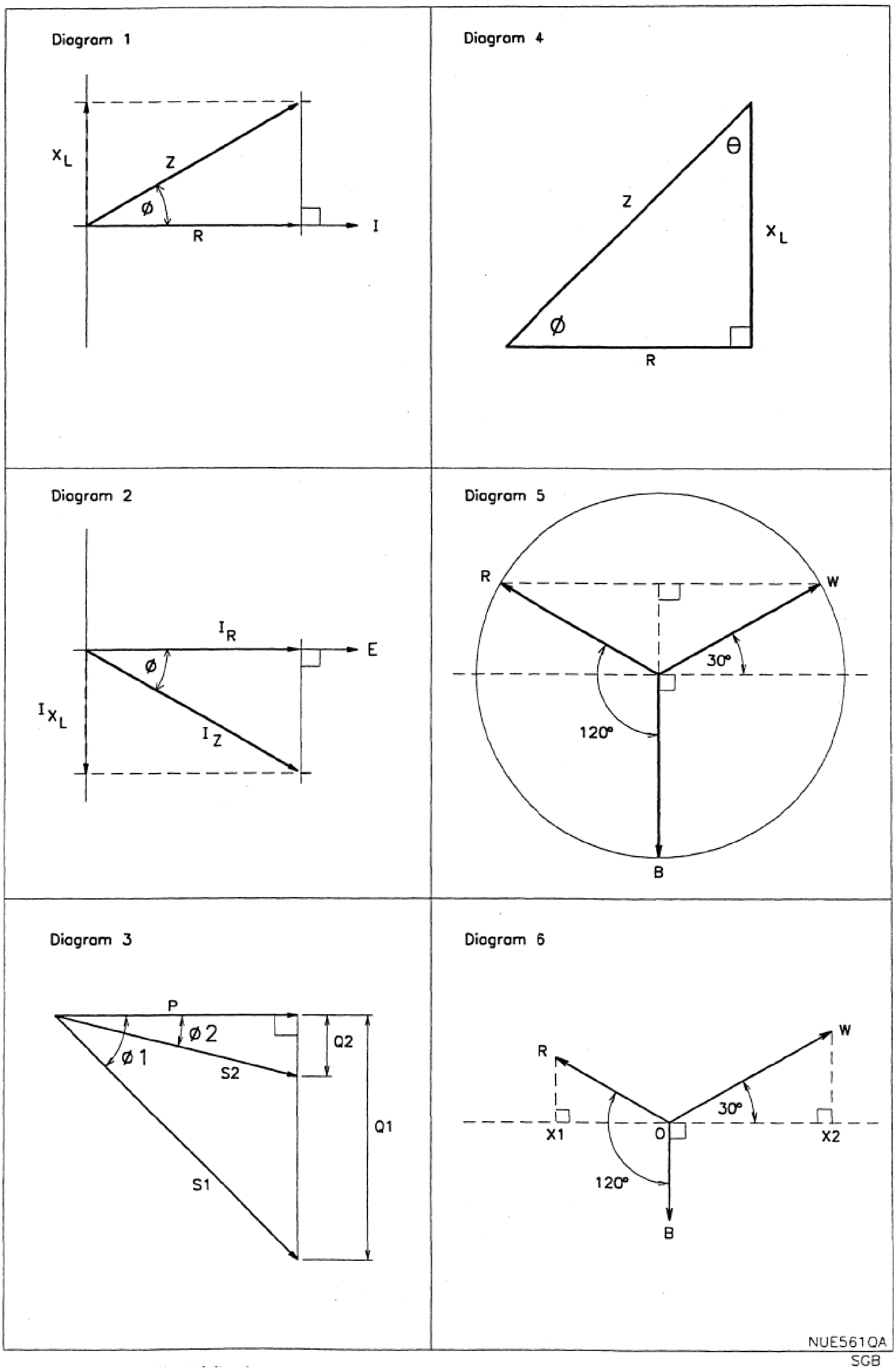
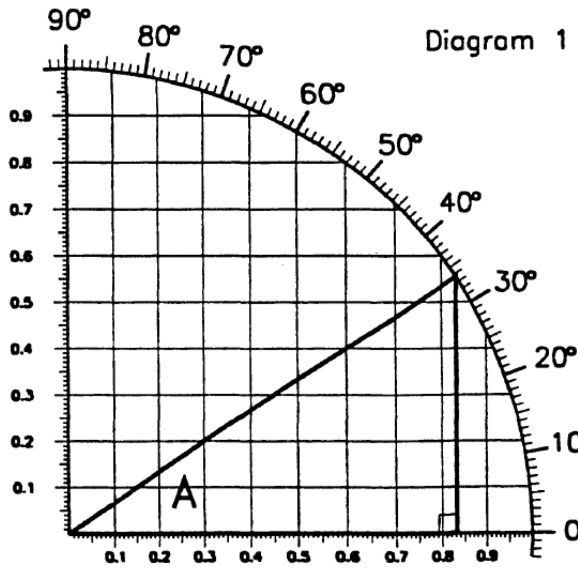
Trigonometry and Pythagoras' Theorem worksheet diagrams



Basic Trigonometry



Refer to diagram 1 for the following questions

1. If the length of the hypotenuse is 73 units, and the angle at A is 40º, what is the length of the side ADJACENT to angle A?
   (Round your answer to ONE decimal place)

2. If the length of the hypotenuse is 68 units, and the angle at A is 49º, what is the length of the side OPPOSITE to angle A?
   (Round your answer to ONE decimal place)

3. If the length of the side opposite angle A is 9 units, and the length of the side adjacent to angle A is 4 units, how many degrees are there in ANGLE A?
   (To the nearest WHOLE number)

4. If the length of the side adjacent to angle A is 15 units, and angle A is 76º, what is the length of the HYPOTENUSE?
   (To the nearest WHOLE number)

5. If the length of the side opposite to angle A is 54 units, and angle A is 41º, what is the length of the HYPOTENUSE?
   (To the nearest WHOLE number)

6. If the length of the side opposite angle A is 18 units, and the side adjacent to angle A is 3, what is the length of the HYPOTENUSE?
   (Round your answer to ONE decimal place)

7. If the length of the side opposite angle A is 69 units, and angle A is 80º, what is the length of the ADJACENT side?
   (To the nearest WHOLE number)

8. If the length of the side opposite angle A is 22 units, and the hypotenuse is 46 units, what is the length of the ADJACENT side?

(To the nearest WHOLE number)

9. If the length of the hypotenuse is 55 units, and angle at A is 20º, what is the length of the side ADJACENT to Angle A?
(Round your answer to ONE decimal place)

10. If the length of the side adjacent to angle A is 46.3 units, and the hypotenuse is 52 units, what is the length of the OPPOSITE side?
(To the nearest WHOLE number)

11. If the length of the side adjacent to angle A is 21 units, and the length of the side opposite angle A is 29 units, how many degrees are there in ANGLE A ?
(To the nearest WHOLE number)

12. If the length of the side opposite angle A is 17 units, and the length of the side opposite the right angle is 50 units, how many degrees are there in ANGLE A?
(To the nearest WHOLE number)

13. If one of the acute angles in a right triangle was 77º, how many degrees would there be in the other ACUTE angle?

END OF QUESTIONS

NOTES

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The A.C. Waveform and Phasors

Task:

To describe the characteristics of the a.c. waveform and use simple phasor diagrams to show phase relationship between relevant components.

Why:

The study of alternating current circuits which have inductive and capacitive components involves currents and voltage which are not occurring at the same time in a given circuit – they are said to be out of phase. The alternating current waveform has several characteristics which require it to be considered from a mathematical viewpoint in order to be able to interpret the readings on measuring instruments.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a written assessment.
2. You must satisfactorily complete the set laboratory tasks.
3. You must achieve 100% in a final practical assessment.

Equipment:

A.C. Theory Project Boards
ELV A.C. Power Supply
A.C. Ammeters
A.C. Voltmeters
Multimeters
Scientific Calculator
300mm Ruler
Drawing Protractor
5mm square graph paper

References

- Electrical Principles for the Electrical Trades (6th ed.) Jenneson & Harper Volume 1: 8.10 Phasers
- AS/NZS 3000-2018
- WAER

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A.C. Components and Circuits
Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades

Section 8.1 – 8.3	Fundamentals of Alternating Current
Section 8.9	Sinusoidal Wave Values
Section 8.10	Phasors

2. Read the Summary and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Complete the projects in this manual.

5. Submit your answers on the Work Sheet to your Lecturer for discussion and assessment.

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The A.C. Waveform and Phasors

Advantages of A.C.

1. Alternating current is used for supply authority distribution systems, because it has several advantages over a direct current distribution system. The main advantages include:

   a. The voltage can be increased or decreased more easily and economically using transformers.
   b. A.C. motors are often simpler, more reliable and require less maintenance than d.c. motors.
   c. A three phase a.c. supply system provides two voltage levels.
   d. A.C. can be transmitted over long distances at high voltages with minimum losses.
   e. Large a.c. generators (alternators) are generally easier to build and maintain than d.c. generators.

2. Although a.c. is generally more economical to produce and distribute than d.c., the behaviour of a.c. is much more complex than d.c., because the effects of inductance and capacitance are of major significance, and because of the characteristics of the sine wave (or sine curve).

Waveforms

3. It is frequently necessary to describe a voltage or current by graphing its value over a given period of time. Direct current maintains the same magnitude and polarity over time, and can be represented as shown in Figure 1.

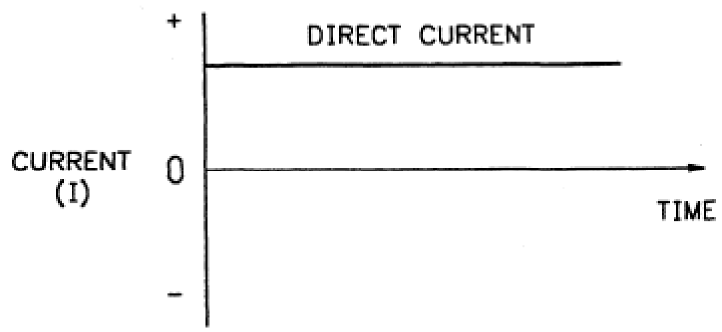
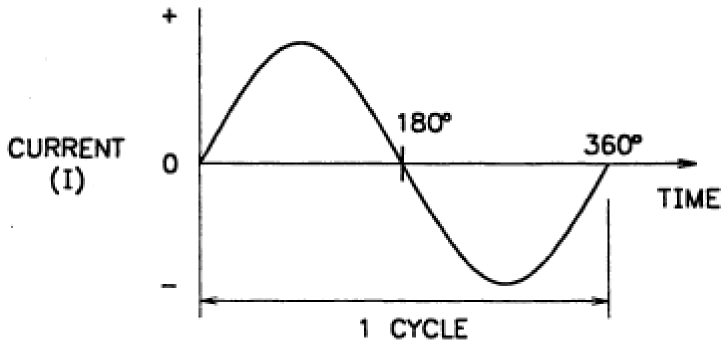


Figure 1 - A graph of direct current

4. A sinusoidal a.c. voltage waveform is a graph of the magnitude and polarity of the voltage induced in a coil rotating uniformly through a two pole magnetic field for one complete revolution or cycle – a cycle is the time taken for the process to begin repeating itself. The number of cycles which occur in a given period is called the **frequency** and is usually expressed in cycles per second. The unit 'cycles per second' is given a special name – Hertz (Hz).
   Note: Period – The time it takes to complete one cycle.

5. The frequency of the 240/415V_{ac} supply is 50Hz (50 cycles per second), so the current (and voltage) is rising and falling at a known rate in such a way that one complete cycle occurs in 1/50th of one second, or 0.02 seconds (20ms). These relationships for a single phase a.c. sine wave are shown graphically in Figure 2.

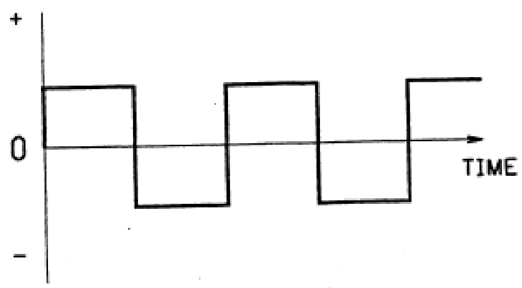


$\text{Period} = \frac{1}{f}$ (seconds) $\text{Frequency} = \frac{1}{t}$ (Hertz)

Figure 2 - Single phase a.c. sine wave

6. All a.c. supply systems generate a sine wave, but other waveforms are used in electronic applications. The most common of these are:

a. Rectangular Waveform



b. Triangular Waveform

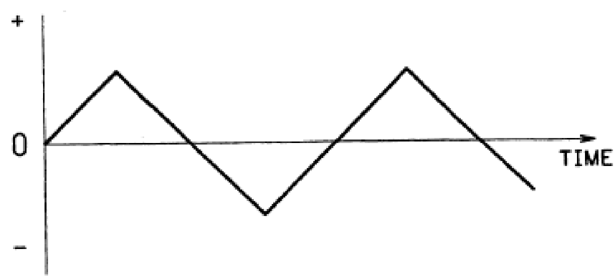


Figure 3 - Waveforms

Values of A.C.

7. The mathematical properties of an a.c. sine wave are such that there are several values associated with it, these are:

   a. The peak (maximum) value
   b. The instantaneous value
   c. The average value
   d. The rms (root mean square) value
   e. The peak to peak value

8. **The Peak Value –** The peak value is the maximum value of the voltage or current reached during each half cycle. The voltage rating of any insulation or component must be at least equal to the PEAK value of the a.c. voltage applied to it. A graphical representation of the peak value is shown in Figure 4.

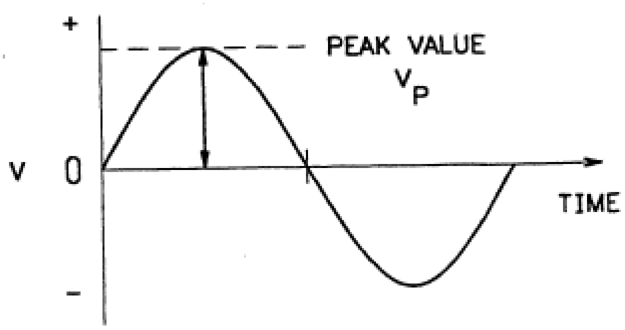


Figure 4 - The peak value of a sine curve

9. Common abbreviations or symbols used to refer to the peak voltage of an a.c. sine wave are:

V_{peak} V_{max} V_m E_p

10. The peak value of a.c. is not the value you would be referring to if you referred to the voltage reading on a typical a.c. voltmeter or multimeter, because it is only reached at two instants during each cycle. The peak value can usually only be displayed on a oscilloscope (CRO), as described later in this module.

11. **The Instantaneous Value -** The instantaneous value is the value of voltage or current at any instant in a given period. In a sine wave, the instantaneous value is constantly changing so it cannot be measured directly – it can only be calculated. One cycle of a sine wave is a graph of the instantaneous values for one revolution of a 2 pole alternator as shown in Figure 3.

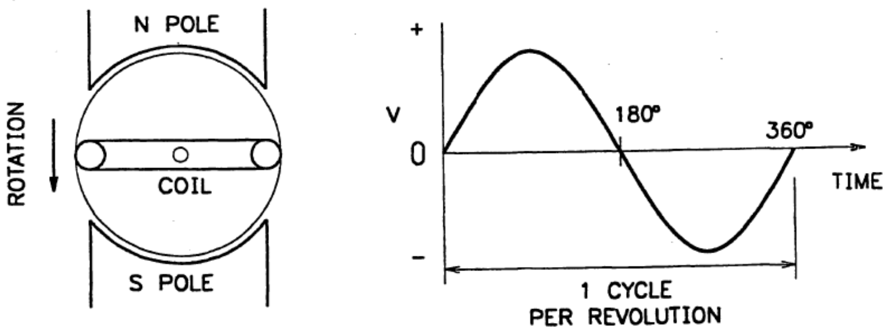
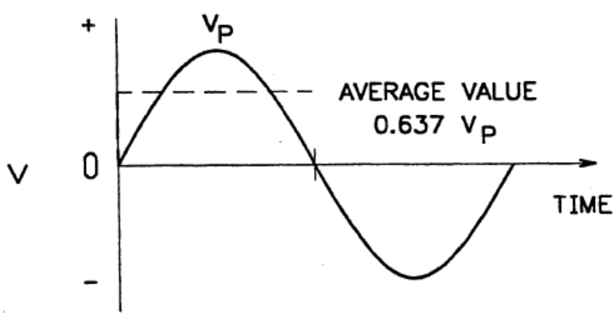


Figure 5 – Graph of instantaneous values over one cycle.

12. The quantity symbol for an instantaneous value is the usual symbol for the value, but in lower case. The symbol 'i' means an instantaneous value of current; the symbol 'v' means an instantaneous value of voltage, and can be calculated by multiplying the PEAK value of the wave by the sine of the angle at that instant:

$$i = I_p \times \sin\phi$$
$$v = V_p \times \sin\phi$$

13. **The Average Value –** The average value is the average of all the instantaneous values over half a sine wave. An approximation of the average value can be found by finding the sum of, say, 10 equally spaced instantaneous values over half a sine wave, then dividing the total by 10. Greater accuracy can be obtained by taking a greater number of instantaneous values. The average of an infinite number of instantaneous values over half a cycle can be found using higher mathematics (Calculus), and it can be shown to be 0.637 of the maximum or peak value (rounded to three places of decimals). A graphical representation of the average value of a sine wave over one half cycle is shown is Figure 6.



$$\text{Average value} = \frac{2V_p}{\pi}$$
$$= 0.636$$

Figure 6 - A graph of the average values over one half cycle

14. Since a sine wave is the same shape above and below the horizontal axis, and the portion below the axis is negative, the average value of a sine wave over one complete cycle is zero.
15. The most common symbols used to refer to an average value are:

V_{avg} V_{av}

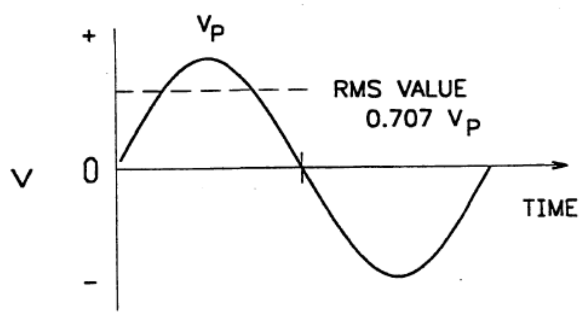
16. The average value is not suitable for general measurements on a.c., but it is significant in some applications such as electroplating, rectification and some analogue measuring instruments.

17. **The RMS Value -** The root mean square value of an a.c. sine wave (also known as the 'effective' or 'virtual' value) is the value of a.c. which would have the same heating effect as an equivalent value on d.c.

18. The symbols used to refer to the rms value on an a.c. sine wave are:

V_{rms} V_{RMS}

19. The rms value is the square root of the mean of the squares of all instantaneous values over one half cycle. The rms value of a sine wave is 0.707 of the peak value (rounded to three decimal places). A graphical representation of the rms value is shown in Figure 7.



$$V_{rms} = \frac{Vp}{\sqrt{2}} = 0.707Vp$$

or

$$V_{rms} = 0.707 \times V_p$$

$$V_p = V_{rms} \times \sqrt{2}$$

or

$$V_p = \frac{V_{rms}}{0.707}$$

Figure 7 - The rms value of a sine wave

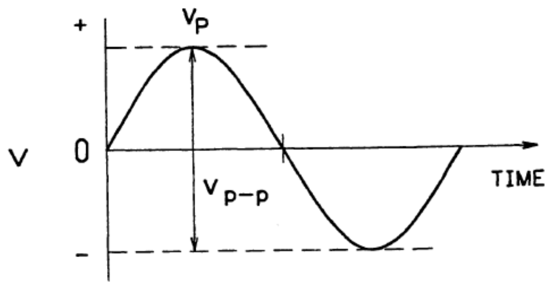
20. Most a.c. general purpose electrical measuring instruments are calibrated to indicate rms values. When an a.c. value of voltage or current is referred to, the rms value is usually intended unless otherwise stated.

21. If an rms value is known, the peak value of the sine wave can be calculated by multiplying the rms value by $\sqrt{2}$ (1.414), or divide the rms value by 0.707. If the peak value is known, the rms value can be calculated by dividing the peak value by $\sqrt{2}$, or by multiplying the peak value by 0.707.

22. The value of 240V given as the nominal voltage of a single phase supply is an rms value – the peak value is actually 339V. 240V_{ac}. (rms) has the same heating effect as 240V_{dc}.

Peak to Peak Value

23. The peak to peak value of a sine wave is the value from the instantaneous peak value of one half cycle to the instantaneous peak of the next half cycle. The peak to peak value is double the value of the peak value, and is usually represented by the symbol $V_{p\text{-}p}$. The graphical representation of the peak to peak value is shown in Figure 8.



$V_{p\text{-}p} = 2V_p$

Figure 8 - The peak to peak value of a sine curve

24. Consideration of peak to peak values of an alternating waveform is important in electronic circuits such as amplifiers, where an a.c. signal is superimposed over a d.c. signal to give an output such as the one shown in Figure 9.

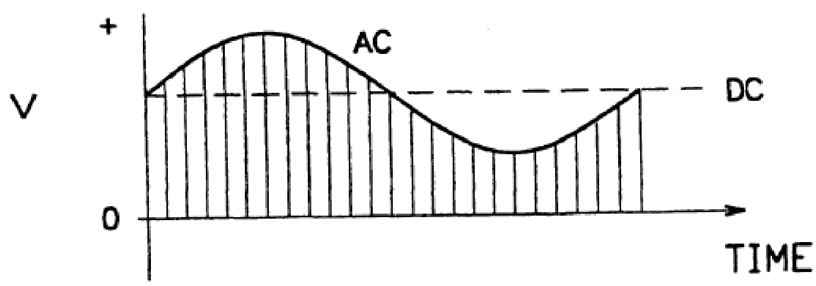
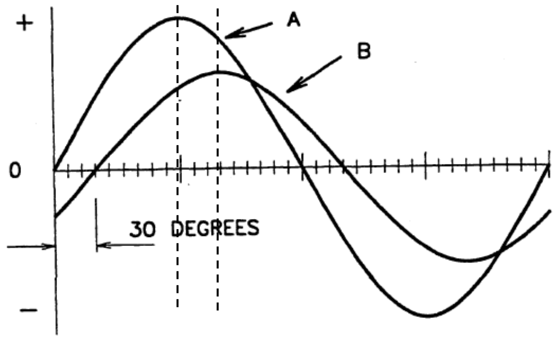


Figure 9 - A.C. and d.c. waveforms combined

Phase Relationship

25. One of the major characteristics of inductive and/or capacitive components on a.c. is that, the current and voltage within a device or circuit can be reaching maximum and minimum values at different times. Under such conditions the values are said to be 'out of phase'. Figure 10 shows how the magnitudes are out of phase by 30°.



B lags A by 30°

Figure 10 - Out of Phase values

26. You can see from Figure 10 that the zero point of the smaller cycle (Cycle B) is 30° later in time than that of the corresponding zero point of the larger cycle (Cycle A). Under these conditions, Cycle B is said to be 'lagging' Cycle A by 30°, or Cycle A is said to be 'leading' Cycle B by 30°. This relationship can also be represented with phasors as covered later in this module.

27. Consideration of the phase relationships in an a.c. circuit involving resistance, capacitance and inductance in series and parallel, forms a major part of the detailed analysis of such circuits.

Phasors

28. The phase relationship between two out of phase sinusoidal waveforms can be represented by two sine waves as shown in Figure 10. Another way of indicating the phase relationship between two sinusoidal waves at the same frequency, is by using phasors.

29. A phasor is a straight line arrow which represents the magnitude and direction of a sinusoidal voltage or current. The relationship between two sinusoidal waves which are of the same frequency, but out of phase, can be shown using two phasors as shown in Figure 11.

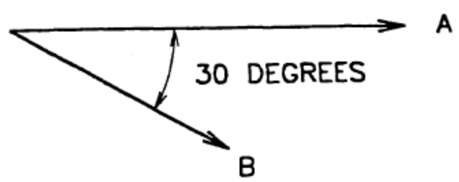
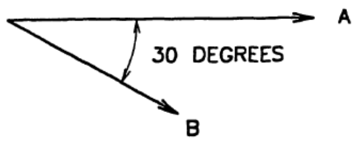
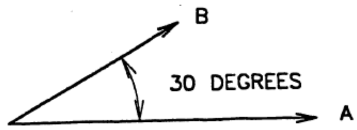


Figure 11 - A phasor representation of two out of phase values

30. The angle between the phasors indicates the difference in time between their adjacent maximum, or coincident values, which corresponds to the time between the start of each sine wave. In phasor diagrams, time (or phase angle, Φ) is usually expressed in degrees, and the direction of rotation is assumed to be ANTICLOCKWISE. In Figure 12a, phasor B is said to LAG behind phasor A by 30°, and in Figure 12b, phasor B is said to LEAD phasor A by 30°.



a. B lags A



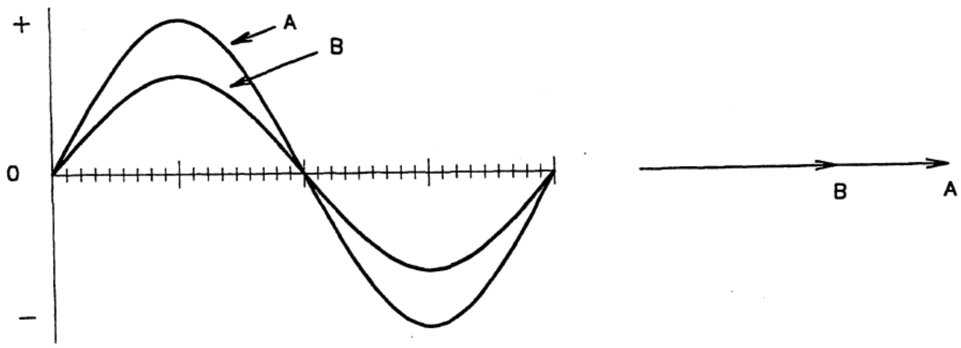
b. B leads A

Figure 12 – Leading and lagging phase relationships

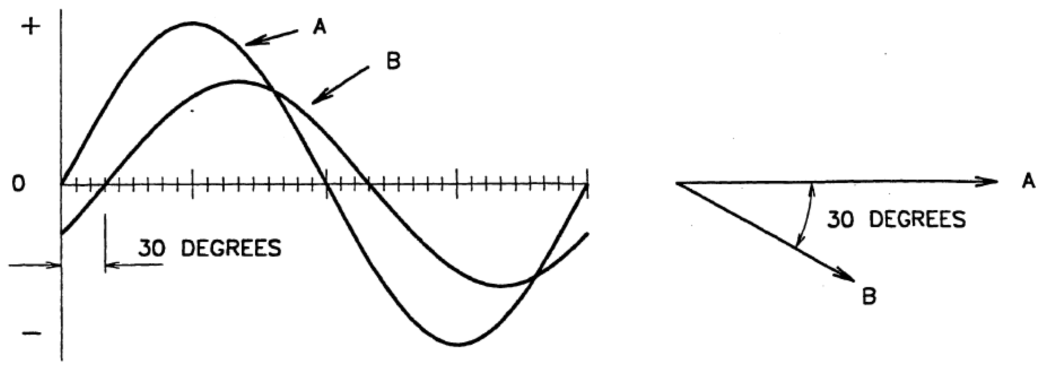
31. It is customary to choose one of the phasors as the REFERENCE PHASOR, and draw it horizontally from left to right. In a.c. circuits, the reference phasor is usually a value which has the same value in all parts of the circuit being considered, and values are assumed to be rms values. Where it is considered necessary to distinguish between a voltage phasor and a current phasor, the arrowhead of the voltage phasor is open and the arrowhead of the current phasor is closed, but this convention is not always followed.

32. The following diagrams show sine waves of values in a circuit, with the corresponding phasor diagram (A is used as the reference phasor in each case).

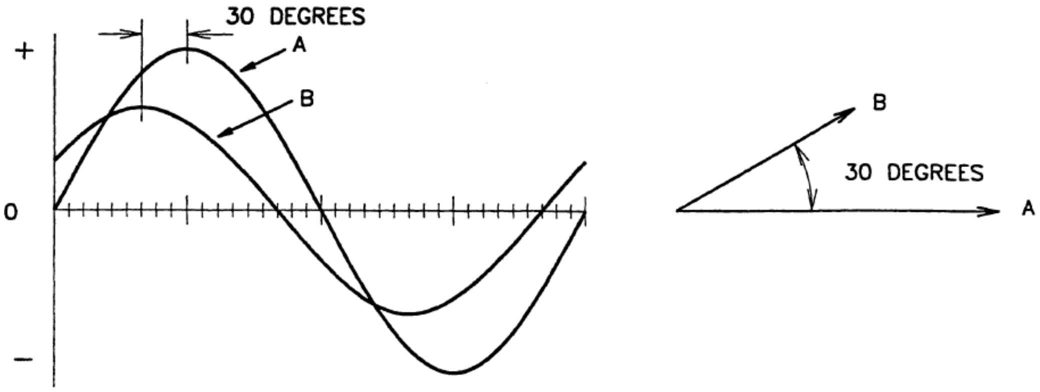
a. Phasor A and phasor B are in phase with each other.



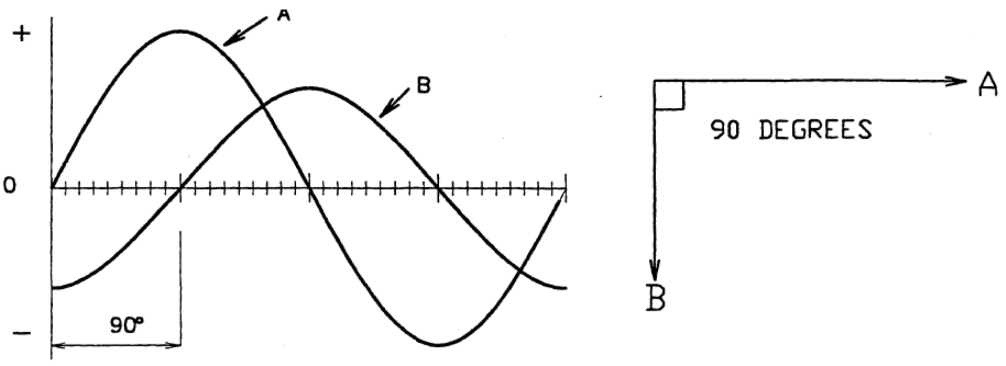
b. Phasor B lags phasor A by 30°.



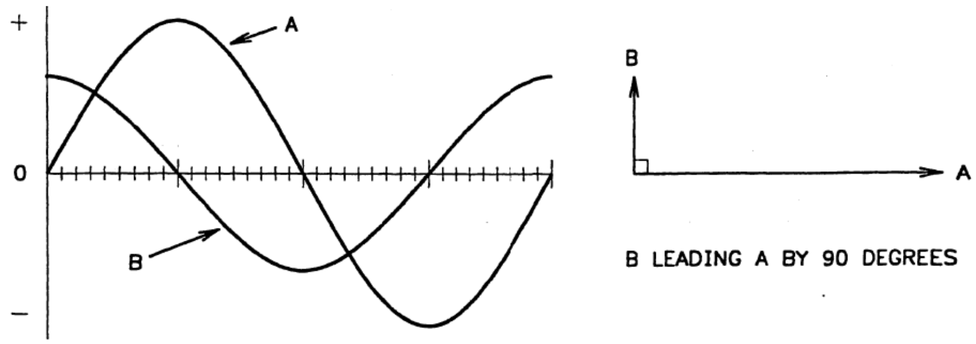
c. Phasor B leads phasor A by 30°.



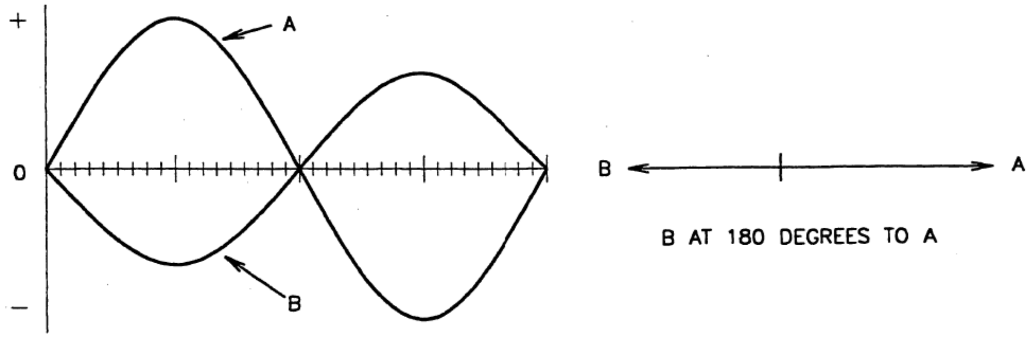
d. Phasor B lags phasor A by 90°.



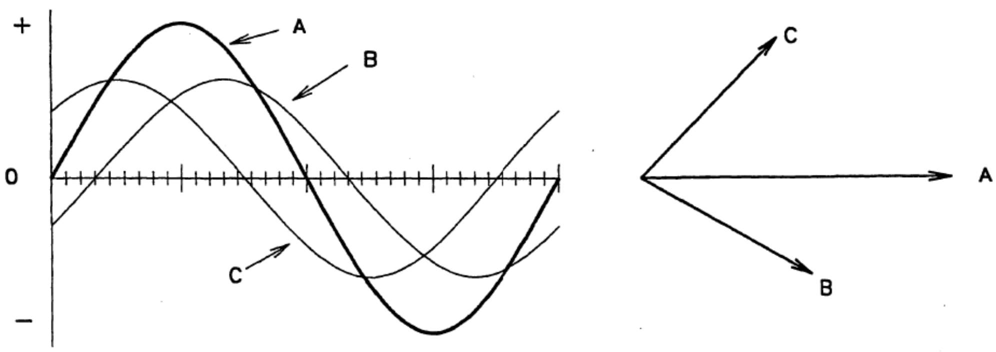
e. Phasor B leads phasor A by 90°.



f. Phasor A and phasor B are 180°out of phase with each other.



g. Phasor B lags phasor A by 30°, and phasor C leads phasor A by 45°.



33. In a.c. circuits which involve inductance and capacitance, various voltages and currents are out of phase with each other for reasons which will be discussed later in this module. Constructing phasor diagrams of the relationships in an a.c. circuit are often a useful tool when calculating various values in a circuit.

Phasor Addition

34. Phasor diagrams can be used to show the phase relationship between two different quantities in the same circuit (such as current lagging voltage by 90°), or they can be used to show the phase relationship between two like quantities (such as the current in a resistor and the current in an inductor). If the phasors represent the SAME quantity in a circuit, the final resultant value can be found by 'phasor addition'.

35. Phasor addition is the process of finding the resultant of two or more like quantities in a circuit (usually when the quantities are out of phase with each other). The resultant is also called the 'phasor sum' of the two quantities. You should always draw a phasor diagram of the quantities being considered before you perform the phasor addition.

36. If two quantities in a circuit are in phase, the phasor sum is found by simply adding the two quantities together.

37. If two quantities in a circuit are out of phase, the phasor sum is found by completing the phasor parallelogram, then finding the resultant. One way to determine the resultant, is by using graphical construction.

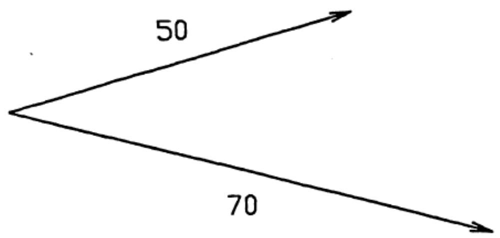
38. **Example 1**

Two components are connected in an a.c. circuit so that the phase angle between the potential differences across them is 30°. The voltages are 50V and 70V respectively. Determine the phasor sum of the two voltages using graphical construction.

Solution

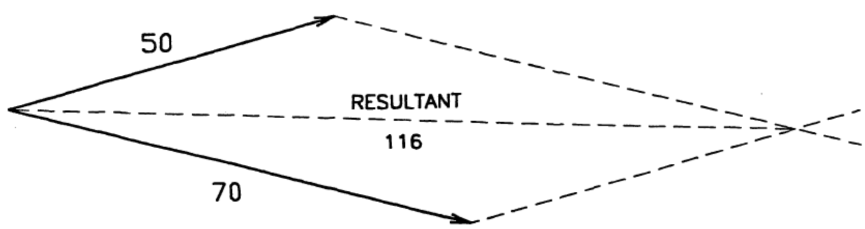
Draw the phasor relationship between the given values to scale (the same scale must be used for both phasors):

Scale: 1mm = 1V



Complete the phasor parallelogram by drawing a line parallel to the phasor for each of the given quantities:

Scale: 1mm = 1V



Measure the length of the resultant, and convert it to the required units using the same scale. In this case, the length of the resultant is approximately 116mm, so the phasor sum is 116V.

39. The trigonometrical processes described earlier in this module cannot be used to determine the resultant in Example 1, because the problem does not involve right triangles. Using more advanced trigonometry to find the resultant in Example 1 is beyond the scope of this module, so if you need to find the resultant in similar cases, you should use graphical construction.

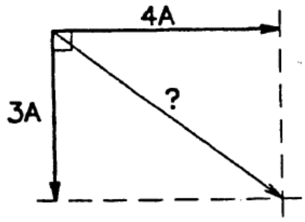
40. If the phasors in a particular circuit are 90° out of phase, trigonometrical methods and/or Pythagoras' Theorem can be used to find the phasor sum or the angles in the circuit.

41. **Example 2**

Two currents in a circuit are 90° out of phase. If their values are 3A and 4A respectively, and the 3A value is lagging, what is the total current in the circuit?

Solution

Draw the phasors, and complete the phasor parallelogram (note that the phasor parallelogram is a rectangle, so the opposite sides are equal in length):



Find the length of the resultant using Pythagoras' Theorem:

$$
\begin{aligned}
c &= \sqrt{a^2 + b^2} \\
&= \sqrt{4^2 + 3^2} \\
&= \sqrt{16 + 9} \\
&= \sqrt{25} \\
c &= 5A
\end{aligned}
$$

So, the phasor sum of the currents in the circuit is 5A.

42. The process of analysing an a.c. circuit to determine the phase relationships between various quantities, and then calculating particular values, is covered later in this module.

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 2 Worksheet	G102A JW/JD DEC 2013

The A.C. Waveform and Phasors

1. What condition is necessary for a voltage to be induced in a conductor by a magnetic field?
2. How much voltage is induced in a conductor when it is moved parallel to the flux in a magnetic field?
3. What is the most common name for the rotating electrical device used to produce alternating current?
4. What effect does it have on the frequency of the output from an alternator if the number of magnetic poles are increased?
5. In what units is frequency usually expressed?
6. What is the meaning of the term “Hertz” when it is applied to the specification of frequency?
7. A conductor is moving uniformly within a two pole magnetic field system. At what point(s) is the induced voltage at a maximum?
8. What is the frequency of the a.c. distribution system in Western Australia?
9. What is the QUANTITY symbol for frequency?
10. What is the customary UNIT symbol for expressing the frequency of an a.c. distribution system?
11. What are four of the ‘values’ of alternating current?
12. What peak value of a.c. voltage would be required to produce the same heating effect as $100V_{dc}$.?
13. What value of d.c. voltage would be required to produce the same heating effect as 100V peak a.c.?
14. What is the rms value of an a.c. sine curve?
15. What is the AVERAGE value of an a.c. sine curve over half of one cycle?

16. Calculate the peak-to-peak value of a sinusoidal wave which has an rms value of 240V.

17. What is the peak value of the single phase a.c. supply voltage in the Western Australia?

18. What values of voltage and current does a multimeter set to an a.c. scale measure/display?

19. What is the instantaneous value of sinusoidal current after 1234° of rotation, if the PEAK value is 100A?

20. Two currents in a $240V_{ac}$ circuit are 90°out of phase. If their values are 10A and 15A respectively, what is the total current in the circuit?

21. Two currents in a $240V_{ac}$ circuit are 45°out of phase. If their values are 50A and 75A respectively, what is the total current in the circuit? (Solve this graphically).

22. Can the process of phasor addition be used to find the phasor sum of two different quantities such as amps and volts?

23. What electrical quantity is usually represented with a phasor which has a closed arrowhead?

24. A phasor always has magnitude and ....?.......

25. What direction of rotation is always assumed in phasor diagrams?

26. What are the common names of two a.c. waveforms, other than the sinusoidal waveform?

27. What is the frequency of a waveform which has a periodic time of 0.01 seconds?

28. What is the periodic time (or period) of a waveform which as a frequency of 60Hz?

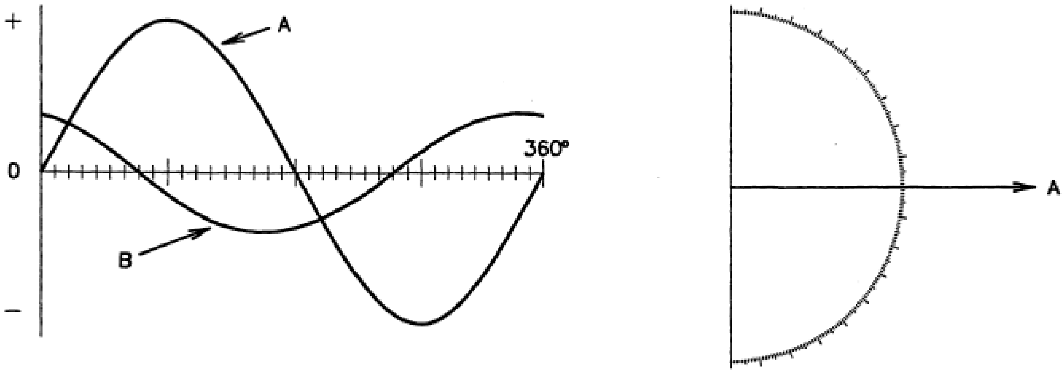
29. What is the phase relationship between the values A and B in each of the waveform diagrams on the attached sheet?

30. Calculate the instantaneous value of a sinusoidal voltage waveform 30° after the beginning of each cycle, if the PEAK value of the waveform is 100V.

31. What general term is used to describe two sinusoidal waveforms which are at the same frequency, but not occurring at the same time?

Diagrams for Section 2 Work Sheet

1



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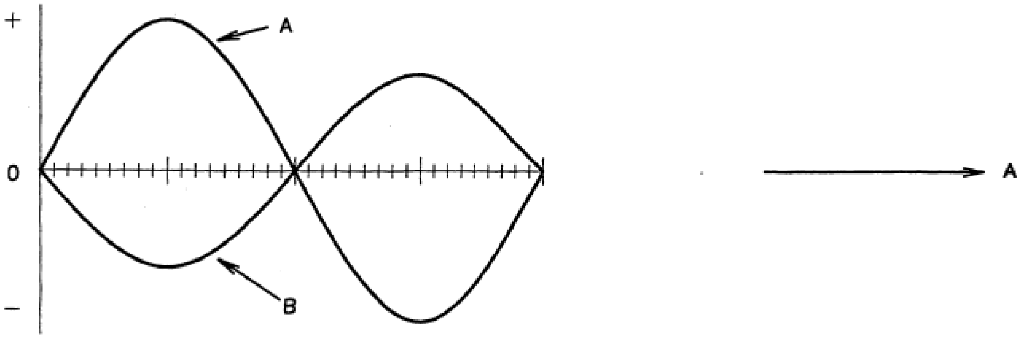

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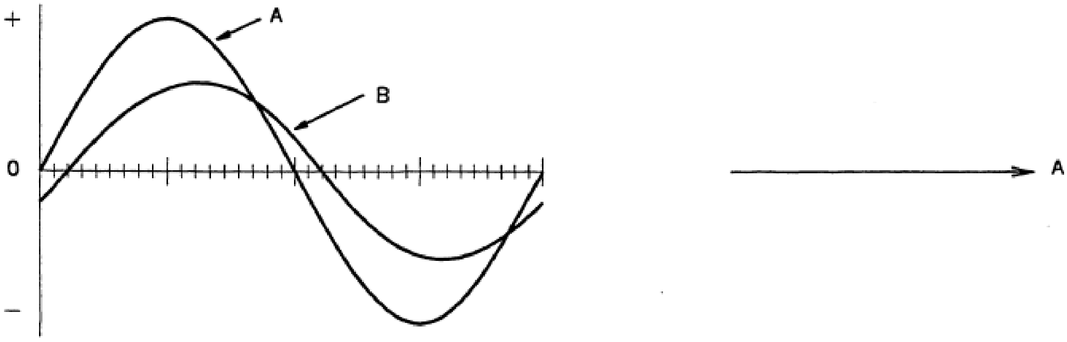

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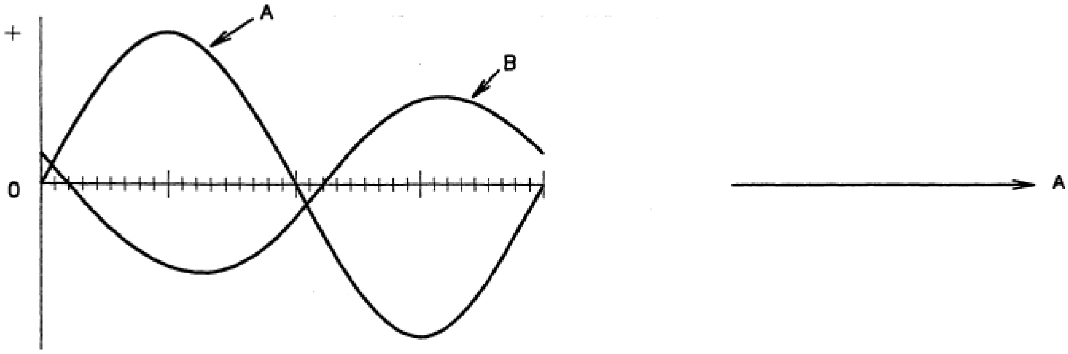


NOTES

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 3 Introduction	G102A JW/JD DEC 2013

The Oscilloscope

Task

To use an Oscilloscope (CRO), to measure the voltage, period and frequency of a single phase sinusoidal a.c. waveform.

Why

You need to be able to determine the peak voltage, period and frequency of a sinusoidal a.c. waveform using a CRO, so that you can understand the basic concepts applying to such waveforms, and measure the values when required in the workplace.

To Pass

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a written assessment.
2. You must satisfactorily complete the set laboratory tasks.
3. You must achieve 100% in a final practical assessment.

Equipment

A typical basic Oscilloscope
A ‘time 10’ CRO probe
CRO Theory Project Boards
ELV A.C. Power Supply
A.C. Ammeters
A.C. Voltmeters
Multimeters
Scientific Calculator
300mm ruler.
Drawing Protractor
5mm square graph paper

References

- Electrical Principles for the Electrical Trades (6th ed.) Jenneson & Harper
- More Electrical Principles, I. Batty. Prentice Hall

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 3 Study Guide	G102A JW/JD DEC 2013

The Oscilloscope

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades

Section 7.12 The Oscilloscope (CRO)

2. Read the Summary and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.
3. Answer the questions given on the Work Sheet. Note that you are required to answer questions correctly, although not necessarily at the same time.
4. Complete the projects in this manual.
5. Submit your answers on the Work Sheet and your completed project reports to your Lecturer for discussion and assessment.

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 3 Summary	G102A JW/JD DEC 2013

The Oscilloscope

1. What is an oscilloscope?

- An oscilloscope is an instrument that allows technicians to view electrical signals represented as a graph of magnitude versus time.
- The horizontal, or X axis, represents time and the vertical, or Y axis, represents magnitude.
- They are often referred to as a CRO (Cathode Ray Oscilloscope) but the modern instrument has an LCD screen and not a cathode ray tube.

2. What can it measure?

- It can measure the amplitude or peak to peak value of an alternating voltage.
- It can measure the time period of one cycle of an alternating voltage and thus provide the ability to calculate frequency.
- It can be used to measure DC voltages both positive and negative.
- Current can be determined by using voltage readings and resistor values to perform simple Ohm’s Law calculations.
- Phase relationships between signals can be compared and calculated.
- Distortion of signals can be observed.
- Electrical signals of all types from DC, to simple sine waves right through to complex waveforms can be viewed, analysed and compared.

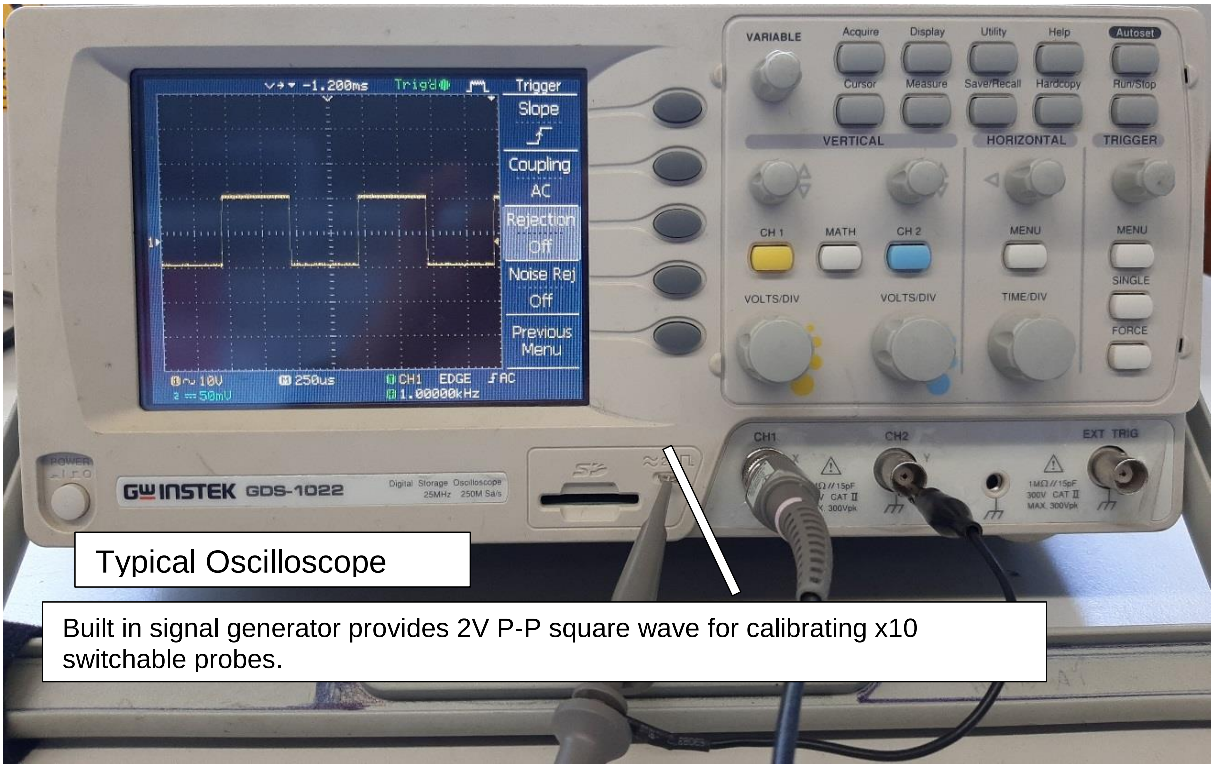


Fig - 1

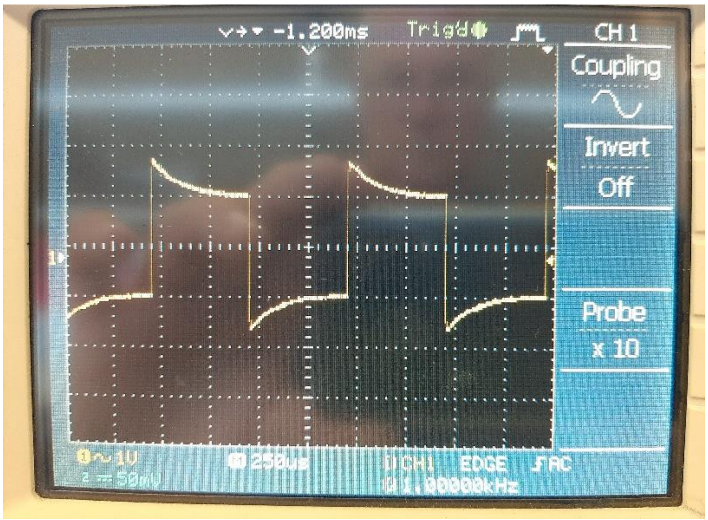


Fig – 2

The waveform shown here is distorted after switching probe to x10 function.

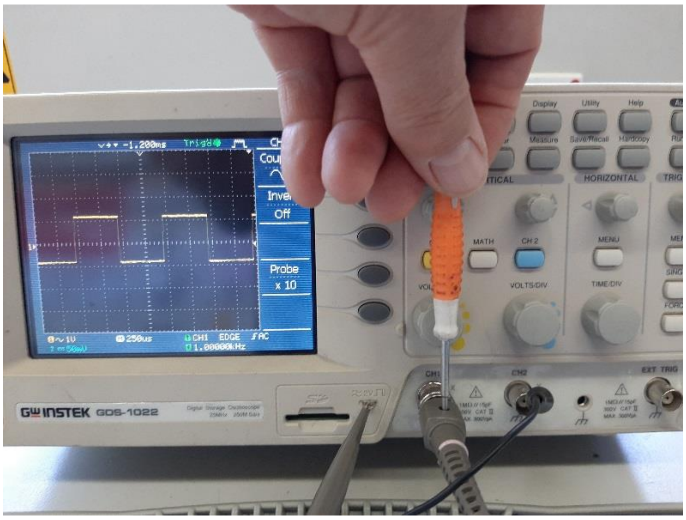


Fig – 3

The variable correction capacitor is adjusted to compensate for the additional resistance of the x10 probe.

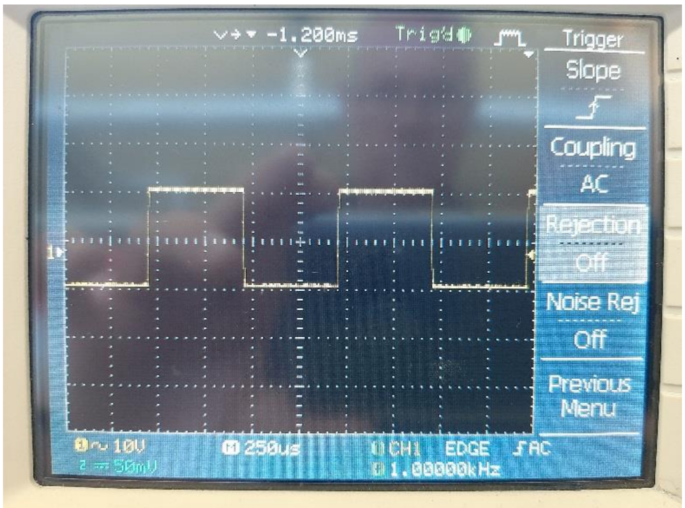


Fig – 4

The waveform shown here after correction

3. **Calibration:**

Figure 1 above shows the oscilloscope with test probe connected to calibration terminal. This terminal provides a 2V P-P, 1kHz square wave for the purpose of checking the calibration the instrument and for adjusting variable capacitor embedded in the probe head or the BNC plug.
Figure 2 shows the uncorrected square wave with probe switched to x10.
Figure 3 shows the variable capacitor being adjusted to compensate for the additional resistance of the x10 probe.
Figure 4 shows the corrected waveform.

4. **Attenuation Control (V/Div):**

Sets the scale to be used for vertical measurement of signal. This can typically range from 5V/Div through to 2mV/Div. A switchable test probe with a x10 switch can be used to extend the voltage range of the instrument.

5. **Vertical Position:**

Sets the position of the trace on the screen vertically. Can be used to move two signals together for comparison and analysis. Also used to position zero reference point when reading DC voltages.

6. **Horizontal Timebase Control (Time/Div):**

Used to adjust the time per division across the screen. This can typically range from 1nS/division – 10S/division.

7. **Horizontal Position Control:** Used to adjust the position of the signal across the screen. It may be necessary to align with the graticule to allow more accurate readings.

8. **Trigger Input:**

Used to allow signals to be triggered from an external source. This does not occur very often as we usually trigger from one of the signals at input Channel 1 or Channel 2.

These are the main controls available on the oscilloscope and most commonly adjusted depending on amplitude (p-p voltage) and frequency.

9. **Oscilloscope Safety:**

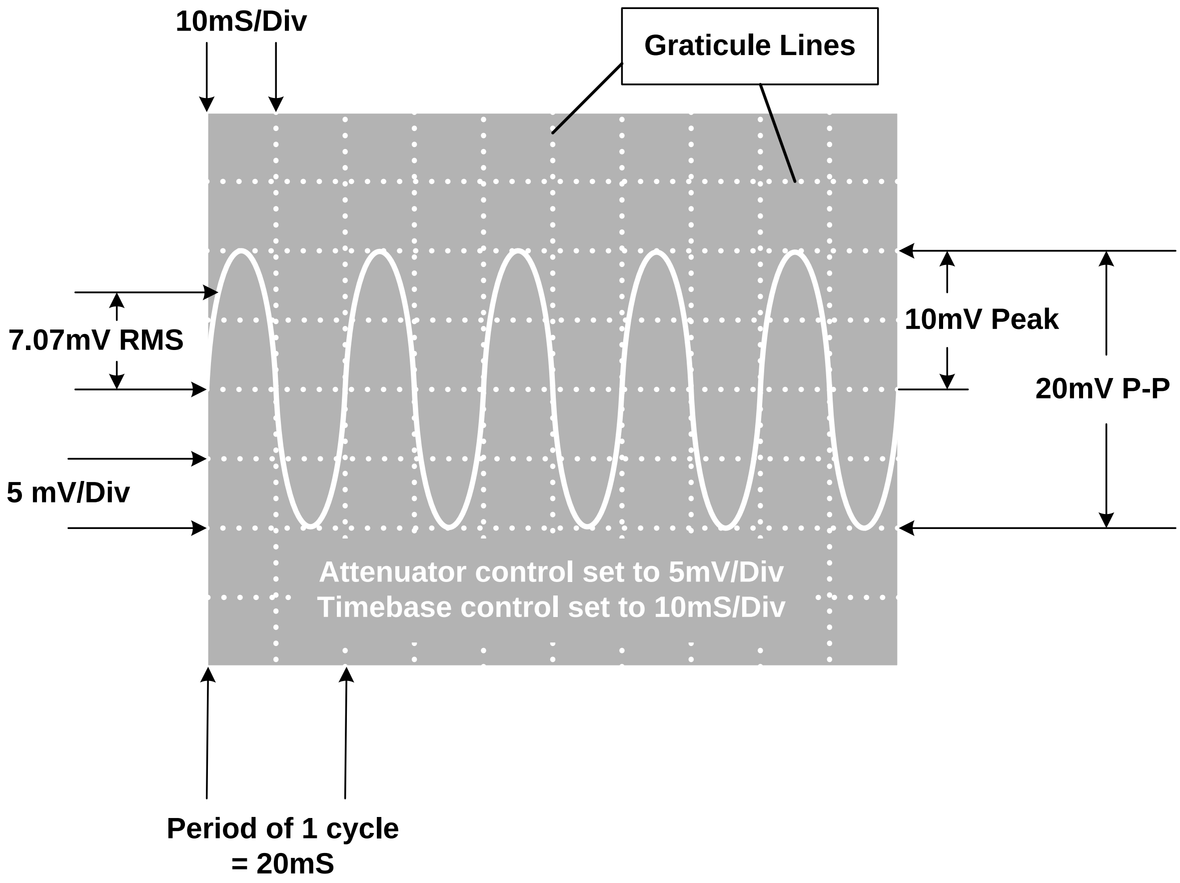
Oscilloscopes are connected to the AC mains supply and also to earth.
When working on equipment with a “LIVE CHASSIS”

- “ALWAYS PLUG THE EQUIPMENT UNDER REPAIR INTO A MAINS ISOLATION TRANSFORMER”.

When working on a “LIVE CIRCUIT”

- “ALWAYS PLUG OSCILLOSCOPE INTO AN ISOLATION TRANSFORMER”
- “ALWAYS ENSURE ONLY ONE HAND IS HOLDING TEST PROBE”

10. How to read the oscilloscope screen to measure voltage and frequency.



The screen above shows oscilloscope settings of
Timebase - 10mS/Division
Attenuator- 5mV/Division

To calculate period for one cycle multiply the number of divisions across the screen by the Timebase control setting.
10mS x 2 divisions = 20mS

To calculate frequency use the formula

$$\text{Frequency} = \frac{1}{\text{Time}} = \frac{1}{20\text{mS}} = 50\text{Hz}$$

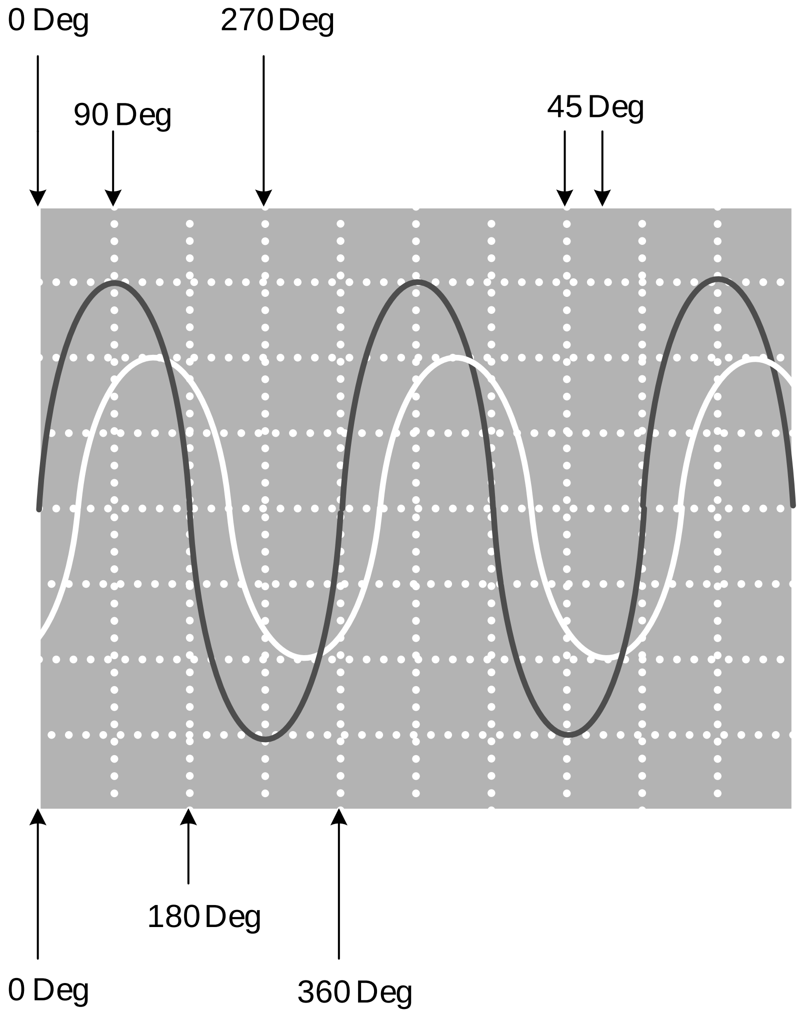
To calculate voltage multiply the number of divisions down the screen by the attenuator control setting.

V P-P = 4 x 5mV
= 20mV P-P

$$\text{V Peak} = \frac{\text{V P-P}}{2}$$

V RMS = V Peak x 0.707

11. How to read the oscilloscope screen when measuring phase relationships between waveforms.



The screen above shows the measurement of phase angle. Note that 360 degrees represents one full cycle of the sine wave. Also note that the darker of the two is at peak 45 degrees before the other. For this reason we would express this as the darker signal leading by 45 degrees or we could say the lighter signal is lagging by 45 degrees.

To calculate the phase relationship between two signals you must determine how many divisions across the screen it takes to complete one full cycle. Then you can divide this by four to determine the number of divisions for each 90 degrees. This can then be divided further for more accurate measurement. For example if the signal being viewed had a period of 1 division for 90 degrees then each of the smaller dots between the divisions would represent 18 degrees. (5 x 18 = 90). If the signal being viewed took two divisions for 90 degrees of the sine wave then each of the five smaller divisions between each of the larger divisions would represent 9 degrees. (10 x 9 = 90)

12. Analysis of phase relationships.

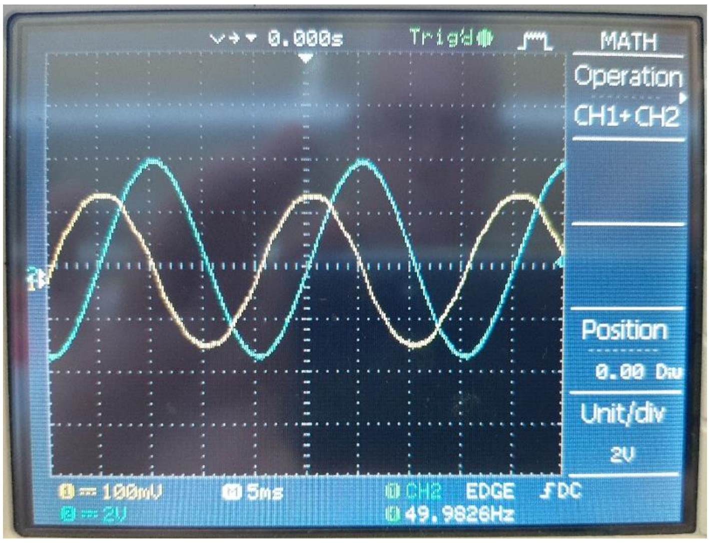


Fig: 5

Figure 5 shows comparison of voltage and current in a capacitive circuit. Yellow waveform is current and leads by 90^0

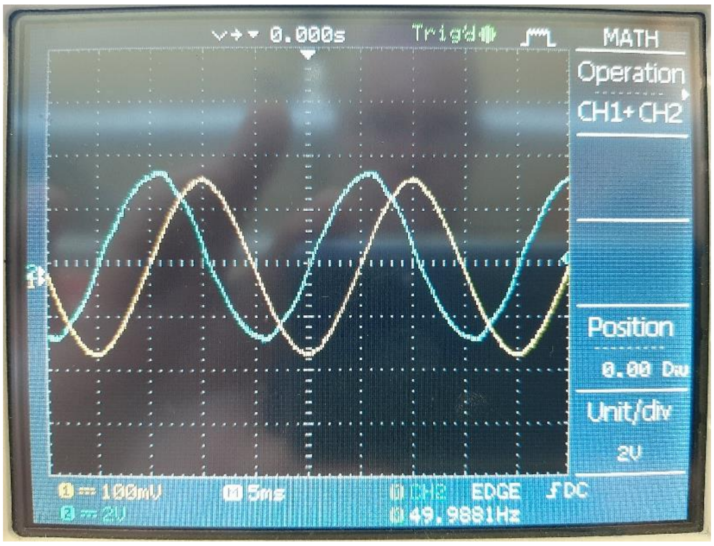


Fig: 6

Figure 6 shows comparison of voltage and current in an inductive circuit. Yellow waveform is current and lags by 90^0

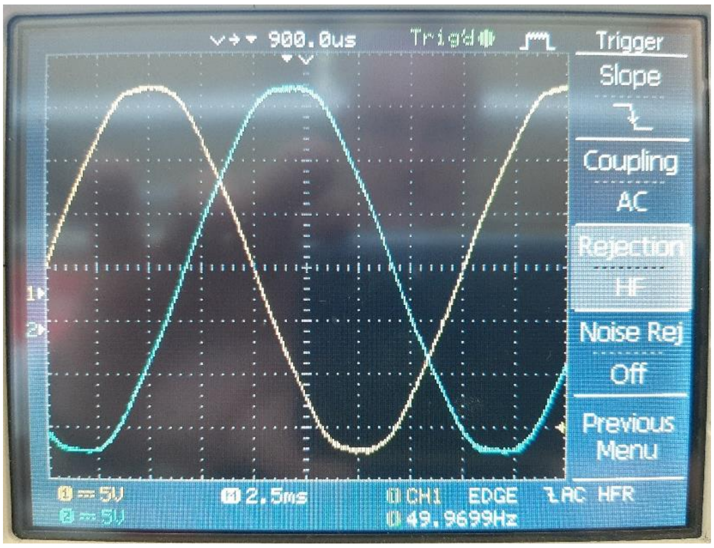


Fig: 7

Figure 7 shows comparison of 2 phases in a 3 phase circuit. Yellow waveform is white phase and leads blue phase by 120^0

13. Waveforms other than sine waves:

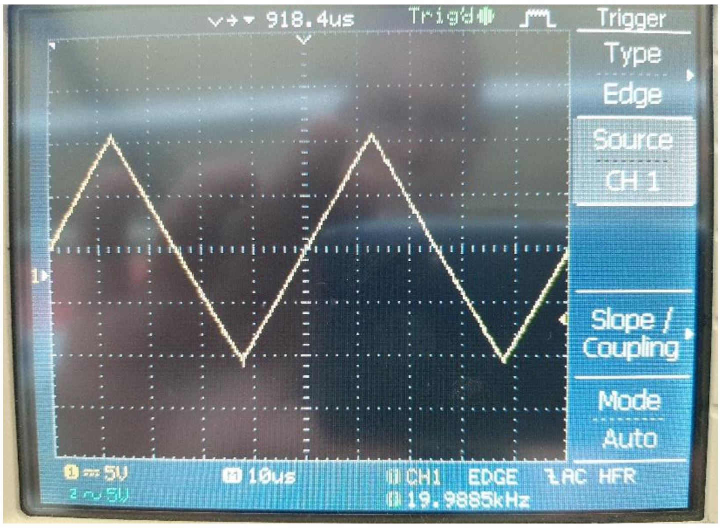


Fig – 8

Figure 8 shows a triangular waveform of 20 v P-P and a frequency of 20kHz. V/Div is set at 5V and is four divisions from peak to peak. Frequency is displayed on screen approx. 20kHz

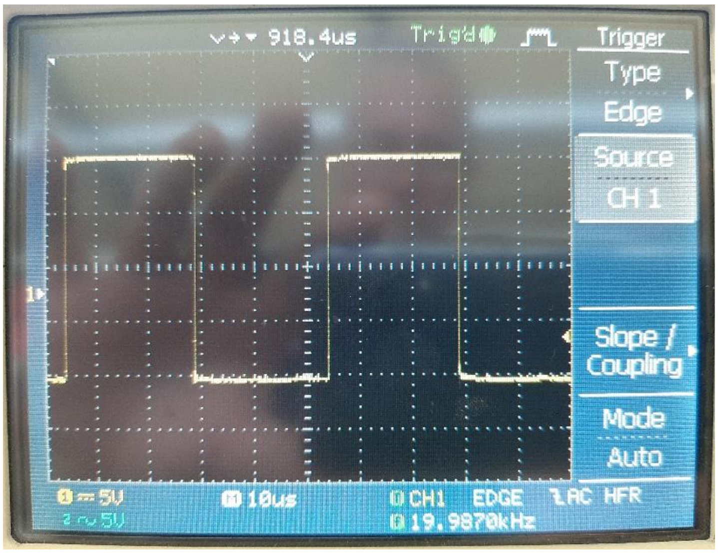


Fig – 9

Figure 9 shows a square waveform of 20 v P-P and a frequency of 20kHz. V/Div is set at 5V and is four divisions from peak to peak. Frequency is displayed on screen approx. 20kHz Duty cycle is 50%, meaning the positive and negative halves of the cycle have the same time period.

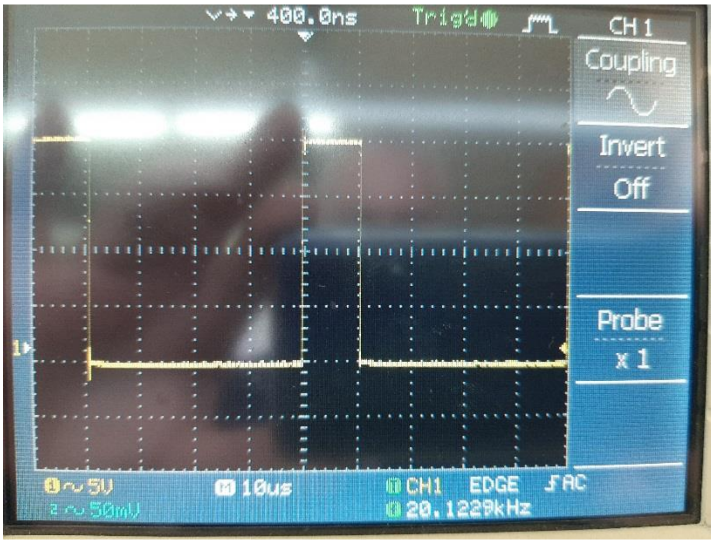


Fig – 10

Figure 10 shows a square waveform with a duty cycle of 20%, meaning the positive and negative halves of the cycle do not have the same time period. In this case the positive going portion only occupies 1 fifth or 20 percent of the time period.

14. Measuring DC voltages:

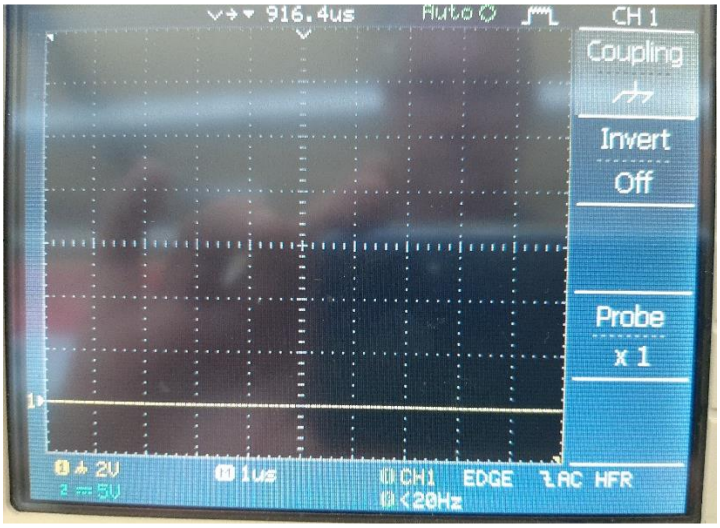


Fig – 11

Figure 11 shows a single line on the screen and the input coupling is showing an earth symbol. The input is grounded and the line which is one division up from the bottom has been designated as zero volts. Any line on the screen can be designated as zero volts by moving the position of the line with the vertical position control.

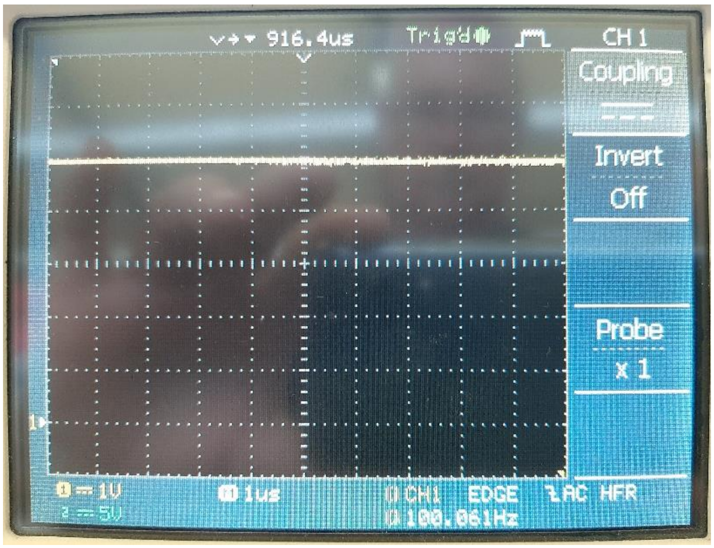


Fig – 12

Figure 12 shows a single line on the screen and the input coupling is showing the DC symbol. The input is now DC coupled which means any DC voltage component of a signal will move the line vertically on the screen. The attenuator is set for 1V/Div and the line has moved up 5 divisions from the reference line. Therefore the DC voltage measured is +5V.

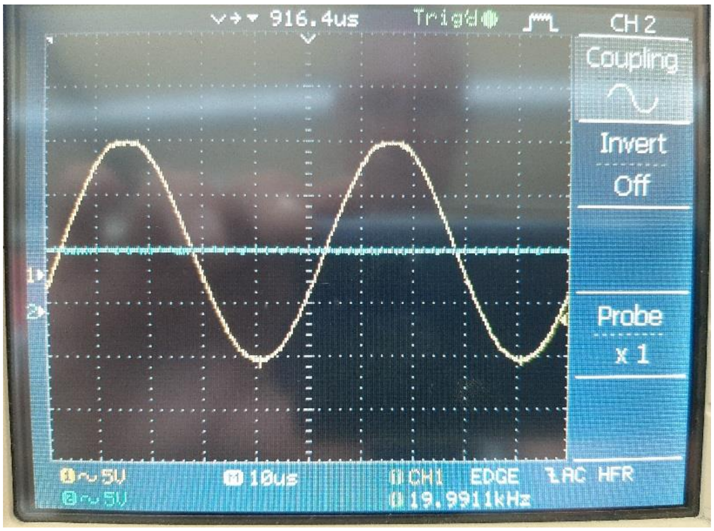


Fig – 13

Figure 13 shows a single line and a sine wave with the input coupling set to AC. The line and the sine wave are both centred vertically on the screen.

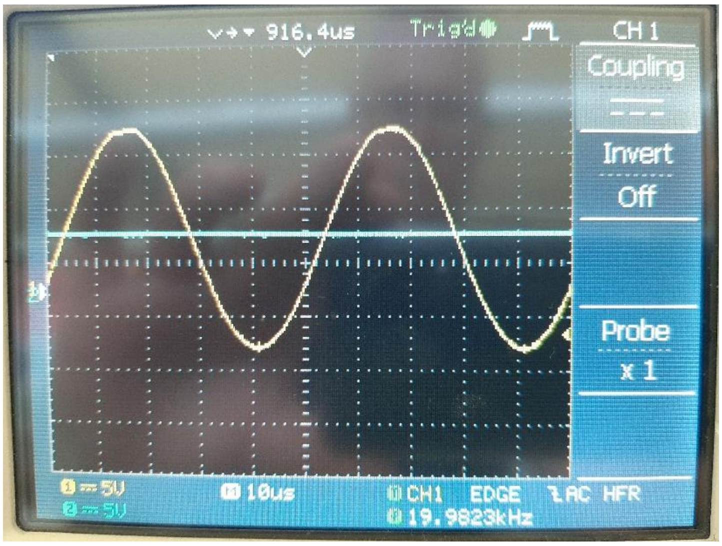


Fig – 14

Figure 14 shows a single line and a sine wave with the input coupling set to DC. The line and the sine wave have both moved up vertically on the screen by 0.5 of one division. The V/Div is set to 5 volts so the DC voltage superimposed on the sine wave is +2.5V.

Attenuator Probes

15. If a CRO is to be used to display a waveform at a voltage which is greater than the voltage rating of the instrument, a special attenuator probe must be used to avoid damage to the CRO. A typical attenuator probe (also known as a 'times 10 probe') reduces the voltage applied to the CRO to one tenth of its actual value, so the value displayed on the CRO has to be multiplied by 10 to give the actual voltage being measured.

CRO Familiarisation

16. Correctly interpreting the indication on a CRO requires skill and practice. The best way to become familiar with the operation of a CRO is to connect it to an extra-low voltage a.c. laboratory power supply (or signal generator), and operate the controls to see what they do.

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The Oscilloscope

1. What is the main advantage of an oscilloscope compared to a standard analogue multimeter when measuring a.c. voltages?
2. Why should a CRO be switched off using the switch provided on the instrument, rather than from the GPO?
3. Which two common electrical values in a.c. can be measured with an oscilloscope?
4. What is the purpose of a 'times 10 probe' when used with a CRO?
5. Why is it undesirable to leave a stationary trace on a CRO screen for long periods?
6. What is the distance between the MAIN grid lines on a typical oscilloscope screen?
7. What is a 'dual trace' CRO?
8. Why is it desirable to supply a CRO through an isolating transformer when measuring 240V mains voltages?
9. Which axis on a CRO is called the "X Axis'?
10. Which direction of movement of the trace on a CRO display is controlled by the Y amplifier?
11. What term is used to describe two waveforms which are at the same frequency, but not occurring at the same time?
12. Complete the exercises on the attached sheets.

The Oscilloscope

1. **Refer to CRO Trace 1**

What PEAK VOLTAGE is indicated on the oscilloscope display (in volts)?

Volts per Division: 100V
Time per Division: 100µs

2. **Refer to CRO Trace 2**

What PEAK VOLTAGE is indicated on the oscilloscope display (in volts)?

Volts per Division: 10mV
Time per Division: 10ms

3. **Refer to CRO Trace 3**

What is the FREQUENCY of the larger sine curve (in Hz)?

Volts per Division: 100V
Time per Division: 10ms

4. **Refer to CRO Trace 4**

What PEAK VOLTAGE is indicated on the oscilloscope display?

Volts per Division: 10V
Time per Division: 100µs

5. **Refer to CRO Trace 5**

What RMS VOLTAGE is indicated on the oscilloscope display?

Volts per Division: 10mV
Time per Division: 100ms

6. **Refer to CRO Trace 6**

What PEAK TO PEAK VOLTAGE is indicated on the CRO display (in volts)?

Volts per Division: 10mV
Time per Division: 10ms

7. **Refer to CRO Trace 7**

What is the FREQUENCY of the square wave on the CRO display (in Hz)?

Volts per Division: 100mV
Time per Division: 1ms

8. **Refer to CRO Trace 8**

What is the FREQUENCY of the sine wave displayed on the CRO (in Hz)?

Volts per Division: 1V
Time per Division: 100µs

9. **Refer to CRO Trace 9**

What is the PERIODIC TIME for the sine wave displayed on the CRO (in seconds)?

Volts per Division: 1V
Time per Division: 100ms

10. **Refer to CRO Trace 1**

What RMS VOLTAGE is indicated on the oscilloscope display?

Volts per Division: 1V
Time per Division: 1ms

11. **Refer to CRO Trace 3**

What is the phase difference between the two sine curves?

Volts per Division: 1V
Time per Division: 100µs

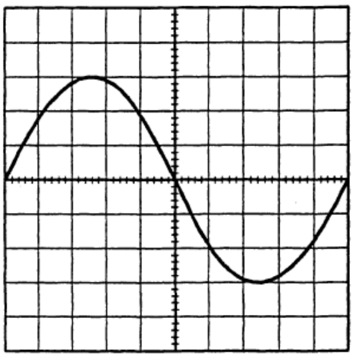
12. **Refer to CRO Trace 1**

What PEAK TO PEAK VOLTAGE is indicated on the CRO display (in volts)?

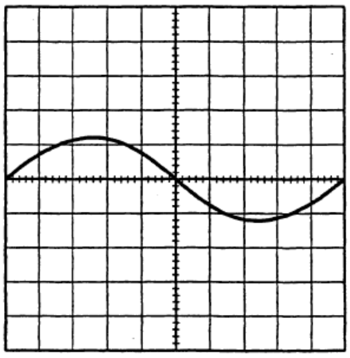
Volts per Division: 100V
Time per Division: 100ms

Oscilloscope Displays

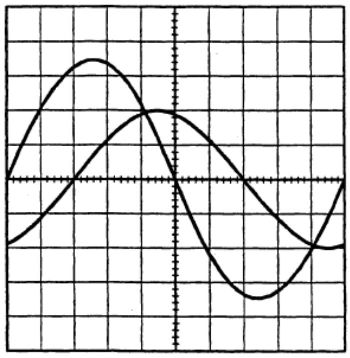
TRACE 1



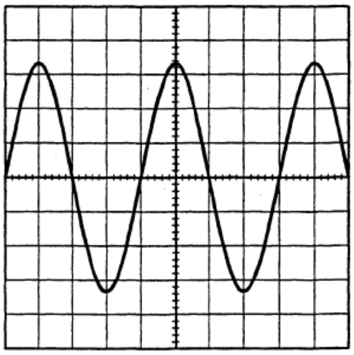
TRACE 2



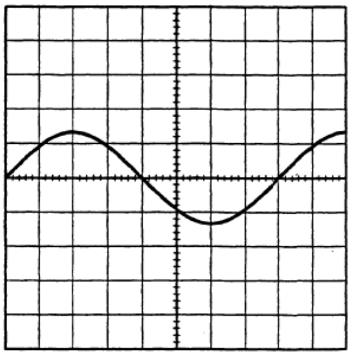
TRACE 3



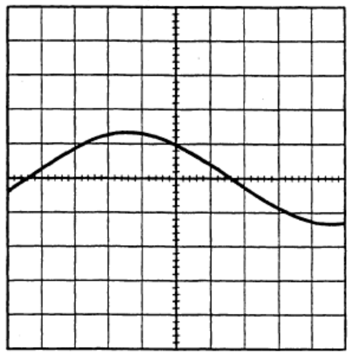
TRACE 4



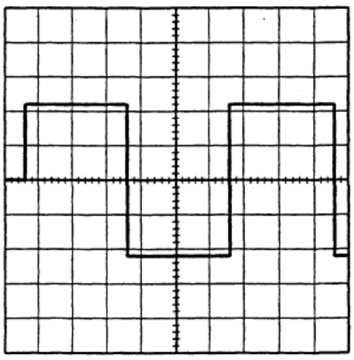
TRACE 5



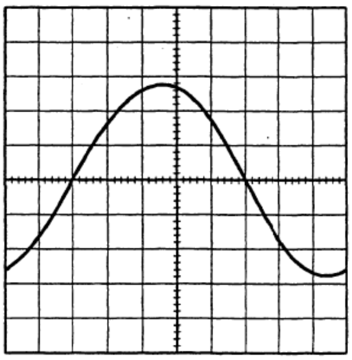
TRACE 6



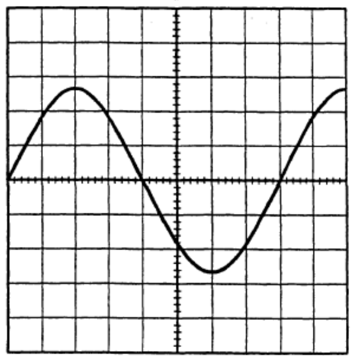
TRACE 7



TRACE 8



TRACE 9



NOTES

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 3 Project	G102A JW/JD DEC 2013

RMS VALUE OF A.C.

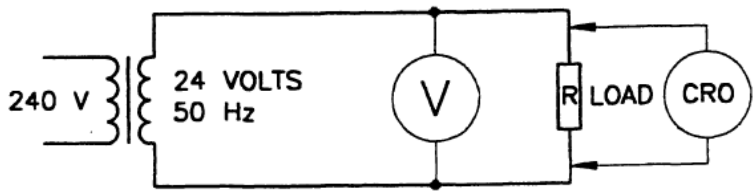
Objective

To verify the relationship between the peak value and the rms value of a sinusoidal a.c. waveform.

Equipment

RMS measurement project board
ELV a.c. power supply (24 volts or similar)
Oscilloscope (CRO)
Connecting leads
Multimeter

Circuit Diagram



Procedure

1. Connect the circuit according to the circuit diagram above.

2. Check for short circuits with a multimeter set on the ohms x 1 range. Switch the multimeter off after the check.

3. Have your connections checked by your Lecturer.

4. Energise the circuit, and determine the peak value and frequency of the waveform using the CRO. Accurately sketch the CRO display in the space provided below.

5. Measure the voltage across the load resistor with a multimeter and record the result.

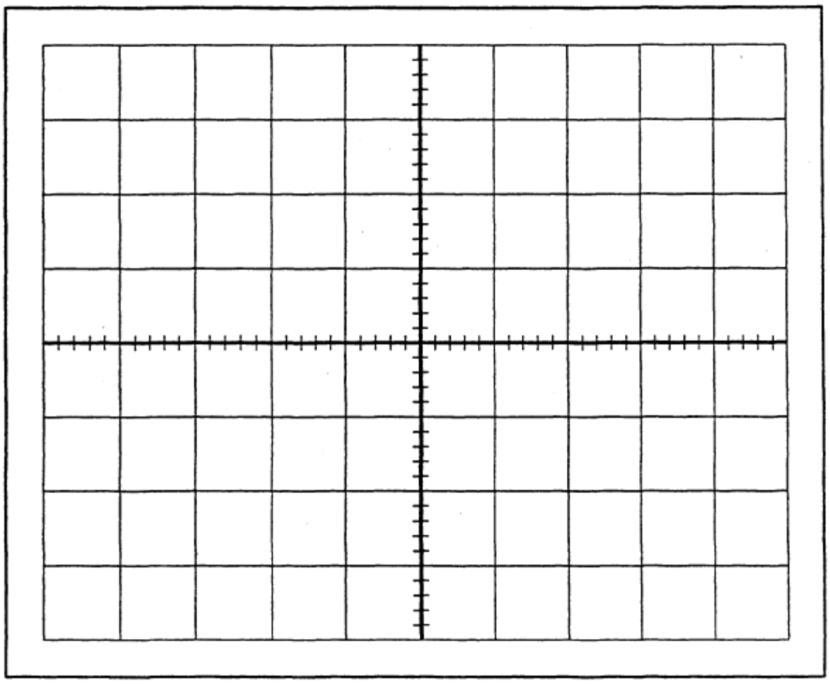
6. Switch the circuit off and remove the plug from the outlet.

7. Have your results checked by your Lecturer.

8. Disconnect your wiring and return all of the equipment to its proper place.

Results

CRO Display



Time/div Setting: ____

Volts/div Setting: ____

Peak Voltage: ____

Peak to Peak Voltage: ____

Instantaneous Voltage at 30º: ____________________________________

Calculated Frequency: ____Hz

Multimeter

Voltage Range: ____

Voltmeter Reading: ____

Questions

1. Was the peak value indicated on the CRO the same as the value indicated on the multimeter? If not, explain why.

2. What is the theoretical rms value of a sinusoidal a.c. waveform which has a peak value of 100V?

   _________________________ volts

3. What is the theoretical peak value of a sinusoidal a.c. waveform which has an rms value of 100V?

   _________________________ volts

4. What peak value of a.c. has the same heating effect as $100V_{dc}$?

5. If a typical multimeter indicated $240V_{ac}$ across the supply terminals of single phase single insulated appliance, what is the minimum voltage the appliance insulation must be able to withstand to earth in the circuit?

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Single element A.C. circuits

Task:

To describe the behaviour and characteristics of resistors, inductors and capacitors in single phase a.c. series and parallel circuits.

Why:

All electrical devices which operate on alternating current have resistance, inductance and capacitance. An understanding of the general principles of the behaviour of resistors, inductors and capacitors in circuits is essential to understanding the operation of all other a.c. devices.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a written assessment.
2. You must satisfactorily complete the set laboratory tasks.
3. You must achieve 100% in a final practical assessment.

Equipment:

a.c. Theory Project Boards
Sample resistors, inductors and capacitors
Oscilloscope
ELV A.C. Power Supply
A.C. Ammeters
A.C. Voltmeters
Multimeters
Scientific Calculator

References

- Electrical Principles for the Electrical Trades (6th ed.) Jenneson & Harper
- AS/NZS 3000-2018
- WAER

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Single Element a.c. Circuits

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades (6th ed.)

Vol 1: 9.2 Resistance in a.c. circuits
Vol 1: 9.3 Inductance in a.c. circuits
Vol 1: 9.4 Capacitors in a.c. circuits

More Electrical Principles

Chapter 7 Inductive and Capacitive Reactance

2. Read the Summary and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Complete the projects in this manual.

5. Submit your answers on the Work Sheet and your completed project reports to your lecturer for discussion and assessment.

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 4 Summary	G102A JW/JD DEC 2013

Single Element A.C. Circuits

Resistance in A.C. Circuits

1. The resistance of a material is the opposition it offers to the passage of current, and it depends upon the type of material, its length, its cross-sectional area and its temperature. When an a.c. circuit contains resistance only, the current in the circuit can be calculated directly from Ohm's Law, provided that rms values are used.

2. In purely resistive circuits, changes in the applied voltage cause corresponding changes in the current, with the result that current and voltage are in phase, as shown in Figure 1.

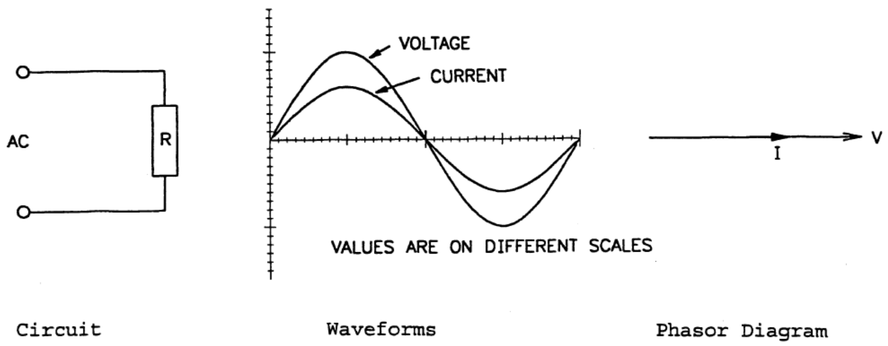


Figure 1 - Voltage and current relationships in a resistor

Power in Resistive Circuits

3. When current flows in a resistive circuit, it produces heat, regardless of its direction. As rms (or effective) values of a.c. produce the same heating effect as the same values of d.c., the rate of energy dissipation, or power, in a purely resistive circuit can be calculated using any one of the following equations (if rms values are used):

$$P = V \times I \qquad P = I^2 \times R \qquad P = \frac{V^2}{R}$$

4. In purely resistive circuits, all of the electrical energy is converted to heat energy. The rate at which electrical energy is converted to heat energy is expressed in watts.

5. The waveforms of the power in a purely resistive circuits on a.c. is shown in Figure 2.

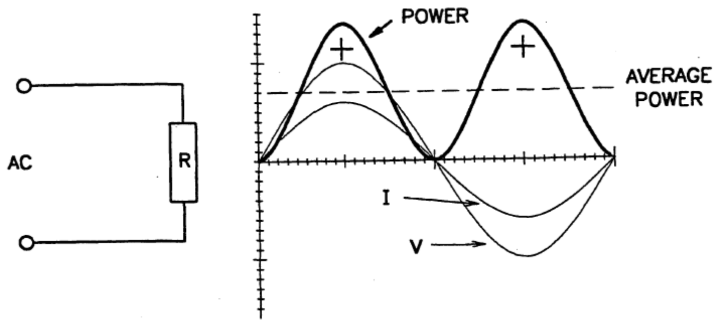


Figure 2 - Power in a purely resistive circuit

6. The waveform in Figure 2 is obtained by plotting the instantaneous values of voltage and current over one complete cycle. The horizontal line which forms the X axis of the POWER curve represents the AVERAGE power over the complete cycle. Note that the algebraic product of two negative values is positive (negative times negative gives positive), so during the half cycle when both voltage and current are negative, the power is positive. Positive power is defined as power taken from the mains, so in a purely resistive circuit, all of the power is taken from the mains and converted to heat.

Inductance in A.C. Circuits

7. An inductor is a device in which energy is stored in a magnetic field. When the current through an inductor changes, the changing magnetic flux induces a back emf in the inductor, which, in accordance with Lenz's Law, opposes the original change in current.

8. The ability of a circuit to oppose any change in the current is known as inductance (L). The unit of inductance is the Henry, and a circuit has an inductance of 1 Henry when a current changing at a rate of one ampere per second, induces in it an emf of one volt.

9. All conductors possess inductance; even a straight wire has an emf induced in it when the magnetic field surrounding it changes. However, almost all practical 'inductors' such as a.c. motors and transformers have insulated winding wire wound into coils, the physical properties of which determine the inductance value.

10. When a.c. flows in an inductive circuit, the continually changing current and magnetic flux causes an opposition to current flow, which is different from the normal circuit resistance. The opposition offered by inductance or capacitance is called reactance (X).

11. The factors which govern the inductance of a coil on a.c. are:

    a. The number of turns – as the turns increases, the inductance increases.

    b. The area of the magnetic core – the larger the core, the higher the inductance.

    c. The relative permeability of the core – the higher the permeability, the higher the inductance.

    d. The length of the inductor – the inductance decreases as the mean length of the magnetic core increases.

12. The opposition to current flow in an inductor is called Inductive Reactance, and is measured in ohms. The quantity symbol for inductive reactance is X_L

13. The inductive reactance of a coli on a.c. can be calculated using the equation:

$$X_L = 2\pi f L$$

$$\begin{aligned} \text{Where } X_L &= \text{Inductance Reactance} \\ \pi &= \text{Pi} \\ f &= \text{Frequency of the supply in Hz} \\ L &= \text{Inductance of the coil in Henrys} \end{aligned}$$

14. **Example 1**

    Find the inductive reactance of a 2H inductor connected to a 50Hz a.c. supply.

    Solution

$$\begin{aligned} X_L &= 2\pi f L \\ &= 2 \times 3.142 \times 50 \times 2 \\ X_L &= 628.3\Omega \end{aligned}$$

15. **Example 2**

    Find the inductive reactance of a 2 Henry inductor when it is connected to a 5000Hz (5 kHz) a.c. supply.

    Solution

$$\begin{aligned} X_L &= 2\pi f L \\ &= 2 \times 3.142 \times 5000 \times 2 \\ X_L &= 62.832k\Omega \end{aligned}$$

16. **Example 3**

Find the inductive reactance of a 2H inductor when it is connected to a 5Hz a.c. supply

Solution

$$\begin{aligned} X_L &= 2\pi f L \\ &= 2 \times 3.142 \times 5 \times 2 \\ X_L &= 62.83\Omega \end{aligned}$$

17. You can see from the examples above that the inductive reactance increases as the frequency increases (they are directly proportional). It is also worth noting that the inductive reactance does NOT depend on the voltage applied to the circuit.

18. In practice, it is impossible to obtain a purely inductive coil, as its windings and connections must possess some resistance, and when this is large, it must be taken into account when determining the total opposition to current. However, when the resistance is small in comparison with the reactance, it can be ignored in simple calculations.

Inductors on AC

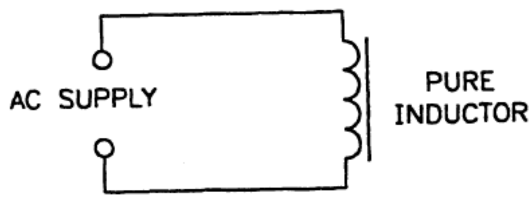
19. An inductor stores energy in the form of a magnetic field, and returns some of the energy to the mains during part of each half cycle, so the behaviour of an inductor on a.c. is quite different to the behaviour of a resistor.

20. The current in a pure inductor lags the voltage by 90 degrees on a.c.

21. The behaviour of a pure inductor (an inductor which has no d.c. resistance) can be described as follows:

Figure 3a shows a circuit containing a pure inductance connected to a sinusoidal a.c. supply.

a



When the voltage is applied, the instantaneous values of current (and magnetism) over one cycle would be as shown in Figure 3b. (Note that current and magnetism are always in phase with each other).

As the magnetic field caused by the current changes, it induces a voltage into the inductor, which opposes the change in current (Lenz's Law). A graph of the resulting induced voltage over one cycle is shown in Figure 3c.

At the instant at which the current and magnetism are maximum (points 2 and 4 in 3d), they are not Changing, therefore there can be no induced voltage. When the current and magnetism are changing at their greatest rate (changing from positive to negative or visa versa – points 1, 3 and 5 in 3d), the induced voltage must be maximum.

Lenz's Law states that an induced voltage will be opposite to the applied voltage, so the voltage causing the current (the applied voltage) must be opposite to the induced voltage (they must be 180° out of phase).

Since there are no losses in the circuit, the applied voltage must be equal to the induced voltage, but 180°out of phase with it, so a graph of the applied voltage and line current would be as shown in Figure 3d.

If the induced voltage is deleted from the graph, it can be seen that the line voltage and line current are 90°out of phase with each other, and the current is lagging the voltage by 90°as shown in Figure 3e.

Figure 3f shows a phasor diagram of the relationship between current and voltage in a purely inductive circuit on a.c.

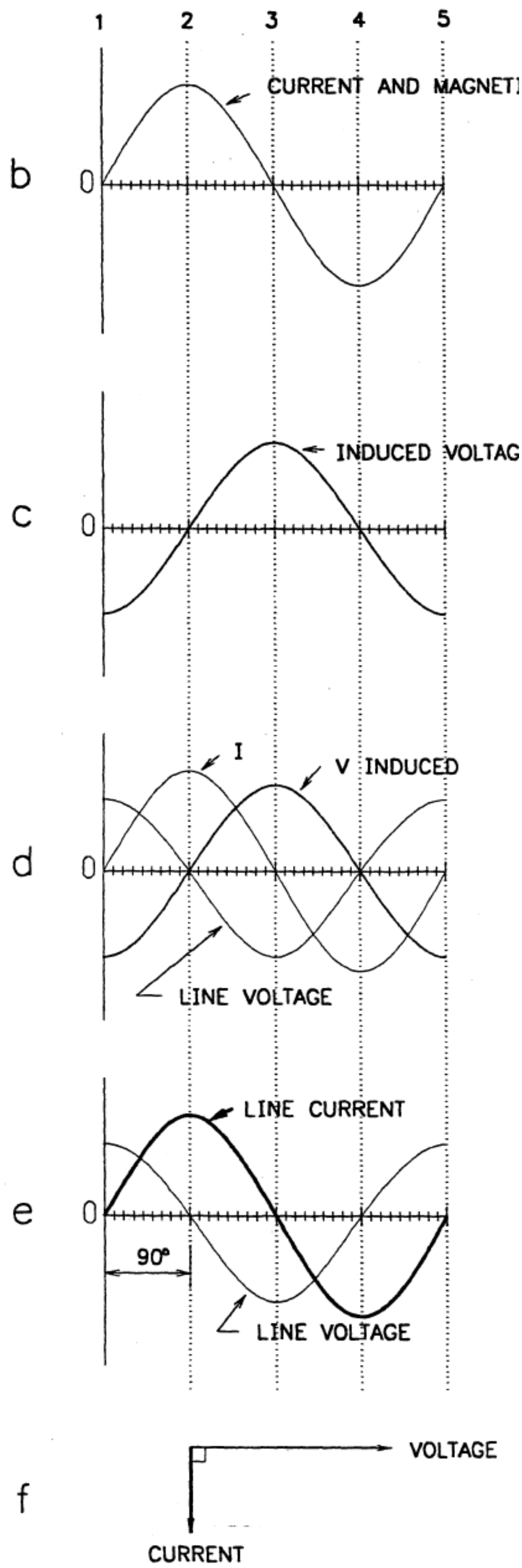


Figure 3 - An inductor on a.c.

22. The statement 'current lags the applied voltage by 90°' is correct only when the inductor has no resistance. In practical inductors, which contain resistance as well as inductive reactance, the applied voltage is distributed partly across the resistance and partly across the reactance.

Power in Inductive Circuits

23. When a.c. flows in an inductor, a magnetic field builds up and collapses every half cycle. During the first quarter cycle, energy is taken from the supply, and when the field collapses during the next quarter cycle, energy is supplied back into the supply. Although current flows, no energy is expended in a purely inductive circuit, so the average power in a purely inductive circuit on a.c. is zero.

24. Figure 4 shows the instantaneous values of power (V x I) over one complete cycle. The power above the X axis is regarded as positive power (power taken from the mains), and the power below the X axis is regarded as negative power (power returned to the mains); since the amount of positive power equals the amount of negative power, the average power in a purely inductive circuit is zero.

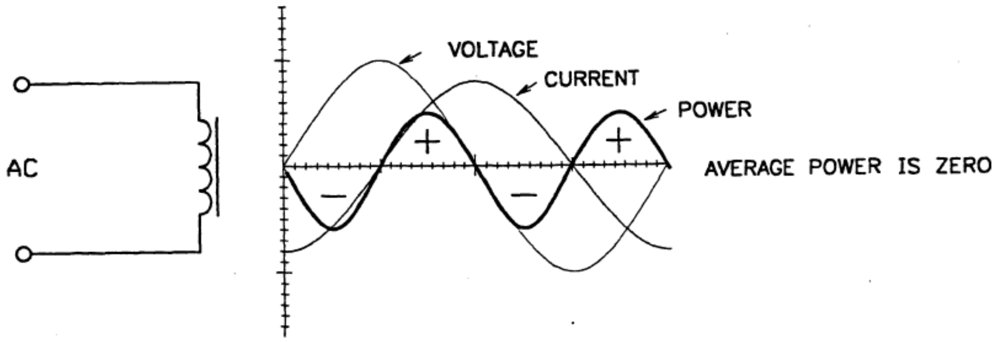


Figure 4 - Instantaneous power over one full cycle.

Capacitance in AC Circuits

25. A capacitor is a device in which electrical energy is stored in an electrostatic field.

26. The unit of capacitance is the Farad. A capacitor has a capacitance of one Farad when a charge of one coulomb raises the potential difference across the plates by one volt.

27. The Farad is too large for practical use, so sub-multiple units are generally used. The most common sub-multiples are the microfarad (μF), which is one millionth of one Farad, and the picofarad (pF), which is one million-millionth of one Farad.

28. When an alternating voltage is applied to a capacitor, the capacitor alternately charges and discharges. Although no current passes through the dielectric, a.c. flows in the external circuit.

29. When a.c. flows in a capacitive circuit, the continual charging and discharging of the capacitor causes an opposition to current flow, which is different from the normal circuit resistance. The opposition offered by a capacitive component is called capacitive reactance (X_C).

30. The factors which govern the capacitance of a capacitor on a.c. are:

    a. The distance between the plates – as the distance increases, the capacitance decreases.
    b. The area of the plates – the larger the plate area, the higher the capacitance.
    c. The dielectric constant of the material between the plates – the higher the dielectric constant, the higher the capacitance.

31. The opposition to current flow in a capacitor is called Capacitive Reactance, and is measured in ohms. The quantity symbol for capacitive reactance is X_C.

32. The capacitive reactance of a capacitor on a.c. can be calculated using the equation:

$$X_C = \frac{1}{2\pi f C}$$

Where X_c = capacitive reactance in ohms
π = Pi
f = frequency of the supply in Hz
C = capacitance of the capacitor in Farads

33. **Example 1**

    Find the capacitive reactance of a 3μF capacitor when it is connected to a 50Hz a.c. supply.

    Solution

$$X_C = \frac{1}{2\pi fC}$$
$$= \frac{1}{2 \times 3.142 \times 50 \times 3 \times 10^{-6}}$$
$$X_C = 1.061\text{k}\,\Omega$$

34. **Example 2**

    Find the capacitive reactance of a 3μF capacitor when it is connected to a 5000Hz (5 kHz) a.c. supply.

    Solution

$$X_C = \frac{1}{2\pi fC}$$
$$= \frac{1}{2 \times 3.142 \times 5000 \times 3 \times 10^{-6}}$$
$$X_C = 10.61\Omega$$

35. **Example 3**

Find the capacitive reactance of a 3μF capacitor when it is connected to a 5Hz a.c. supply.

Solution

$$X_C = \frac{1}{2\pi fC}$$

$$= \frac{1}{2 \times 3.142 \times 5 \times 3 \times 10^{-6}}$$

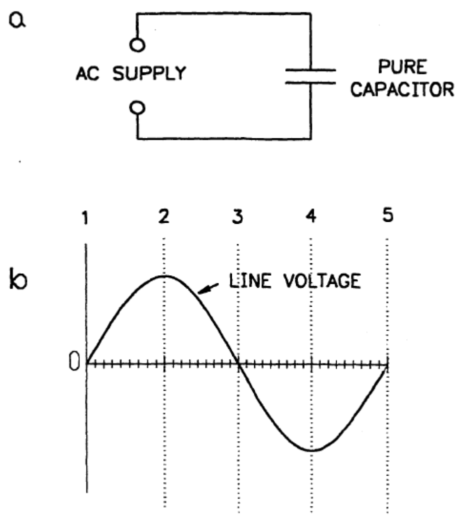
$$X_C = 10.61k\Omega$$

36. You can see from the examples above that the capacitive reactance decreases as the frequency increases (they are inversely proportional). If a capacitor is connected to d.c. (0Hz), the capacitive reactance (X_C) is infinite. It is also worth noting that the capacitive reactance does NOT depend on the voltage applied to the circuit.

Capacitors on AC

37. Current only flows in a capacitive circuit while the capacitor is charging or discharging (when the state of charge is changing). Maximum current flows when the charge is changing at the greatest rate. In a.c. circuits containing capacitance only, this instant occurs when the applied voltage is zero. In such circuits, the current leads the applied voltage by 90°.

Figure 5a shows a circuit in which a 'pure' capacitance is connected to a sinusoidal a.c. supply. An alternating sine wave voltage is applied and a current flows. The voltage maintained across the capacitor is shown in Figure 5b.



As the charge on the capacitor is proportional to the voltage maintained across it, (Q = CV), the charge on the capacitor rises and falls in phase with this voltage, as shown in Figure 5c.

At points 2 and 4 on Figure 5d, the charge is momentarily steady. As current can flow only when the state of charge is changing, the current at these points is zero.

At point 1, 3 and 5, the charge is changing at the greater rate, and thus the current is at a maximum value at these instants. At points 1 and 5, the charge is changing in a positive direction, co current at these points reaches its maximum positive value. At point 3, the charge is changing in a negative direction, therefore the current attains its maximum negative value. The variations in current are shown in Figure 5d.

In Figure 5e it can be seen that the current reaches its maximum positive value one quarter of a cycle, or 90°, before the voltage.

In a purely capacitive circuit therefore, the current leads the applied voltage by 90°.
The phasor diagram of current and voltage in a purely capacitive circuit is shown in Figure 5f.

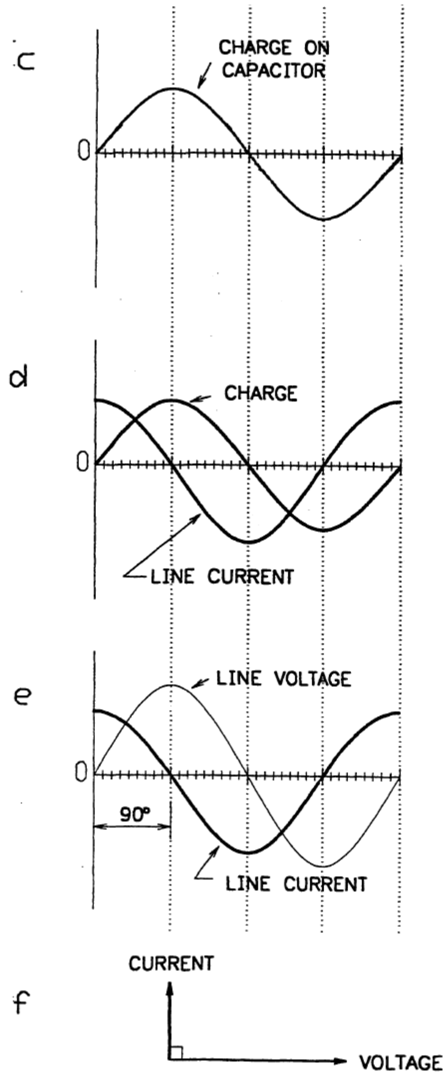


Figure 5 – Capacitor on a.c.

Power in Capacitive Circuits

38. A capacitor in an a.c. circuit charges and discharges twice during each cycle. The energy stored when the capacitor charges is returned to the circuit during discharge, and total power dissipation for each half cycle is zero.

39. When a.c. flows in a capacitor, the capacitor charges and discharges at regular times during each cycle. During the first quarter cycle, energy is taken from the source to create the electrostatic field. This energy is returned to the supply when the capacitor discharges during the next quarter cycle. Although current flows, no energy is expended in a purely capacitive circuit, so the average power in a purely capacitive circuit on a.c. is zero.

40. Figure 6 shows the instantaneous values of power (V x I) over one complete cycle. The power above the X axis is regarded as positive power (power taken from the mains), and the power below the X axis is regarded as negative power (power returned

to the mains). Since the amount of positive power equals the amount of negative power, the average power in a purely capacitive circuit is zero.

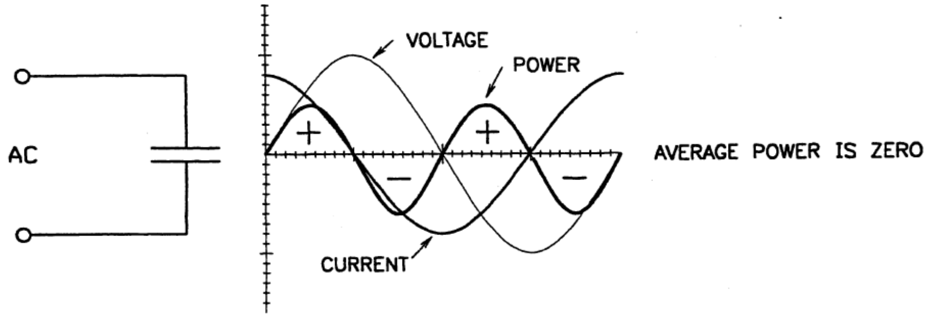


Figure 6 – Power in a purely capacitive circuit

Safety

41. Capacitors can retain a charge after the charging voltage has been removed, so it is possible for them to be charged although they are not connected in a circuit. As a safety precaution, you should always short circuit the line terminals of a disconnected capacitor before you begin working on it. Capacitors in typical a.c. fluorescent luminaires have a 1MΩ ‘bleed’ resistor connected across them to discharge the capacitor as required by the Wiring Rules.
    Read AS/NZS 3000 Clause 4.15 to be familiar with the requirements for capacitors connected to the electrical supply system.

Inductors and Capacitors in Series and Parallel

42. Inductors can be connected in series and parallel to increase or decrease the total inductance or inductive reactance of the circuit. The method of calculating total inductive reactance is similar to the method used for series and parallel resistors:

Series Inductors

$$X_{L_T} = X_{L_1} + X_{L_2} + X_{L_3} + ...$$

Parallel Inductors

$$\frac{1}{X_{L_T}} = \frac{1}{X_{L_1}} + \frac{1}{X_{L_2}} + \frac{1}{X_{L_3}} + ...$$

Exercise

43. Calculate the total inductive reactance of a bank of two inductors connected in parallel, if the inductances are 0.5H and 1.5H respectively. The supply frequency is 50 Hz.

44. Capacitors can be connected in series and parallel to decrease or increase the total capacitance or capacitive reactance of the circuit. The method of calculating total capacitive reactance is similar to the method used for inductive reactance.

Series Capacitors

$$X_{C_T} = X_{C_1} + X_{C_2} + X_{C_3} + ...$$

Parallel Capacitors

$$\frac{1}{X_{C_T}} = \frac{1}{X_{C_1}} + \frac{1}{X_{C_2}} + \frac{1}{X_{C_3}} + ...$$

Exercise

45. Calculate the total capacitive reactance of a bank of three paper capacitors connected in parallel, if the capacities are 12µF, 6µF and 2µF respectively, and the supply frequency is 50 Hz. What is the total capacitive reactance if the capacitors were re-connected in series?

Capacitor Application

46. The three main applications for capacitors in power electrical work are power factor improvement, single phase motor starting and arc suppression. They are widely used in electronic circuits. Detailed consideration of these applications is beyond the scope of this module.

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Single Element a.c. Circuits

1. Name the unit in which the opposition to current flow is expressed in a .d.c. circuit.
2. All electrical devices have three (and only three) basic electrical properties – what are they?
3. Which two basic electrical properties can usually be disregarded in a resistor at normal power frequencies (i.e. at 50 Hz)?
4. What is the phase relationship between voltage and current in an AC circuit which consists entirely of resistive components?
5. What is the QUANTITY symbol for resistance?
6. What is the UNIT symbol for the basic unit of resistance?
7. How much of the electrical energy dissipated by the resistor is converted to heat energy?
8. What is the most significant electrical property possessed by a coil wound on a ferromagnetic core, and connected to an a.c. supply?
9. In what basic unit is inductance expressed?
10. What is the quantity symbol for inductance?
11. What is the unit symbol for the basic unit of inductance?
12. What is the average power consumed by a pure inductor in an a.c. circuit?
13. A particular a.c. coil draws 4A from a 240V, 50Hz supply. What is the inductance of the coil (ignore its d.c. resistance)?
14. What effect does it have on the inductance of an inductor if the supply frequency is increased?
15. If an inductor had an inductive reactance of 200Ω, what is its inductance if the supply frequency is 50 Hz?
16. What is the name given the opposition to current flow offered by a purely inductive device on a.c.?
17. What is the QUANTITY symbol for inductive reactance?
18. In what unit is inductive reactance expressed?
19. What is the UNIT symbol for the basic unit of inductive reactance?

20. What effect would it have on the inductive reactance of an inductor if the supply frequency was increased?

21. How much electrical energy is converted to heat energy in a purely inductive component over a period of one cycle?

22. Draw a phasor diagram showing the relationship between line current and line voltage in a purely inductive circuit.

23. Calculate the inductive reactance of a 0.4H inductor when it is connected to a 240V, 50Hz supply. Neglect the resistance of the coil.

24. What is the most common practical unit in which capacitance is expressed?

25. What is the quantity symbol for capacitance?

26. What is the unit symbol for the most common practical unit of capacitance?

27. If a single fixed capacitor has been installed in an a.c. circuit, what can cause its capacitance to change significantly?

28. What is the name given the opposition to current flow offered by a purely capacitive device on a.c.?

29. What is the QUANTITY symbol for capacitive reactance?

30. In what unit is the basic unit of capacitive reactance expressed?

31. What is the UNIT symbol for the basic unit of capacitive reactance?

32. What effect would it have on the capacitive reactance of a capacitor if the supply frequency was increased?

33. How much electrical energy is converted to heat energy in a purely capacitive component over a period of one cycle?

34. Draw a phasor diagram showing the relationship between line current and line voltage in a purely capacitive circuit on a.c.

35. Calculate the capacitive reactance of a 3.5μF capacitor on a 50Hz supply.

36. What is meant by the term ‘positive power’ when applied to the power in an a.c. circuit?

37. What type of a.c. circuit does not have any negative power?

38. A particular capacitor draws 3A from a 240V, 50Hz supply. What is the capacitive reactance of the capacitor?

39. Calculate the total inductive reactance of two 1.5H inductors, if they are connected in series to a 50Hz a.c. supply.

40. Calculate the total capacitive reactance of THREE 6μF capacitors if they are connected in series to a 50Hz supply.

41. What safety precaution should be taken before handling a 240V, 5µF power capacitor?

42. What is the smallest capacity capacitor which may be installed without a discharge path according to AS/NZS 3000:2018?

43. What are the two factors which govern the voltage drop in a purely resistive a.c. circuit, according to Ohm's law?

NOTES

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Resistance in an A.C. Circuit

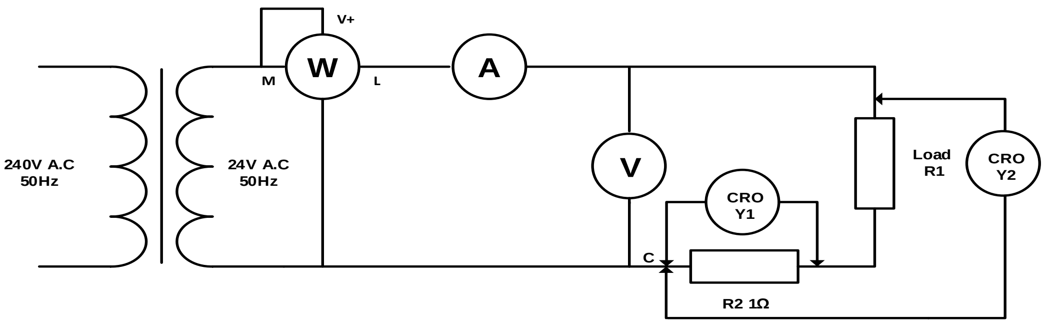
Objective

To verify the relationship between the values in a resistive a.c. circuit

Equipment

Resistive a.c. project board with 2 power resistors
1 ohm wire wound series resistor
0 – 1 KW single phase analogue wattmeter
Dual Trace Oscilloscope (CRO)
Bridge Megger
Ammeters and voltmeters as required
Multimeter
ELV a.c. power supply – 24 volts or similar (double wound transformer)
Connecting leads

Circuit Diagram



Procedure

1. Measure the resistance of R1 using the Bridge Megger. Record the resistance in Results Table 1.

2. Determine the nominal voltage of the extra-low voltage a.c. power supply by inspection of the nameplate.

3. Calculate the expected values of current and power in the circuit, and record your results in Table 1.

4. Connect the components as shown in the circuit diagram above. Make sure that the ranges of the instruments selected are appropriate for the expected circuit values.

5. Connect one channel of the CRO across the output from the ELV supply, and the other in parallel with the 1Ω series resistor. **Make sure that the common terminal is connected as shown in the circuit diagram.**

6. Have your connections checked by your Lecturer.

7. Energise the circuit and adjust the CRO to display at least one cycle on each channel. Record all readings in the Results Table; the readings need to be as accurate as possible.

8. Determine the peak voltage indicated on the CRO. Accurately sketch the CRO display in the space provided below.

9. Compare the readings obtained with the values previously calculated.

10. Switch the circuit off, and remove the plug from the outlet.

11. Have your results checked by your Lecturer.

12. Repeat the procedure using the other load resistor on the project board.

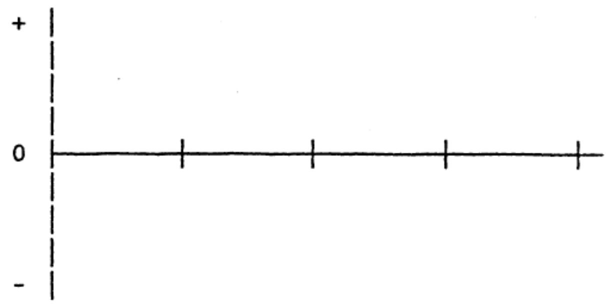
13. Disconnect your wiring and return all of the equipment to its proper place.

Results Table 1 (Resistor 1)

	Observed or Calculated	Measured	Comment
Resistance			
Applied Voltage			
Line Current			
Power			

Observed phase angle between voltage and current ____________________degrees

Sketch of phase Relationship (1 cycle):

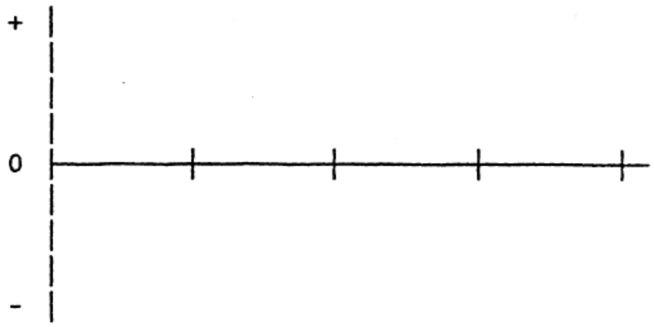


Results Table 2 (Resistor 2)

	Observed or Calculated	Measured	Comment
Resistance			
Applied Voltage			
Line Current			
Power			

Observed phase angle between voltage and current ____________________degrees

Sketch of phase Relationship (1 cycle):



Questions

1. Were the meter readings exactly the same as the calculated values? If not, explain why there were differences.

2. Was the voltmeter reading approximately equal to the peak voltage displayed on the CRO? If not, explain why they were different.

3. From your results, what was the average rate at which electrical energy was being converted to heat when the circuit was operating?

   Resistor 1: ______________________________

   Resistor 2: ______________________________

4. What was the phase relationship between the line voltage and the current through the resistor, as indicated on the CRO?

____

5. Was the wattmeter reading approximately equal to the product of the measured line current and line voltage in the circuit?

____

6. How much of the total circuit power was being dissipated in the resistors?

   For Resistor 1: ______________________________

   For Resistor 2: ______________________________

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R, L and C in Parallel

Task:

To describe the behaviour of a.c. circuits consisting of resistive, inductive and capacitive components connected in parallel to a sinusoidal single phase supply.

Why:

All electrical devices which operate on alternating current have resistance, inductance and capacitance. An understanding of the general principles of the behaviour of resistors, inductors and capacitors in parallel is essential to understanding the operation of a.c. devices.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a written assessment.
2. You must satisfactorily complete the set laboratory tasks.
3. You must achieve 100% in a practical assessment.

Equipment

A.C Theory Project Boards
Sample resistors, inductors and capacitors
ELV A.C. Power Supply
A.C. Ammeters
A.C. Voltmeters
Multimeters
Scientific Calculator

References

- Electrical Principles for the Electrical Trade, J.R. Jenneson
- More Electrical Principles, I. Batty. Prentice Hall

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R, L and C in Parallel

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades (6th ed.)

Vol. 1: 9.6 Parallel R-L-C circuits on a.c. current

More Electrical Principles

Chapter 7 Inductive and Capacitive Reactance

2. Read the Summary and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.
3. Answer the questions given on the Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.
4. Complete the projects in this manual.
5. Submit your answers on the Work Sheet and your completed project reports to your Lecturer for discussion and assessment.

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Resistance, Inductance and Capacitance in Parallel

1. In a resistive circuit on a.c., the current is limited by the resistance of the resistor, and all the energy going into the circuit is converted to heat energy.

Inductive Circuits

2. In a purely inductive circuit on a.c., the current is limited by the inductive reactance of the inductor, and all of the energy going into the circuit is stored in a magnetic field and returned to the mains during each quarter cycle, so the total energy consumption is zero. Although the total energy consumption is zero, current still flows in the circuit – (it can be measured with a normal ammeter), but it is 90°out of phase with the voltage. The current in an inductor LAGS the voltage by 90°.

Parallel RL Circuit

3. If a resistor with a resistance (R) of 10Ωwas connected in parallel with a pure inductor with an inductive reactance (X_L) of 10Ω, and the supply voltage was 100V a.c., the circuit could be drawn as shown in Figure 1.

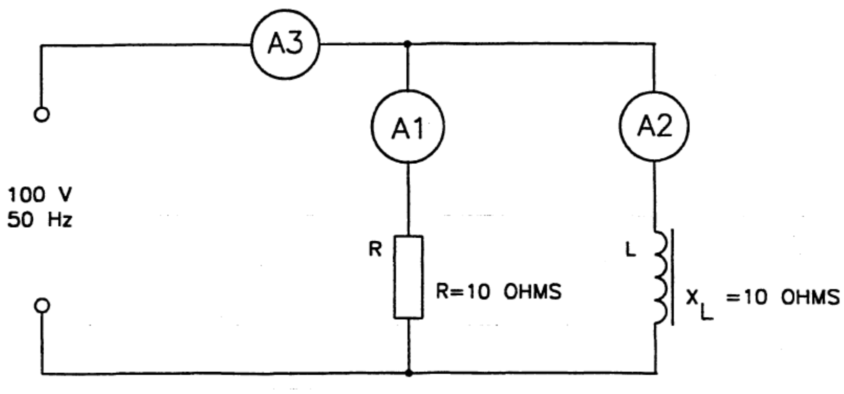


Figure 1 – RL parallel circuit

4. The current flowing in each individual component of the circuit in Figure 1 could be calculated using Ohm's Law:

Resistor Current

$$I = \frac{V}{R} = \frac{100}{10}$$
$$I = 10A$$

Inductor Current

$$I = \frac{V}{X_L} = \frac{100}{10}$$
$$I = 10A$$

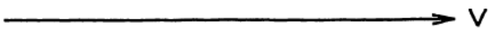
5. Thus, the ammeters A1 and A2 would each be indicating 10A. What do you think the reading would be on the ammeter A3?

6. If it was a d.c. circuit with two 10Ω resistors in parallel, the total current in the circuit would be 20A. However, since it is an a.c. circuit, the current in the inductor is lagging behind the line voltage by 90°, so the currents are not reaching maximum at the same time during each cycle, therefore the total current is NOT the sum of the two component currents. Although each ammeter would be indicating 10A, the instruments are not capable of indicating that the maximum values of current are occurring at different times during each cycle.

Phasors

7. To calculate the line current (the current which would be indicated on ammeter A3), it is necessary to draw a phasor diagram of the currents in each component, and determine the resultant current using phasor addition.

8. When drawing a phasor diagram involving more than one component, it is usually necessary to begin by drawing the phasor for the value which is the same in each component. In a parallel circuit the VOLTAGE is the same in each component, so the voltage phasor is used as the reference phasor. The reference phasor should be drawn as horizontal phasor pointing from left to right; current phasors are drawn with closed arrowheads and voltage, resistive or reactive phasors are drawn with open arrowheads.



REFERENCE PHASOR

Reference Phasor (Volts)

9. Using the voltage phasor as the reference, the current in the resistor (I_R) and the current in the inductor (I_L) would be shown as in Figure 2.

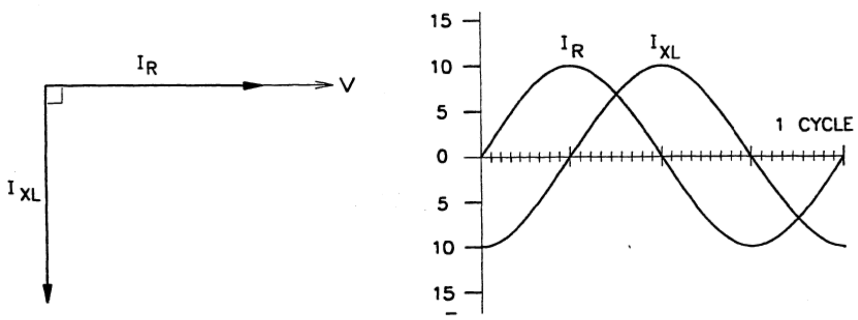


Figure 2 – Phasor Diagram

10. Phasors can be used to show the phase relationship between two or more quantities, but they can only be added if they are the SAME quantity. To add the phasors of the two currents, complete the phasor parallelogram – the diagonal line then represents the phasor sum (or resultant) as shown in Figure 3.

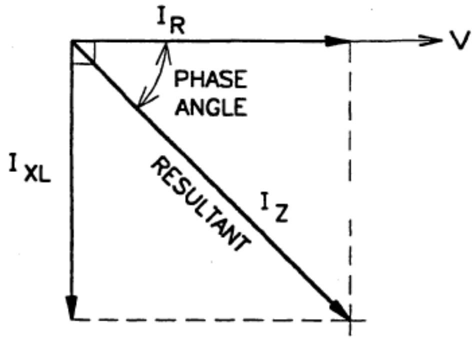


Figure 3 – the phasor sum of I_R and I_{XL}

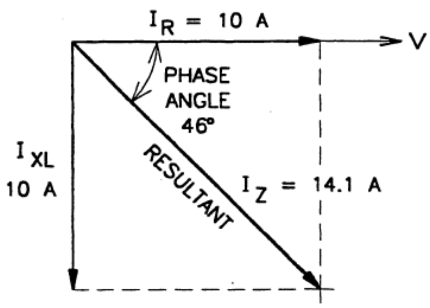
11. The length of the resultant represents the line current (total circuit current), and the angle between the resultant and the reference phasor, represents the angle by which the current is lagging the line voltage.

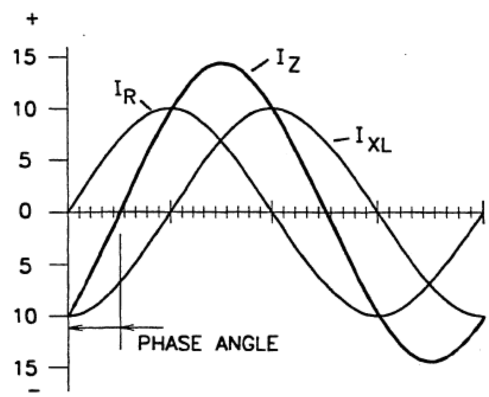
12. The length of the resultant can be found using Pythagoras' Theorem:

$$I_Z = \sqrt{I_{R_2} + I_{X_{L2}}}$$
$$= \sqrt{10^2 + 10^2}$$
$$= \sqrt{200}$$
$$I_Z = 14.1A$$

13. So the reading on the line ammeter (A3) in Figure 1 would be 14.1A (rounded to 1 decimal place).

14. If we show the resultant (the line current) on a phasor diagram, it becomes:





The Phase Angle

15. Since the phasor diagram is based on right triangles, trigonometry can be used to find the phase angle. The cosine is adj/hyp, so the cosine of the phase angle (Phi) is 10/14.1, or 0.707. The angle which has a cosine of 0.707 is 45°, so the phase angle (Φ) is 45°(using a calculator). Since the circuit is inductive, the current must be LAGGING the applied voltage, so the phase angle (Φ) is 45° lagging. (The phase angle can also be found using other trigonometrical ratios).

Impedance (Z)

16. You know from Ohm's Law that I = V/R, where R is the total opposition to the flow of current. In a.c. circuits, which have inductive or capacitive components, the opposition to current flow is called REACTANCE instead of resistance, because the currents are out of phase with the voltage. Therefore, the terms inductive reactance (X_L) and capacitive reactance (X_C) are used. In resistive a.c. circuits, the opposition to current flow is still known as resistance (R). In a.c. circuits the term IMPEDANCE (Z) is used to represent the total opposition to current flow. Resistance, inductive reactance, capacitive reactance and impedance are all expressed in OHMS (or a metric multiple or sub-multiple).

17. In the parallel circuit in Figure 1, the current in the circuit is the result of a particular value of total opposition to current flow (impedance) when connected to $100V_{ac}$. We know that the line current is 14.1A from the earlier calculation, so we can calculate the opposition to current flow using a variation of Ohm's Law in which impedance replaces resistance. On d.c. R = V/I, but on a.c. Z = V/I.

18. Thus the total opposition to the flow of current in the circuit (the impedance) is:

$$
\begin{aligned}
Z &= \frac{V}{I} \\
&= \frac{100}{14.1} \\
Z &= 7.09\Omega
\end{aligned}
$$

Calculating Inductive Reactance

19. In the circuit given above, the current in the inductive reactance was given as 10A. If the inductance (L) was given instead of the inductive reactance (XL), the inductive reactance would have to be calculated before the current in the inductor could be obtained. Inductive reactance can be calculated using the equation:

$$X_L = 2\pi fL$$

Using The Pol Function to Calculate Impedance Of a Parallel Circuit.

Example: A resistor and inductor in series in a circuit with an AC supply of 230V 50Hz as shown below in Fig 1.

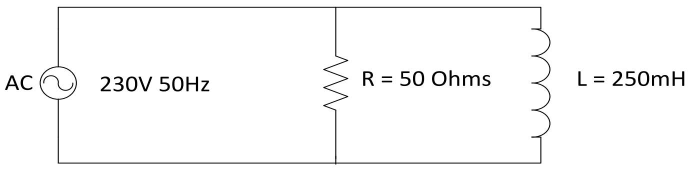
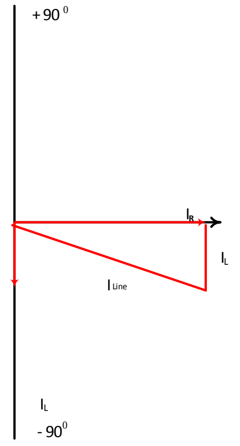


Fig 1



Phasor Diagram

Calculation:

$X_L = 2\pi f L = 2\pi x 50 x 0.25$ = 78.5Ω

R = 50 Ω

I_R = V/R = 230/50 = 4.6A

$I_L = V/X_L$ = 230/78.5 = 2.93A

Pol(enter I_R value of rectangular co-ordinates (4.6) then press comma , key.

Display shows - Pol(4.6,

Then enter I_L value of rectangular co-ordinates (-2.93).

Display shows – Pol(4.6, -2.93

Press = Display shows – 5.453888521 – this is the hypotenuse (Line current) and after rounding is 5.45.

Now press the RCL button (recall) and the tan button (F in pink) and see the angle displayed

F = -32.49536432 – this is the angle and after rounding is -32.50^0 .

You can switch between display of hypotenuse and angle by pressing RCL cos (E in pink) and RCL tan (F in pink). This is not using the tan and cos functions but it is showing the memory positions “E” and “F” available by using these keys.

Impedance (Z) = V/I $_{Line}$ = 230/5.45 = 42.2 Ω

This is much simpler method of calculating line current, impedance and phase angle.

This instruction is for the Casio FX Series. You will need to try this on your own calculator as the order in which data is entered may vary for different models. Other brands such as Sharp use →r θ (radius and angle)for polar function and →xy for rectangular function. Enter data first with comma in between then select function →rθ or →xy then =. Use ←,→ to toggle between x & y or r & θ.

True Power (P)

20. The TRUE Power (P) in the circuit is the power which is being converted to heat by the RESISTOR. The true power being converted to heat in the circuit can be found by applying any one of the three standard power equations (P = VI, P = V^2 / R or P = I^2R), but the current or voltages must only be those associated with the RESISTOR.

21. Thus, the true power in the circuit in Figure 1 could be found using any one of the three power equations:

$$P = V_R \times I_R$$
$$= 100 \times 10$$
$$P = 1000W$$

$$P = \frac{{V_R}^2}{R}$$
$$= \frac{100^2}{10}$$
$$P = 1000W$$

$$P = {I_R}^2 \times R$$
$$= 10^2 \times 10$$
$$P = 1000W$$

Apparent Power (S)

22. You know from d.c. that the total power dissipated in a d.c. circuit can be found by multiplying the line voltage by the line current (P = V x I). On a.c., multiplying the line voltage by the line current gives a value called APPARENT power (S); it is the power which APPEARS to be being dissipated in the circuit (because V x I = power on d.c.). However, if you connect a wattmeter in the circuit, it will indicate a value less than the apparent power, because some of the power is being stored in the magnetic field and returned to the mains during each cycle. The base unit of apparent power is the volt amp (VA).

Power Factor (Cos Φ)

23. The ratio between the true power and the apparent power is called the power factor (Cos Φ), and it is a measure of the current in the circuit which is doing useful work (the other current is flowing in the circuit, but it is only magnetising the core of the inductor – it is not doing useful work). Power factor is a RATIO, so it has no units. Power factor can be lagging or leading, depending on whether the circuit is mainly inductive or mainly capacitive. If the power factor is known, the true power in any sinusoidal single phase circuit can be found using the equation:

$$P = V \times I \times \cos\phi \times \eta$$

Where $\eta = \%$ efficiency of the machine

24. Referring to the phasor diagram in Figure 3, the power factor is the ratio between the current in the resistor and the resultant current (I_R/I_Z).

$$\text{Power factor} = \frac{I_R}{I_Z}$$
$$= \frac{10}{14.1}$$
$$PF = 0.707 \text{ lagging (because it is an inductive circuit)}$$

25. The angle of lag as previously calculated was 45°. Notice that the ratio I_R to I_Z on the phasor diagram is the cosine ratio, so the power factor is the cosine of the angle of lag (or lead). Since the power factor is the cosine of the angle of lag (or lead), the symbol for power factor is cos Φ.

26. Since the power factor is the cosine of the angle of lag (or lead), and the length of I_R on the phasor diagram can never be greater than the length of I_Z, the power factor can never be more than 1. You should also notice that if the resistor current (I_R) and the resultant current (I_Z) are equal, the angle of lag is zero degrees, and the cosine of the angle of lag is 1. A power factor of 1 is sometimes known as a power factor of UNITY. Sine true power and apparent power are equal in a purely resistive circuit, the power factor must always be 1 or unity.

27. The phase angle can never be less than zero degrees or more than 90 degrees, therefore the power factor can never be less than zero or greater than 1. The closer the power factor gets to unity, the 'better' or 'higher' it is said to be. A 'poor' or 'low' power factor is one closer to zero. Supply authorities often insist on a power factor of 0.8 (lagging or leading) or higher. Most a.c. motors operate at a power factor of 0.8 or higher on full load.

28. Regardless of the power factor, the cost of operating an a.c. machine depends on the value of TRUE power, not the apparent power.

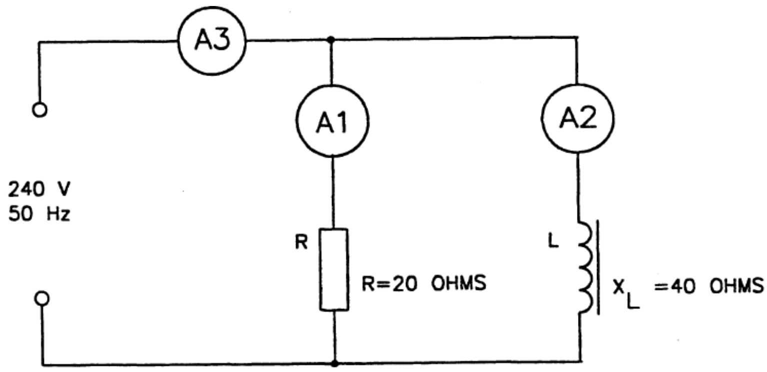
29. Power factor should not be confused with efficiency – they are two entirely different considerations. Power factor is an electrical ratio between the true power and the apparent power in a circuit – efficiency is a ratio between the output power and the input power.

30. The power factor of an inductive a.c. circuit can be improved by connecting a capacitor in parallel with the load – this will be covered later in this unit of competency.

Exercise 1

31. An inductor having an inductive reactance of 40Ω, and a resistor having a resistance of 20Ω are connected in parallel to a 240V, 50Hz a.c. supply. Draw the circuit and the phasor diagram, then determine the following:

    a. Line Current
    b. Phase angle
    c. Circuit impedance
    d. True Power
    e. Apparent power
    f. Power factor



Exercise 2

32. An inductor having an inductance of 0.5H and a resistor having a resistance of 120Ω are connected in parallel to a 240V, 50Hz a.c. supply. Draw the circuit and the phasor diagram, then determine the following:

    a. Inductive reactance of the inductor
    b. Line current
    c. Phase angle
    d. Circuit impedance
    e. True power
    f. Apparent power
    g. Power factor

Capacitive Circuits

33. In a purely capacitive circuit on a.c., the current is limited by the capacitive reactance (Xc) of the capacitor. All of the energy going into the circuit is stored in an electrostatic field and returned to the mains during each quarter cycle, so the total energy consumption is zero. Although the total energy consumption is zero, current still flows in the circuit – (it can be measured with a normal ammeter), but it is 90° out of phase with the voltage. The current in a capacitor LEADS the voltage by 90°as shown in Figure 4.

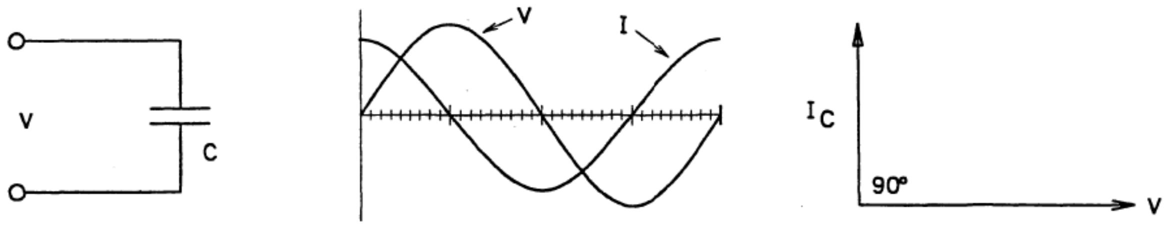


Figure 4 – Current leads voltage in a capacitor

Parallel RC Circuit

34. If a resistor with a resistance (R) of 10Ω was connected in parallel with a pure capacitor with a capacitive reactance (Xc) of 10Ω, and the supply voltage was $100V_{ac}$,the circuit could be drawn as shown in Figure 5.

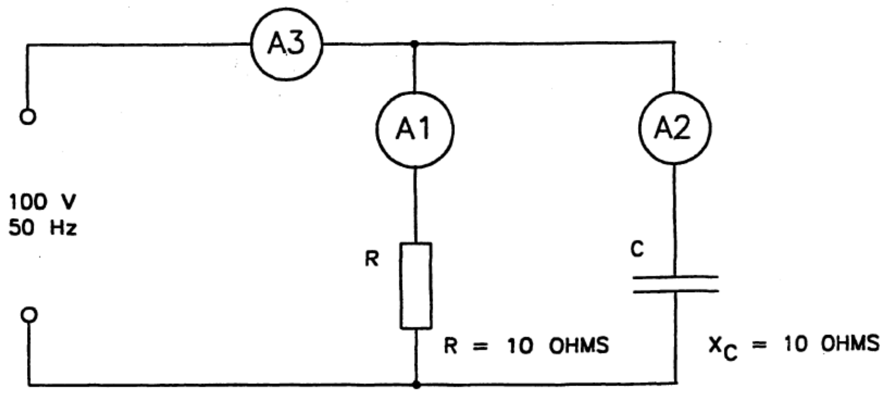


Figure 5 – RC parallel circuit

35. The current flowing in each individual component of the circuit in Figure 5 could be calculated using Ohm's Law.

Resistor Current

$$I = \frac{V}{R}$$
$$= \frac{100}{10}$$
$$I = 10A$$

Capacitor Current

$$I = X_C$$
$$= \frac{100}{10}$$
$$I = 10A$$

Phasor Diagram

36. Using the voltage phasor as a reference, the current in the resistor and the current in the capacitor would be 90°out of phase as shown in Figure 6.

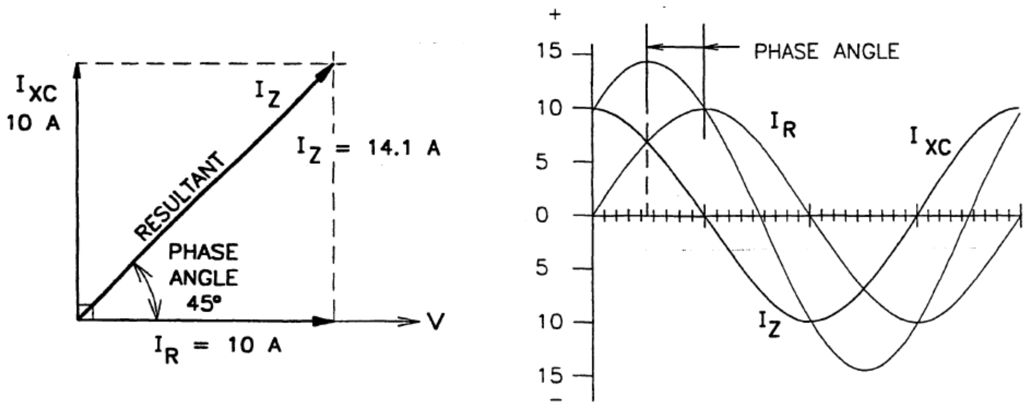


Figure 6 – Phasor diagram of RC in parallel

37. If you compare the phasor diagram for the RC parallel circuit with the RL parallel circuit previously discussed, you will see that it is identical in shape, but the resultant current (I_Z) is LEADING the supply voltage. The true power, apparent power and power factor are identical except that the phase angle is leading instead of lagging.

38. If the capacitance (C) was given instead of the capacitive reactance (X_C), the capacitive reactance could be calculated using the equation:

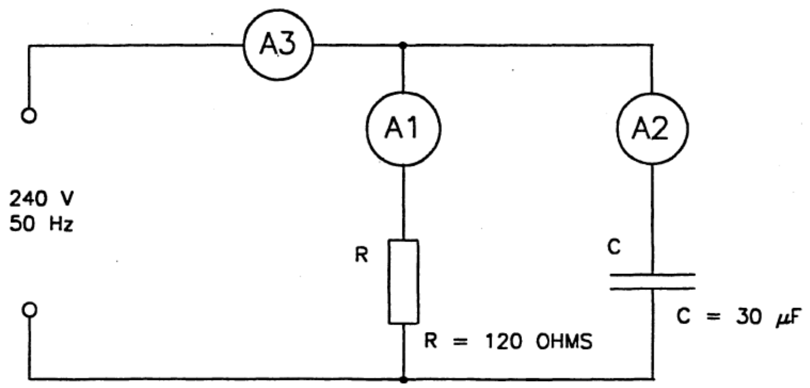
$$X_C = \frac{1}{2\pi f C}$$

39. The discussion relating to power factor is the same, except that the power factor in a capacitive circuit is leading instead of lagging, because electrical energy is stored in an electrostatic field instead of a magnetic field.

Exercise 3

40. A capacitor having a capacity of 30μF, and a resistor having a resistance of 120Ω are connected in parallel to a 240V, 50Hz a.c. supply. Draw the circuit and the phasor diagram, then determine the following:

    a. Capacitive reactance of the capacitor
    b. Line current
    c. Phase angle
    d. Circuit impedance
    e. True power
    f. Apparent power
    g. Power factor



R, L and C in Parallel

41. If a circuit contains resistance (R), inductance (L) and capacitance (C) connected in parallel, the current in the inductor and the current in the capacitor have opposite polarities (they are 180° out of phase with each other), so one tends to cancel the other.

42. Figure 7 represents an RLC parallel circuit in which the component values are:

Resistance (R)	=	600 ohms
Inductance (L)	=	2 henrys
Capacitance (C)	=	3 microfarads
Line voltage	=	240 volts
Frequency	=	50 Hz

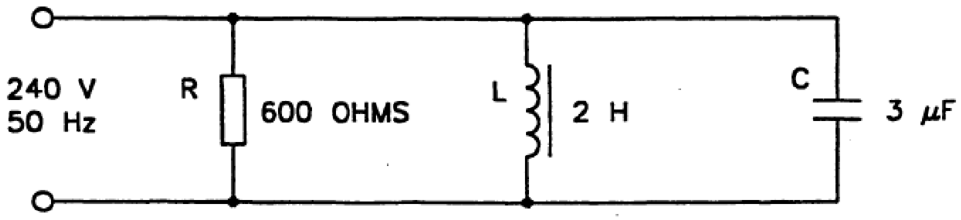


Figure 7 – RLC parallel circuit

43. It is a parallel circuit, so the voltage is the same across all components, therefore the voltage is the reference phasor. The currents in the circuit can be shown on a phasor diagram as in Figure 8.

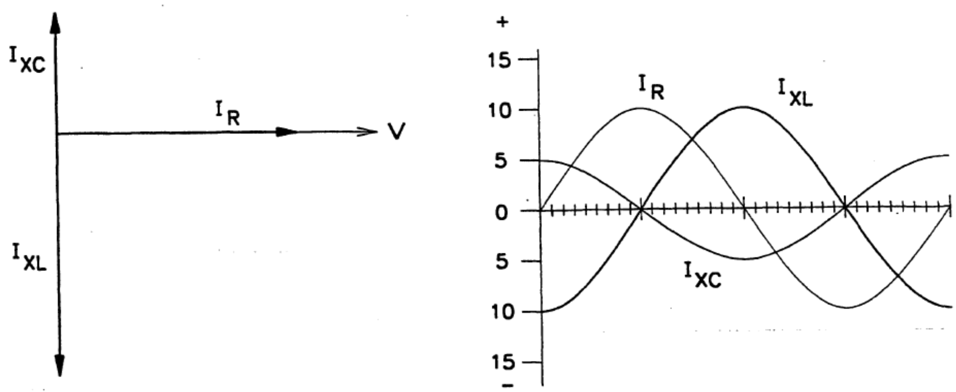


Figure 8 – Phasor diagram of a parallel RLC circuit

44. The opposition to current flow in the inductor and the capacitor have not been given, therefore it is necessary to calculate the inductive reactance and the capacitive reactance before the reactive currents can be calculated.

Inductive Reactance (X_L)

$$X_L = 2\pi fL$$
$$= 2 \times 3.142 \times 50 \times 2$$
$$X_L = 628\Omega$$

Capacitive Reactance (X_C)

$$X_C = \frac{1}{2\pi fC}$$
$$= \frac{1}{2 \times 3.142 \times 50 \times 3 \times 10^{-6}}$$
$$X_C = 1061\Omega$$

45. Having determined the reactances, the current in each component can now be calculated.

a. Resistor current (I_R):

$$I_R = \frac{V}{R}$$
$$= \frac{240}{600}$$
$$I_R = 0.4A$$

b. Inductor current (I_L)

$$I_L = \frac{V}{X_L}$$
$$= \frac{240}{628}$$
$$I_L = 0.38A$$

c. Capacitor current (I_C)

$$I_C = \frac{V}{X_C}$$
$$= \frac{240}{1061}$$
$$I_C = 0.23A$$

46. The relationship between the calculated currents can be shown on a phasor diagram (using voltage as the reference phasor) as shown in Figure 9:

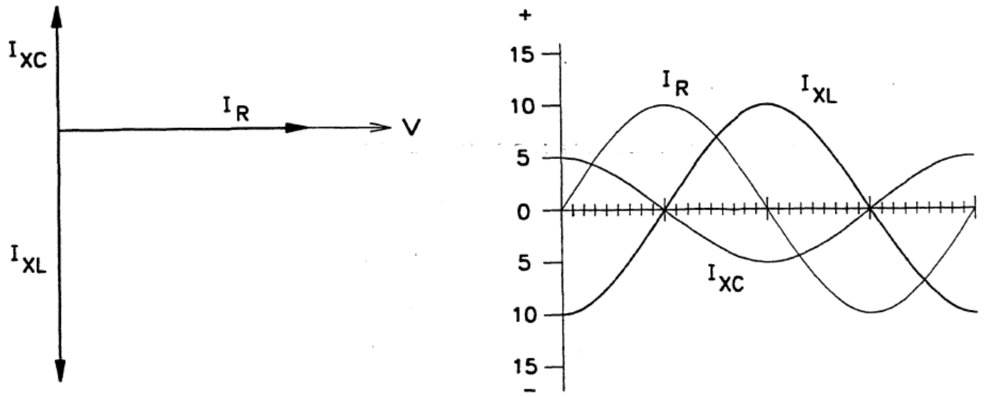


Figure 9 – Phasor diagram of calculated currents

47. It can be seen from the phasor diagram that the current in the inductor and the current in the capacitor are exactly opposite (180°out of phase), so the resultant reactive phasor (I_X) will be the difference between the two reactive currents (I_L minus I_C).

48. The current in the inductor is greater than the current in the capacitor, so the resulting reactive current (I_X) will be lagging:

$$\begin{aligned} I_X &= I_L - I_C \\ &= 0.38 - 0.23 \\ I_X &= 0.15\text{A Lagging} \end{aligned}$$

49. The resulting reactive current (I_X) can be shown on the phasor diagram, then the phasor sum of the two quantities I_X and I_R can be shown as in Figure 10.

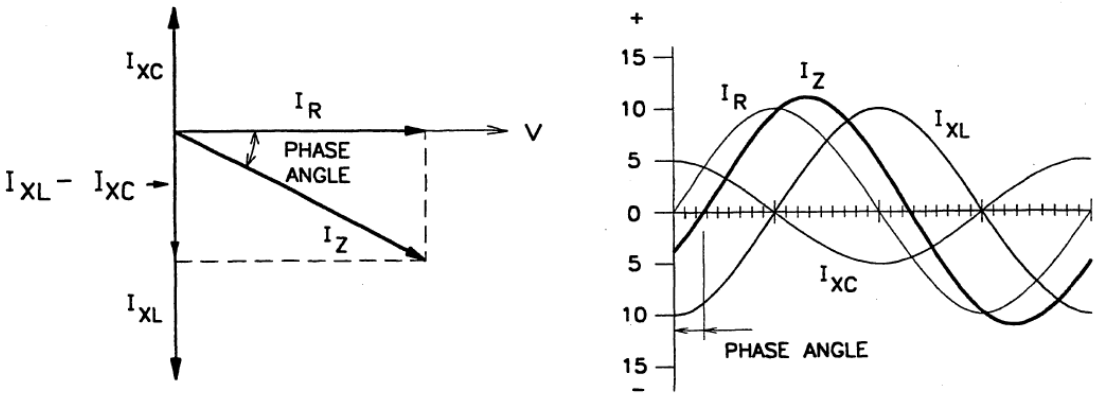


Figure 10 – Resulting reactive current (IX)

50. The line current (I_T) can then be found by calculating the phasor sum of I_R and I_X:

$$\begin{aligned} I_T &= \sqrt{I_R{}^2 + (I_L - I_C)^2} \\ &= \sqrt{0.4^2 + 0.15^2} \\ I_T &= 0.43\text{A} \end{aligned}$$

51. The process of determining the other circuit values is now identical to that used to find the values in an RL circuit.

Circuit Impedance:

$$\begin{aligned} Z &= \frac{V}{I_T} \\ &= \frac{240}{0.43} \\ Z &= 558\Omega \end{aligned}$$

Power factor:

$$\begin{aligned} \cos\theta &= \frac{I_R}{I_T} \\ &= \frac{0.4}{0.43} \\ \cos\theta &= 0.93 \text{ lagging} \end{aligned}$$

Phase angle:

$\cos^{-1}0.93 = 22°$ (The angle which has a cosine of 0.93 is 22°)

True Power (P):

$$\begin{aligned} P &= V \times I_T \times \cos\theta \\ &= 240 \times 0.43 \times 0.93 \\ P &= 96\text{W} \end{aligned}$$

Apparent Power (S)

$$\begin{aligned} S &= V_T \times I_T \\ &= 240 \times 0.43 \\ S &= 103\text{ VA} \end{aligned}$$

Check Power Factor:

$$\cos\theta = \frac{P}{S}$$

$$= \frac{96}{103}$$

$$\cos\theta = 0.93 \quad \text{(lagging because } I_L > I_C\text{)}$$

Resonance

52. If the values of inductive reactance (X_L) and capacitive reactance (X_C) are the same in an a.c. circuit, a condition of RESONANCE is said to exist. If the circuit is a parallel circuit the condition is known as 'parallel resonance'.

53. In a parallel resonant circuit the current in the inductor and the current in the capacitor are equal and opposite, so they cancel each other out, therefore the current in the circuit is at its lowest possible value because it is limited only by the d.c. resistance of the resistive component, as shown in Figure 11.

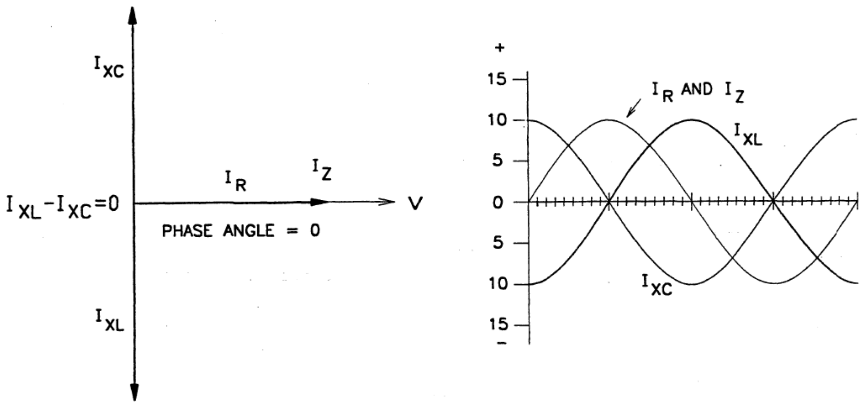


Figure 11 – Parallel resonant circuit

54. If the d.c. resistance is high the circuit impedance will also be high. The inductive reactance of an inductor increases as the frequency increases, and the capacitive reactance of a capacitor decreases as the frequency increases, so for every reactive a.c. circuit there is a frequency at which resonance occurs (the 'resonant frequency'). In higher frequency electronic circuits, the effects of parallel resonance can be used to detect particular frequencies – the resonant frequency is reached when the circuit current is lowest (i.e. when the impedance is highest).

55. Resonant frequency (f_o) for an RLC circuit in which the resistance of the inductor is negligible, can be calculated using the following equation:

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

Where f_o = Resonant frequency in hertz
L = Inductance in henrys
C = Capacitance in farads

56. The impedance characteristic of a parallel resonant circuit can be represented in graphical form as shown in Figure 12.

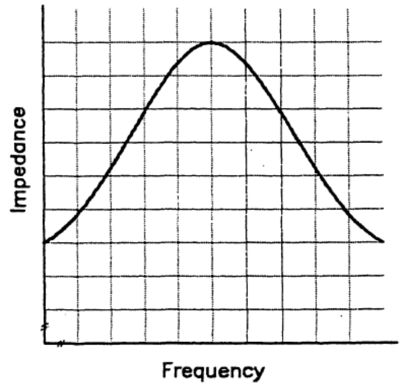


Figure 12 – Impedance characteristic of a parallel resonant circuit

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Formula Sheet	G102A JW/JD DEC 2013

Formula sheet

1. $X_L = 2\pi fL$

2. $X_C = \dfrac{1}{2\pi fC}$

3. $Z = \dfrac{V}{I_T}$

4. $I_T = \dfrac{V}{Z}$

5. $Z = \sqrt{R^2 + (X_L - X_C)^2}$

6. $I_T = \sqrt{I_R{}^2 + (I_L - I_C)^2}$

7. $V_T = \sqrt{V_R{}^2 + (V_L - V_C)^2}$

8. $\cos\theta = \dfrac{R}{Z}$ or $\dfrac{I_R}{I_T}$ or $\dfrac{V_R}{V_T}$ or $\dfrac{P}{S}$ or $\dfrac{W}{VA}$

9. $P = V_R \times I_R$ or $I_R{}^2 \text{ x } R$ or $\dfrac{V_R{}^2}{R}$

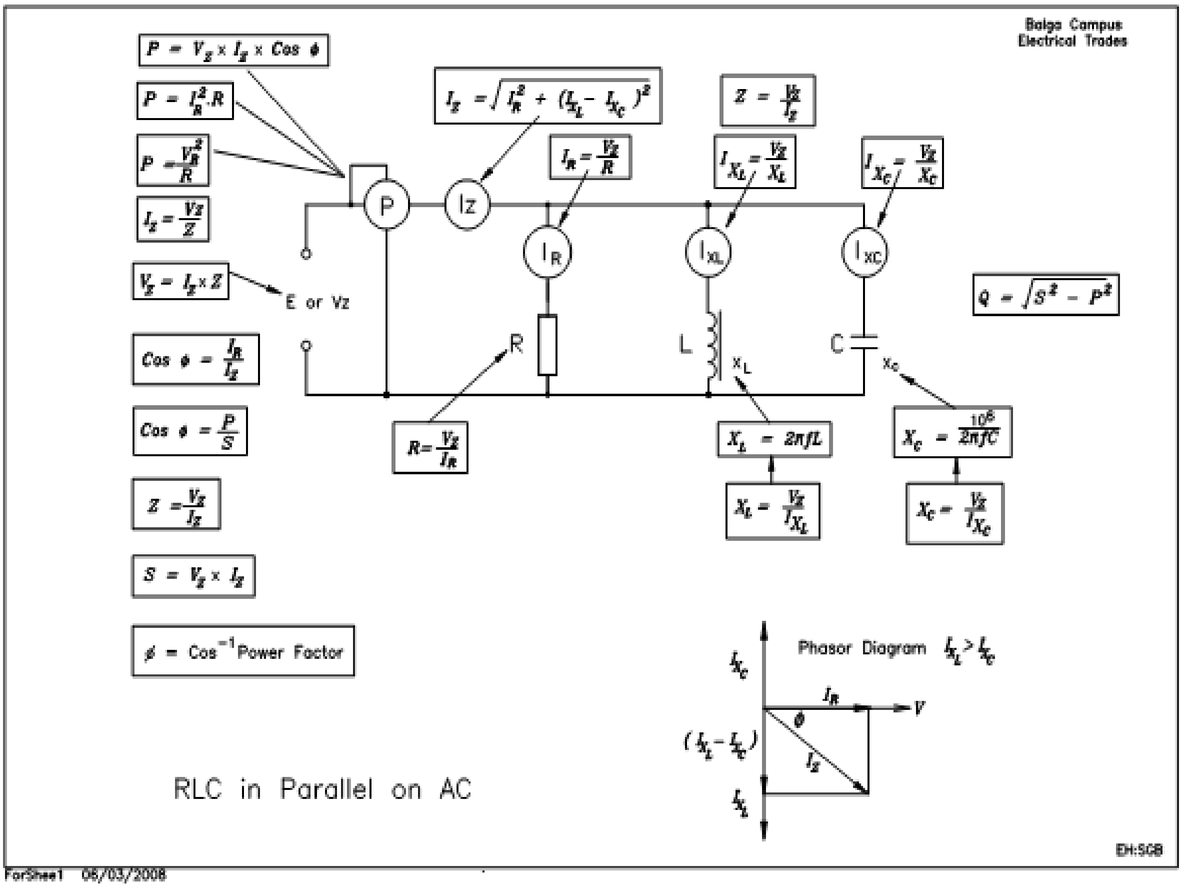
10. $P = V_T \times I_T \times \cos\theta$

11. $f_o = \dfrac{1}{2\pi\sqrt{LC}}$

12. $f = \dfrac{1}{t}$

13. $t = \dfrac{1}{f}$

14. $t = RC$ $\quad t = \dfrac{L}{R}$


Balga Campus
Electrical Trades
$P = V_Z \times I_Z \times Cos\ \phi$
$P = I_R^2 . R$
$P = \frac{V_R^2}{R}$
$I_Z = \frac{V_Z}{Z}$
$V_Z = I_Z \times Z$
E or Vz
$Cos\ \phi = \frac{I_R}{I_Z}$
$Cos\ \phi = \frac{P}{S}$
$Z = \frac{V_Z}{I_Z}$
$S = V_Z \times I_Z$
$\phi = Cos^{-1}$ Power Factor
$I_Z = \sqrt{I_R^2 + (I_{X_L} - I_{X_C})^2}$
$Z = \frac{V_Z}{I_Z}$
$I_R = \frac{V_Z}{R}$
$I_{X_L} = \frac{V_Z}{X_L}$
$I_{X_C} = \frac{V_Z}{X_C}$
P
Iz
I_R
I_{XL}
I_{XC}
R
L
X_L
C
X_C
$Q = \sqrt{S^2 - P^2}$
$R = \frac{V_Z}{I_R}$
$X_L = 2\pi fL$
$X_C = \frac{10^6}{2\pi fC}$
$X_L = \frac{V_Z}{I_{X_L}}$
$X_C = \frac{V_Z}{I_{X_C}}$
Phasor Diagram $I_{X_L} > I_{X_C}$
I_{X_C}
I_R
V
ϕ
$(I_{X_L} - I_{X_C})$
I_Z
I_{X_L}
RLC in Parallel on AC
EH:SGB
ForShee1 06/03/2008

	Solve problems in low voltage a.c. circuits	Section 5 Work Sheet	G102A JW/JD DEC 2013

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R, L and C in Parallel

1. What value is used as the 'reference phasor' in a parallel RLC circuit?

2. What name is given to the total opposition to current flow in an RLC series or parallel a.c. circuit?

3. A resistor, a capacitor and an inductor are connected in parallel. What is the LINE CURRENT if the individual branch currents are as follows. Draw a phasor diagram showing the phase relationship between the relevant values.

   Current in R1 = 0.14A
   Current in C1 = 0.8A
   Current in L1 = 3.48A

4. A parallel RLC circuit has a line current of 1.38A with a supply voltage of 230V. If the supply frequency is 50 Hz, what is the IMPEDANCE of the circuit?

5. An inductor, a resistor and a capacitor are connected in parallel to a 270V, 40Hz supply. What is the TRUE POWER in the circuit if the branch currents are:

   Current in L1 = 1.36A
   Current in R1 = 0.18A
   Current in C1 = 1.43A

6. An inductor, resistor and capacitor are connected in parallel to a 230V, 40Hz supply. What is the APPARENT POWER in the circuit if the line current is 3.73A?

7. The line current in a parallel RLC circuit is 5.39A. The current in the individual components are as follows:

   Inductor current = 6A
   Resistor current = 5A
   Capacitor current = 4A

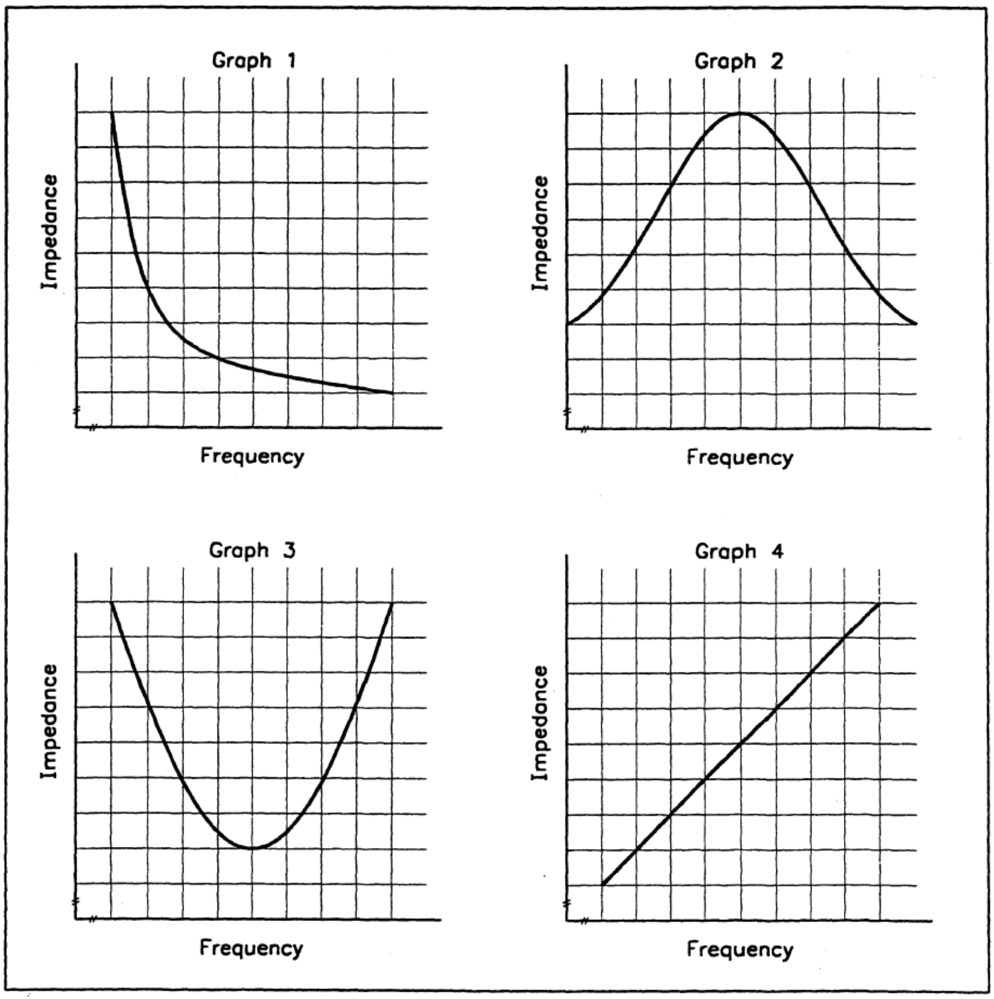
   What is the POWER FACTOR of the circuit?

8. The power factor in an inductive a.c. circuit is found to be 0.77. What is the value of the angle of lag (in degrees)?

9. The inductive component in a 240V resonant RLC circuit has an inductive reactance of 398Ω at 50Hz. Estimate the capacitive reactance in the circuit (assuming that the resistance is negligible).

10. When is the current flow in an a.c. parallel RLC circuit minimum, if the supply frequency is varied?

11. Which of the following graphs represents part of the circuit impedance characteristic of a parallel RLC circuit on a.c. as the frequency changes?.



NOTES

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 5 Project 1	G102A JW/JD DEC 2013

Resistance and Inductance in Parallel

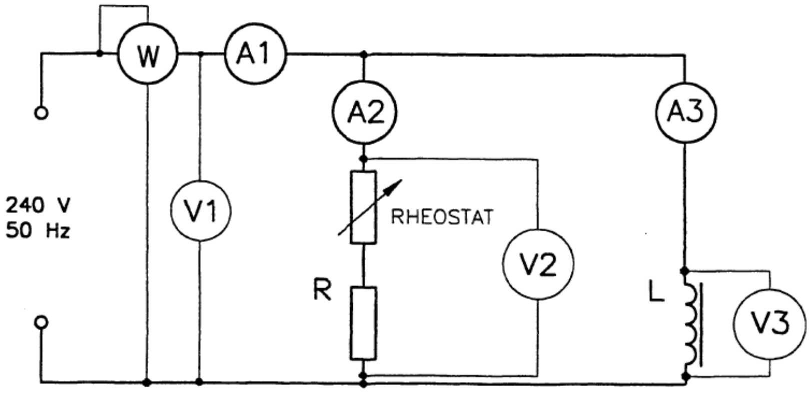
Objective

To observe the effects of changing the resistance in an a.c. circuit consisting of a resistor and an inductor connected in parallel.

Equipment

240V, 50Hz a.c. supply
An inductor (40W fluorescent choke or similar)
480Ω resistor (1A or similar)
1000Ω rheostat (1A or similar)
0 – 150W single phase analogue wattmeter or similar
Three 0-1A a.c. ammeters
Multimeter
Single phase power board
Connecting leads

Circuit Diagram



DANGER TAG PROCEDURE REQUIRED

Procedure

1. Connect the circuit according to the circuit diagram given above.

2. Set the 1000Ω rheostat to MAXIMUM resistance.

3. Check for short circuits with a multimeter set on the ohms x 1 range. Switch the multimeter off after the check.

4. Have your connections checked by your Lecturer.

5. Connect the circuit to the 240V, 50Hz supply. Record the meter readings in the Results Table.

6. Reduce the resistance of the 1000Ω rheostat to zero in three approximately equal steps, and record the meter readings at each step. Do not allow the current in the rheostat to exceed 1A at any time.

7. Switch the circuit off, remove the plug from the outlet and attach your danger tag to the plug top.

8. Have your results checked by your Lecturer.

9. Disconnect your wiring and return all of the equipment to its proper place.

Measurements

Results Table – R and L in Parallel

	Measurements				Calculations	
Rheostat Setting	I_R	I_L	I_Z	P	Z	Power Factor
Step 1 (Maximum R)						
Step 2						
Step 3						
Step 4 (Minimum R)						

Line voltage: ____________________________

Phasor Diagram

Questions

1. Draw a phasor diagram to scale and show the relationship between I_R, I_L and I_Z for each setting of the rheostat (all on one phasor diagram).
   Use a scale of 20mm = 0.1A.

2. Use your scaled phasor diagram to ESTIMATE what the line current and power factor would be if the current in the resistor was increased to 1A (with the inductor current I_L remaining unchanged).

   ____

3. Why was there a slight difference between the calculated line current and the measured line current?

   ____

   ____

4. When was the power factor of this test circuit ‘best’ (ie. closer to 1) – when the resistance was high or low?

   ____

5. Calculate the resistance of the resistive branch when it has 0.6A flowing through it, assuming a line voltage of 240V.

   ____

6. What would happen to the power factor of the circuit if the line voltage was reduced to 120V?

   ____

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 5 Project 2	G102A JW/JD DEC 2013

Resistance, Inductance and Capacitance in Parallel

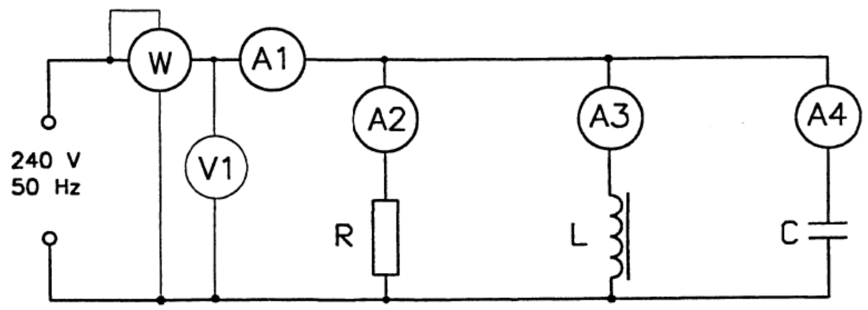
Objective

To observe the characteristics of an a.c. circuit consisting of a resistor an inductor and a capacitor connected in parallel.

Equipment

240V, 50Hz a.c. supply
480Ω resistor (1A)
An inductor (40W fluorescent ballast or similar)
A 3µF paper capacitor
A 0-150W single phase analogue wattmeter or similar
Three 0-1A a.c. ammeters
Multimeter
Single phase power board
Connecting leads

Circuit Diagram



DANGER TAG PROCEDURE REQUIRED

Procedure

1. Connect the circuit according to the circuit diagram given above.

2. Check for short circuits with a multimeter set on the ohms x 1 range. Switch the multimeter off after the check.

3. Have your connections checked by your Lecturer.

4. Connect the circuit to the 240V, 50Hz supply. Record the meter readings in the Measurements Results Table.

5. Switch the circuit off, remove the plug from the outlet and attach your danger tag to the plug top.

6. Calculate the values necessary to complete the Calculations Results Table.

7. Have your results checked by your Lecturer.

8. Disconnect your wiring and return all of the equipment to its proper place.

Results

Results Table – R, L and C in Parallel

Measurements					
E	I_Z	I_R	I_L	I_C	P

Calculations							
R	L	X_L	X_C	Z	S	Q	Cos θ

Phasor Diagram

Questions

1. Prove by calculation that the power dissipated by the circuit (as indicated on the wattmeter) is the power dissipated only by the resistor (disregard power losses in the ballast).

2. Was the power factor of the circuit 'good' or 'bad'?

3. What would the impedance of the circuit be if the frequency was increased to the point of resonance?

4. Was the line current the sum of the currents in the individual parallel branches? Why?

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 5 Project 3	G102A JW/JD DEC 2013

Varying Capacitance in a Parallel RLC Circuit

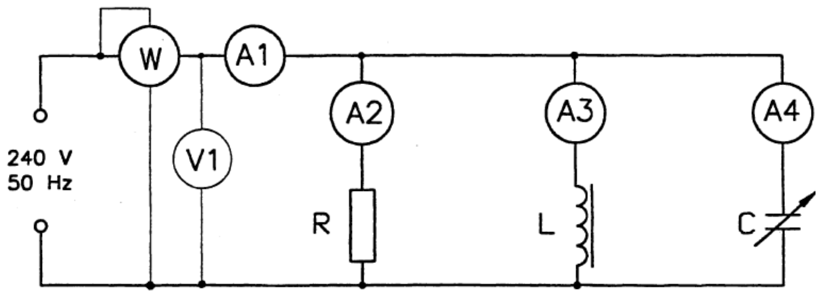
Objective

To observe the effect of varying the capacitance in an parallel RLC circuit.

Equipment

240V, 50Hz a.c. supply
480Ω resistor (1A)
An inductor (36W fluorescent ballast or similar)
A variable 240V switchable paper capacitor bank (about 2μF to 10μF)
A 0-150W single phase analogue wattmeter or similar
Three 0-1A a.c. ammeters
One 0-2A a.c. ammeter
Multimeter
Single phase power board
Connecting leads

Circuit Diagram



DANGER TAG PROCEDURE REQUIRED

Procedure

1. Connect the circuit according to the circuit diagram given above (with no capacitance in the circuit).

2. Check for short circuits with a multimeter set on the ohms x 1 range. Switch the multimeter off after the check.

3. Have your connections checked by your Lecturer.

4. Connect the circuit to the 240V, 50Hz supply. Record the meter readings in the Measurements Results Table.

5. Alter the value of capacitance to about 2μF by operating the switches on the capacitor bank. Record the meter readings in the Measurements Results Table.

6. Alter the value of the capacitance to about 6μF and 10μF by operating the switches on the capacitor bank. Record the meter readings in the Measurements Results Table.

7. Switch the circuit off and remove the plug from the outlet. Attach your danger tag to the plug top.

8. Calculate the values necessary to complete the Calculations Results Table, and draw a phasor diagram of each condition (using the same scale for each).

9. Have your results checked by your Lecturer.

10. Disconnect your wiring and return all of the equipment to its proper place.

Results

Results Tables- RLC in Parallel with Variable Capacitance

	Measurements					
	E	I_Z	I_R	I_L	I_C	P
R & L Only						
2 µF						
6 µF						
10 µF						

	Calculations							
	R	L	X_L	X_C	Z	S	Q	Cos Θ
R & L Only								
2 µF								
6 µF								
10 µF								

Phasor Diagrams:

Questions

1. At what value of capacitance was the line current (I_Z) least.

____

2. Did the line current fall each time capacitance was connected into the circuit? Give a reason for your answer.

____

3. At what value of capacitance was the power factor of the circuit 'best' (closest to a unity power factor)?

____

4. Did the reading on the wattmeter change significantly as more capacitance was connected into the circuit?

____

5. Calculate the cost of operating the circuit for 10 hours in each condition, assuming that electrical energy costs 25 cents for every kilowatt hour (Cost = kW x hr x cost per kWh)

____

6. On the basis of your results, does an a.c. circuit cost more to operate if the power factor is 'low'?

____

7. Calculate the resonant frequency for each value of capacitance in the circuit.

____

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 6 Introduction	G102A JW/JD DEC 2013

R, L and C in Series

Task

To describe the behaviour of a.c. circuits consisting of resistive, inductive and capacitive components, connected in series to a sinusoidal single phase supply.

Why

All electrical devices which operate on alternating current have resistance, inductance and capacitance. An understanding of the general principles of the behaviour of resistors, inductors and capacitors in series is essential to understanding the operation of a.c. devices.

Pass

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a written assessment.
2. You must satisfactorily complete the set laboratory tasks.
3. You must achieve 100% in a final practical assessment.

Equipment

A.C. Theory Project Boards
Sample resistors, inductors and capacitors
ELV A.C. Power Supply
A.C. Ammeters
A.C. Voltmeters
Multimeters
Scientific Calculator

References

- Electrical Principles for the Electrical Trades, J.R. Jenneson
- AS/NZS 3000-2018
- WAER

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R, L and C in Series

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades (6th ed.)

Vol. 1: 9.5 Series R-L-C circuits on a.c. current

More Electrical Principles

Chapter 7 Inductive and Capacitive Reactance

2. Read the Summary and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.
3. Answer the questions given on the Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.
4. Complete the projects in this manual.
5. Submit your answers in the Work Sheet and your completed project reports to your Lecturer for discussion and assessment.

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 6 Summary	G102A JW/JD DEC 2013

Resistance, Inductance and Capacitance in Series

1. In a resistive circuit on a.c., the current is limited by the resistance of the resistor, and all the energy going into the circuit is converted to heat energy.

Inductive Circuits

2. In a purely inductive circuit on a.c., the current is limited by the inductive reactance of the inductor, and all of the energy going into the circuit is stored in a magnetic field and returned to the mains during each quarter cycle. The the total energy consumption, therefor, is zero. Although the total energy consumption is zero, current still flows in the circuit – (it can be measured with a normal ammeter), but it is 90°out of phase with the voltage. The current in an inductor LAGS the voltage by 90°.

Series RL Circuit

3. If a resistor with a resistance (R) of 10Ω was connected in series with a pure inductor which had an inductive reactance (XL) of 10Ω, and the supply voltage was 100V, 50Hz a.c., the circuit could be drawn as shown in Figure 1.

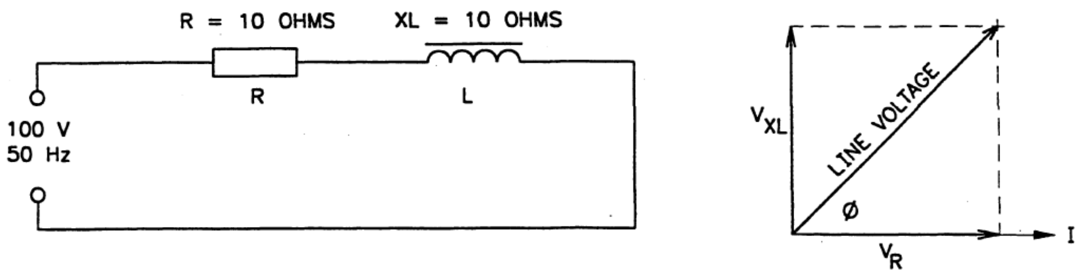


Figure 1 - RL Series Circuit

4. At first glance it may appear as though the total opposition to current flow in the circuit would be the resistance of the resistor plus the inductive reactance of the inductor. However, resistance and reactance cannot be added together directly in series a.c. circuits, because the voltage drops across the components are out of phase with each other. In a.c. series circuits the total opposition to the flow of current in a circuit is known as the impedance (Z), and it is measured in ohms – the same as for parallel circuits.

5. The current flowing in each component in the circuit must be the same (because it is a series circuit). The voltage across the resistor is in phase with the applied voltage, and the current in an inductor lags the voltage by 90°, therefore the voltage drop across the resistor and the voltage drop across the inductor are out of phase by 90°.

6. The phasor diagram showing the relationships between the component voltages and the reference line current is shown in Figure 2.

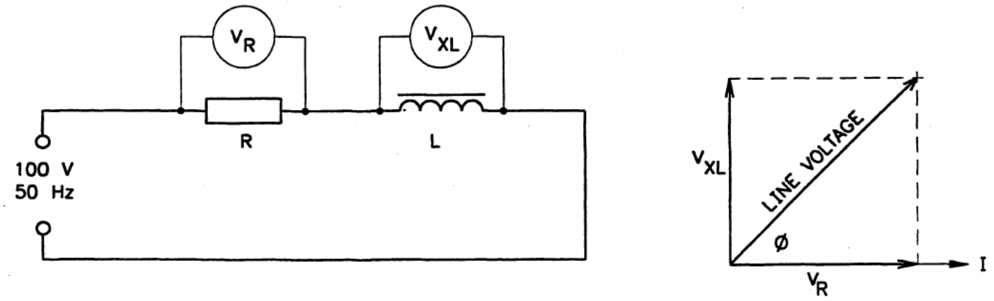


Figure 2 – Voltage phasor diagram for R and L in series

7. The length of the resultant in Figure 2 represents the applied line voltage. This is the phasor sum of V_R and V_L, and the angle between the resultant and the reference phasor represents the phase angle between the line voltage and the line current.

8. Since the current is common to all series components, the phasor diagram in Figure 2 can also be used to represent the values of resistance and inductive reactance. In a series RL circuit, the impedance is the phasor sum of the resistance of the resistor and the inductive reactance of the inductor as shown in Figure 3. The triangle formed by the resistance, inductive reactance and the resulting impedance, is known as an 'impedance triangle'. (The impedance triangle can only be used for SERIES circuits).

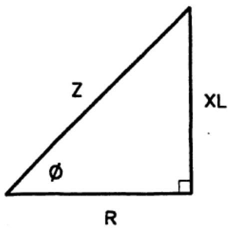


Figure 3 - An impedance triangle for an RL series circuit

9. The length of the resultant (the impedance, Z) can be found using Pythagoras' Theorem:

$$Z = \sqrt{R^2 + {X_L}^2}$$
$$= \sqrt{10^2 + 10^2}$$
$$= \sqrt{200}$$
$$Z = 14.14\Omega$$

The Phase Angle

10. Since the phasor diagram is based on right triangles, trigonometry can be used to find the phase angle. The cosine is adj/hyp, so the cosine of the phase angle (Phi) is 10/14.14 or 0.707. The angle which has a cosine of 0.707 is 45°, so the phase angle (Φ) is 45° (using a calculator). Since the circuit is inductive, the current must be LAGGING the applied voltage, therefor, the phase angle (Φ) is 45° lagging. (The phase angle can also be found using other trigonometrical ratios).

11. In the series circuit in Figure 1, the impedance of the circuit is the total opposition to current flow when connected to $100V_{ac}$. We know that the impedance is 14.14Ω from an earlier calculation, so we can calculate the current flow using a variation of Ohm's Law in which impedance replaces resistance. On d.c. I = V / R, but on a.c. I = V / Z, thus the total current in the circuit (the line current) is:

$$\begin{aligned} I &= \frac{V}{Z} \\ &= \frac{100}{14.14} \\ I &= 7.07A \end{aligned}$$

12. The phasor diagram in Figure 2 shows the phase relationship between the voltages in the circuit, but it does not show the values of voltage. The voltage drop (or potential difference) across each of the components can be calculated using Ohm's Law.

$$\begin{aligned} V_R &= I_R \times R \\ &= 7.07 \times 10 \\ V_R &= 70.7V \end{aligned}$$

$$\begin{aligned} V_L &= I_L \times X_L \\ &= 7.07 \times 10 \\ V_L &= 70.7V \end{aligned}$$

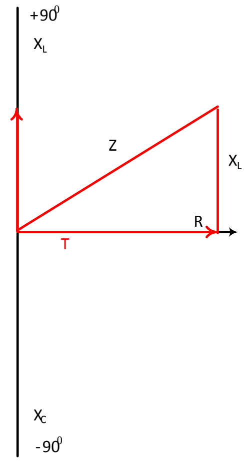
13. Since the reactance and resistance are equal, the voltages across the components are equal, but notice that the voltages do not add up to the line voltages. The line voltage V_T must be the PHASOR sum of the voltage across the resistor and the voltage across the inductor.

$$\begin{aligned} V_T &= \sqrt{V_R{}^2 + V_L{}^2} \\ &= \sqrt{70.72 + 70.72} \\ &= \sqrt{9997} \\ V_T &= 100V \end{aligned}$$

Using The Pol Function to Calculate Impedance Of a Series Circuit.

Example: A resistor and inductor in series in a circuit with an AC supply of 230V 50Hz as shown below in Fig 1.

Fig 1



Phasor Diagram

Calculation:

$X_L = 2\pi f L = 2\pi x 50 x 0.25 = 78.5\Omega$

R = 50 Ω

Pol(enter R value of rectangular co-ordinates (50) then press comma , key.

Display shows - Pol(50,

Then enter X_L value of rectangular co-ordinates (78.5).

Display shows – Pol(50,78.5

Press = Display shows – 93.0712093 – this is the hypotenuse (Impedance) and after rounding is 93 Ω.

Now press the RCL button (recall) and the tan button (F in pink) and see the angle displayed

F = 57.50520006 – this is the angle and after rounding is 57.5^0 .

You can switch between display of hypotenuse and angle by pressing RCL cos (E in pink) and RCL tan (F in pink). This is not using the tan and cos functions but it is showing the memory positions "E" and "F" available by using these keys.

I = V/Z = 230/93 = 2.47A

This is much simpler method of calculating line current, impedance and phase angle.

This instruction is for the Casio FX series. You will need to try this on your own calculator as the order in which data is entered may vary for different models. Other brands such as Sharp use →r θ (radius and angle)for polar function and →xy for rectangular function. Enter data first with comma in between then select function →rθ or →xy then =. Use ←,→ to toggle between x & y or r & θ.

Calculating Inductive Reactance

14. In the circuit given above, the inductive reactance was given as 10Ω. If the inductance (L) was given instead of the inductive reactance (XL), the inductive reactance would have to be calculated using the equation:

$$X_L = 2\pi fL$$

Where:

π = the constant Pi (approximately 3.14)
f = the supply frequency in Hz
L = the inductance of the coil in Henrys

True Power (P)

15. The TRUE Power (P) in the circuit is the power (in watts or kW) which is being converted to heat by the RESISTOR. The true power being converted to heat in the circuit can be found by applying any one of the three standard power equations ($P=VI$, $P=V^2/R$ or $P=I^2R$), but the currents or voltages must only be those associated with the RESISTOR. Thus the true power in the circuit in Figure 1 could be found using any one of the three power equations:

$$\begin{aligned} P &= V_R \times I_R \\ &= 70.7 \times 7.07 \\ P &= 500\text{W} \end{aligned}$$

$$\begin{aligned} P &= \frac{{V_R}^2}{R} \\ &= \frac{70.7^2}{10} \\ P &= 500\text{W} \end{aligned}$$

$$\begin{aligned} P &= {I_R}^2 \times R \\ &= 7.07^2 \times 10 \\ P &= 500\text{W} \end{aligned}$$

16. True power is the power measured on a wattmeter as shown in Figure 4.

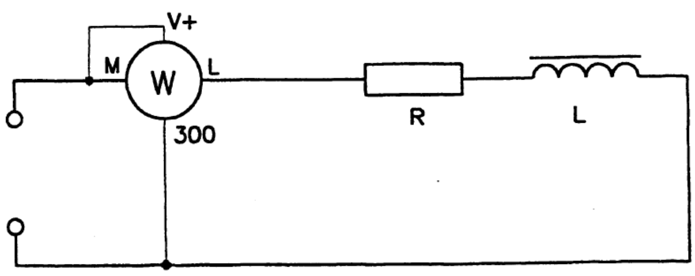


Figure 4 - Measuring power with a wattmeter

Apparent Power (S)

17. You know from d.c. that the total power dissipated in a d.c. circuit can be found by multiplying the line voltage by the line current (P = VI). On a.c., multiplying the line voltage by the line line current gives a value called APPARENT power (S); it is the power which APPEARS to be being dissipated in the circuit. However, if you connect a wattmeter in the circuit, it will indicate a value less than the apparent power, because some of the power is being stored in the magnetic field and returned to the mains during each cycle. The basic unit of apparent power is the volt amp (VA), and it is obtained by multiplying the line voltage by the line current:

Apparent power = line voltage x line current

$$S = V_T \times I_T$$

18. Apparent power cannot be measured directly using conventional measuring instruments – it can only be calculated by multiplying the line voltage by the line current in a circuit.

Reactive Power

19. The reactive power (Q) in a circuit is the power required to magnetise the core of the inductor. Reactive power is not consumed, because the energy stored in the magnetic field is returned to the mains during the next quarter cycle. The basic unit in which reactive power is expressed, cannot be measured directly using conventional measuring instruments – it can only be calculated from other circuit measurements.

Power Factor (Cos Φ)

20. The ratio between the true power and the apparent power is called the power factor (Cos Φ), and is a measure of the current in the circuit which is doing useful work. Referring to the impedance triangle, the power factor is the ratio between the resistance and the impedance (R/Z)

$$\text{Power factor} = \frac{R}{Z}$$
$$= \frac{10}{14.14}$$
$$PF = 0.71 \text{ lagging}$$

21. The angle of lag as previously calculated was 45°. Notice that the ratio R to Z on the impedance triangle (Figure 3) is the cosine ratio, so the power factor is the cosine of the angle of lag (or lead).

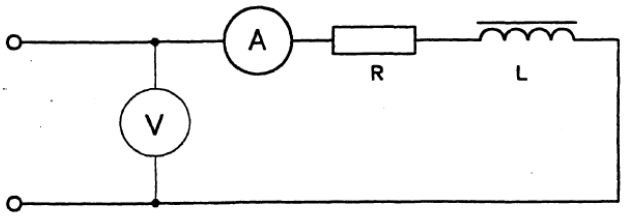
22. Since the power factor is the cosine of the angle of lag (or lead), and the length of R on the phasor diagram can never be greater than the length of Z, the power factor can never be more than 1. You should also notice that if the resistance of the resistor (R) and the impedance (Z) are equal, the angle of the lag is zero degrees, and the cosine of the angle of lag is 1. A d.c. circuit can be regarded as having a power factor of 1.

23. The phase angle can never be less than zero degrees, or more than 90°, therefore the power factor can never be less than zero or greater than 1. The closer the power factor gets to unity, the 'better' or 'higher' it is said to be.

Exercise 1

24. An inductor having an inductive reactance of 5Ω, and a resistor having a resistance of 12Ω are connected in series to a 240V, 50Hz a.c. supply. Draw the circuit and the phasor diagram, then determine the following:

a. Circuit impedance
b. Line current
c. True power
d. Apparent power
e. Power factor
f. Phase angle



Exercise 2

25. An inductor having an inductance of 0.5H, and a resistor having a resistance of 120Ω are connected in series to a 240V, 50Hz a.c. supply. Draw the circuit and the phasor diagram, then determine the following:

a. Inductive reactance of the inductor
b. Line current
c. Circuit impedance
d. True power
e. Apparent power
f. Power factor
g. Potential difference across each series component
h. Phase angle

Capacitive Circuits

26. In a purely capacitive circuit on a.c., the current is limited by the capacitive reactance (Xc) of the capacitor, and all of the energy going into the circuit is stored in an electrostatic field and returned to the mains during each quarter cycle, so the total energy consumption is zero. Although the total energy consumption is zero, current still flows in the circuit – (it can be measured with a normal ammeter), but it is 90° out of phase with the voltage. The current in a capacitor LEADS the voltage by 90° as shown in Figure 5.

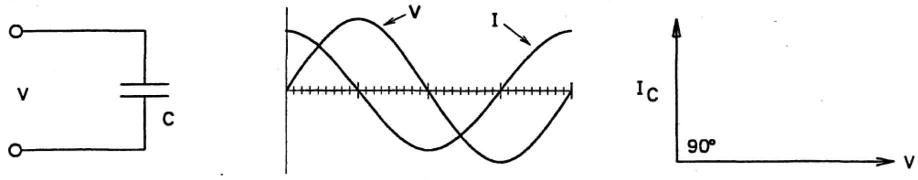


Figure 5 - Phase relationships in a pure capacitor

Series RC Circuit

27. If a resistor with a resistance (R) of 10Ω was connected in series with a pure capacitor with a capacitive reactance (Xc) of 10Ω, and the supply voltage was 100V, 50Hz a.c., the circuit could be drawn as shown in Figure 6.

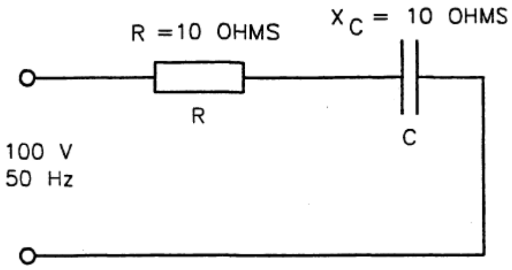


Figure 6 - RC series circuit

Phasor Diagram

28. Using the current phasor as a reference, the resistance of the resistor and the capacitive reactance of the capacitor could be drawn 90° out of phase as shown in Figure 7. The resultant (Z) is the total opposition to current flow in the circuit.

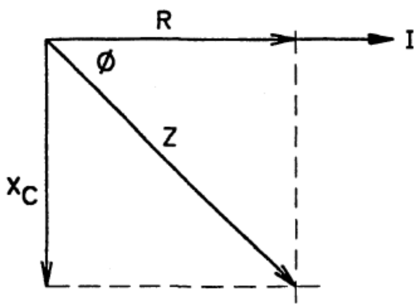


Figure 7 - Phasor diagram of R and C in series

29. If you compare the phasor diagram for the RC series circuit with the RL series circuit previously discussed, you will see that it is identical in shape, but the impedance (Z) is LEADING the supply voltage by 45°, instead of lagging. The calculations for impedance, true power, apparent power and power factor are identical except that the phase angle is leading instead of lagging.

30. If the capacitance (C) was given instead of the capacitive reactance (Xc), the capacitive reactance could be calculated using the equation:

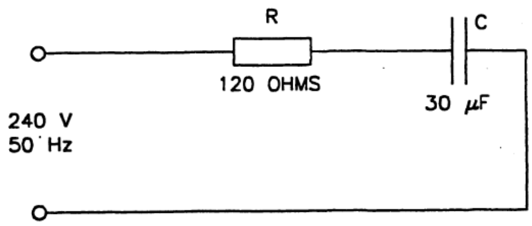
$$X_C = \frac{1}{2\pi f C}$$ Where C is in Farads

31. The discussion relating to power factor is the same, except that the power factor in a capacitive circuit is leading instead of lagging, because electrical energy is stored in an electrostatic field instead of a magnetic field.

Exercise 3

32. A capacitor having a capacity of 30µF, and a resistor having a resistance of 120Ω are connected in series to a 240V, 50 Hz a.c. supply. Draw the circuit and the phasor diagram, then determine the following:

a. Capacitive reactance of the capacitor
b. Line current
c. Circuit impedance
d. True power
e. Apparent power
f. Power factor
g. Potential differences
h. Phase angle



R, L and C in Series

33. If a circuit contains resistance (R), inductance (L) and capacitance (C) connected in series, the voltage across the inductor and the voltage across the capacitor are exactly opposite (they are 180° out of phase with each other), so one tends to cancel the other.

34. Figure 8 represents an RLC series circuit in which the component values are:

Resistance (R)	=	120Ω
Inductance (L)	=	0.5H
Capacitance (C)	=	30µF
Line voltage	=	240V
Frequency	=	50Hz

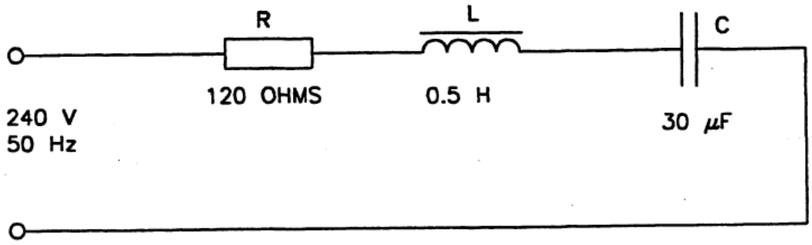


Figure 8 - RLC series circuit

35. It is a series circuit, so the current is the same in all components, therefore the current is the reference phasor. The relationships in the circuit can be shown on a phasor diagram as in Figure 9.

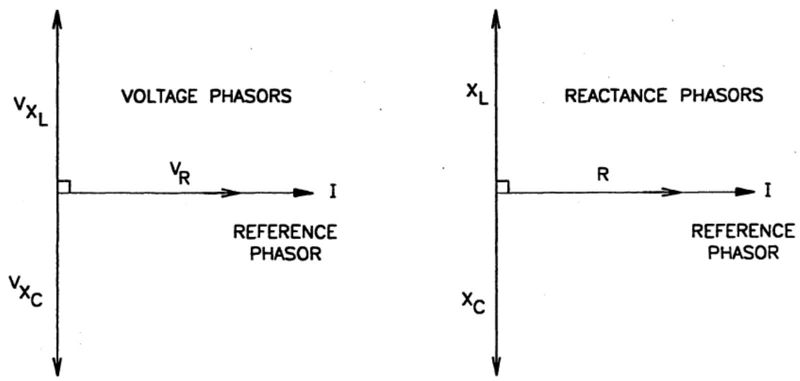


Figure 9 - Phasor diagram – RLC series circuit

36. The opposition to current flow in the inductor and the capacitor have not been given, therefore it is necessary to calculate the inductive reactance and the capacitive reactance before the impedance can be calculated:

Inductive Reactance (XL)

$$X_L = 2\pi fL$$
$$= 2 \times \pi \times 50 \times 0.5$$
$$X_L = 157.08\Omega$$

Capacitive Reactance (Xc)

$$X_C = \frac{1}{2\pi fC}$$
$$= \frac{1}{2 \times \pi \times 50 \times 30 \times 10^{-6}}$$
$$X_C = 106.1\Omega$$

37. The relationship between these calculated values can be shown on the phasor diagram (using the current as the reference phasor), as shown in Figure 10.

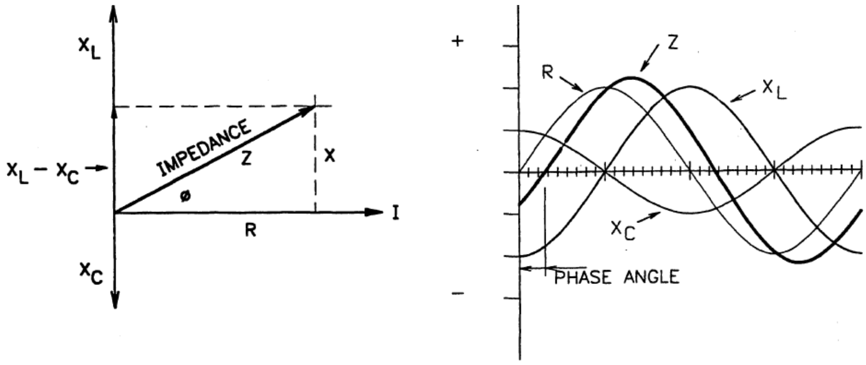


Figure 10 - Relationships in an RLC series circuit

38. You can see from the phasor diagram that the voltage across the inductor and the voltage across the capacitor are exactly opposite (180° out of phase), so the resulting reactance phasor (X) will be the difference between the two reactances (X_L- X_C). The inductive reactance of the inductor is greater than the capacitive reactance of the capacitor, so the resulting reactance (X) will be lagging:

$$X = X_L - X_C$$
$$= 157.08 - 106.1$$
$$X = 50.98\Omega$$

39. The reactance (X) can be shown on the phasor diagram, then the phasor sum of the two quantities X and R can be shown as an impedance triangle as shown in Figure 11.

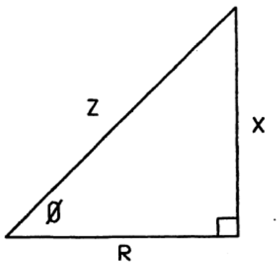


Figure 11 - RLC impedance triangle

40. The impedance (Z) can then be found:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$= \sqrt{120^2 + 50.98^2}$$
$$Z = 130.38\Omega$$

41. The process of determining the other circuit values is now identical to that used to find the values in a series RL circuit, as shown below (with some insignificant differences between calculations due to rounding errors).

Line Current:

$$I_T = \frac{V}{Z}$$
$$= \frac{240}{130.38}$$
$$I_T = 1.84A$$

Potential Differences across components:

$$V_R = I_T \times R \quad = 1.84 \times 120 \quad V_R = 220.85V$$

$$V_L = I_T \times X_L \quad = 1.84 \times 157.08 \quad V_L = 289.15V$$

$$V_C = I_T \times X_C \quad = 1.84 \times 106.1 \quad V_C = 195.31V$$

Power Factor (CosΦ):

$$\cos\phi = \frac{R}{Z} = \frac{120}{130.38}$$
$$\cos\phi = 0.92 \text{ lagging}$$

or

$$\cos\phi = \frac{V_R}{V_T} = \frac{220.85}{240}$$
$$\cos\phi = 0.92 \text{ lagging}$$

Phase Angle:

$$\cos^{-1}0.92 = 25.57^\circ \text{ lagging}$$

True power (P):

$$P = V_R \times I_T$$
$$= 220.85 \times 1.84$$
$$P = 406.53W$$

or

$$P = V_T \times I_T \times \cos\phi$$
$$= 240 \times 1.84 \times 0.92$$
$$P = 406.44W$$

Apparent Power (S):

$$S = V_T \times I_T$$
$$= 240 \times 1.84$$
$$S = 441.97VA$$

Check Power Factor:

$$\cos\phi = \frac{P}{S}$$
$$= \frac{406.53}{441.97}$$
$$\cos\phi = 0.92 \text{ lagging}$$

Resonance

42. If the values of inductive reactance (X_L) and capacitive reactance (X_C) are the same in an a.c. circuit, a condition of RESONANCE is said to exist. If the circuit is a series circuit the condition is known as 'series resonance'.

43. In a series resonant circuit the inductive reactance and the capacitive reactance are equal and opposite, so they cancel each other out, therefore the impedance of the circuit is equal to the d.c. resistance of the resistive components.

44. Under these conditions it is possible for an extremely high current to flow in the circuit, and for dangerously high voltages to occur across the reactive components. Consider the example of a 240V, 50Hz series RLC circuit, in which the inductive reactance and the capacitive reactance are both 1000Ω, and the resistance is 12Ω – as shown in Figure 12.

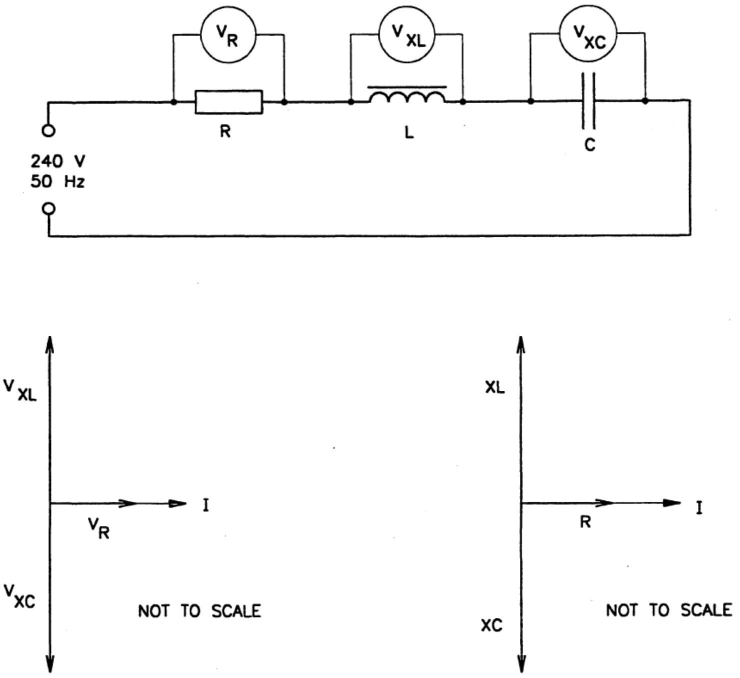


Figure 12 - Resonant RLC series circuit

45. The line current in the circuit would be 240/12 or 20A. The voltages across the three components would be:

$$V_R = I_T \times R \qquad V_L = I_T \times X_L \qquad V_C = I_T \times X_C$$
$$= 20 \times 12 \qquad = 20 \times 1000 \qquad = 20 \times 1000$$
$$V_R = 240\text{V} \qquad V_L = 20000\text{V or } 20\text{kV} \qquad V_C = 20000\text{V or } 20\text{kV}$$

46. You can see that the voltage across the resistor would be the line voltage, but the voltage across each of the reactive components would be 20,000V.

47. This dangerously high voltage could cause damage to insulation in components if they were designed to only withstand voltages of 240V. Care must be taken to avoid conditions of unwanted series resonance. The inductive reactance of an inductor increases as the frequency increases, and the capacitive reactance of a capacitor decreases as the frequency increases, so for every reactive a.c. circuit there is a frequency at which resonance occurs (the 'resonant frequency'). In higher frequency electronic circuits, the effects of series resonance can be used to advantage to provide an alternate path for currents at particular frequencies.

48. Resonant frequency (f_o) for an RLC circuit, in which the resistance of the inductor is negligible, can be calculated using the following equation:

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

$$\begin{aligned} \text{where } f_o &= \text{Resonant frequency in Hz} \\ L &= \text{Inductance in Henrys} \\ C &= \text{Capacitance in Farads} \end{aligned}$$

49. The impedance characteristic of a series resonant circuit can be represented in graphical form as shown in Figure 13.

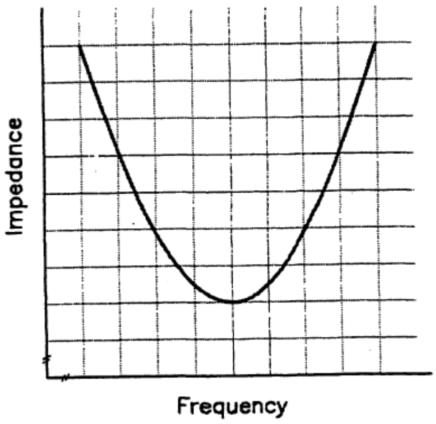


Figure 13 – Impedance characteristic of a series resonant circuit

Inductors as current Limiting Devices

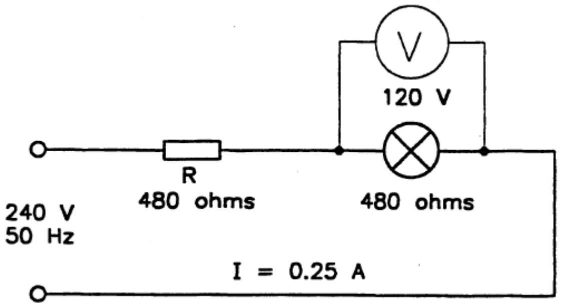
50. Resistors can be connected in series with other devices to limit the current in a circuit for a particular purpose, such as to reduce the voltage across the other device. Inductors can be used in the same way in a.c. circuits, with the advantage that the overall power loss in the circuit can be significantly reduced. However, using inductors to limit current, can result in a lower circuit power factor, and if capacitive components are in the series circuit, the possibility of high voltage across components under conditions approaching resonance.

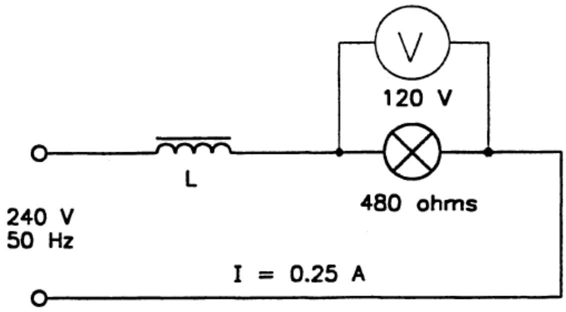
Exercise

51. A 480Ω resistor is to be connected in series with a 480Ω incandescent lamp to reduce the voltage across the lamp to 120V. The circuit supply is 240V, 50Hz. Calculate:

    a. The total power dissipated by the circuit.
    b. Calculate the power dissipated by the entire circuit if a suitable inductor was used to reduce the voltage across the lamp to 120V instead of a resistor.

    Neglect the d.c. resistance of the inductor and the effects of temperature on the resistance of the lamp. Draw the impedance triangle for the inductor circuit.





Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 6 Work Sheet	G102A JW/JD DEC 2013

R, L and C in Series

1. What value is used as the 'reference phasor' in a series RLC circuit?

2. A 1040Ω resistor, 0.79H inductor and 21μF capacitor are connected in series. What is the IMPEDANCE of the circuit on a 280V, 50Hz supply?

3. The line current in a series RLC circuit is 0.18A when the supply voltage is 200V, and the frequency is 50Hz. What is the IMPEDANCE of the circuit?

4. A series RLC circuit consists of a resistor, capacitor and an inductor, and it draws 0.2A from a 260V, 50Hz supply. What is the TRUE POWER in the circuit if the component values are:

   Resistance of R : 1290Ω
   Reactance of C : 107Ω
   Reactance of L : 354Ω

5. A series RLC circuit draws a line current of 0.16A from a 220V, 40Hz supply. What is the APPARENT POWER in the circuit?

6. What is the VOLTAGE across the resistor in an RLC series circuit if it has a resistance of 1920 Ω, the line voltage is 250V, and the line current is 0.13A?

7. A 230V series RLC circuit has a 1770Ω resistor, 0.55Hchoke and a 10μF capacitor. If the impedance of the circuit is 1775.9Ω, what is the POWER FACTOR?

8. A single phase AC circuit has instruments showing the following values:

Voltmeter:	220V
Wattmeter	6000W
Line ammeter	45A
Frequency	50Hz

   What is the POWER FACTOR of the circuit?

9. What name is given to the condition in which the inductive reactance and the capacitive reactance in an RLC circuit are equal? What limits the line current if it is a series circuit? What is the power factor?

10. Calculate the voltage across the resistor in an RLC series circuit if the circuit values are as follows:

    $R = 580\Omega$
    $X_C = 28\Omega$
    $X_L = 146\Omega$
    Line $I = 0.43A$

11. Calculate the voltage across the inductor in an RLC series circuit if the circuit values are as follows:

    $X_L = 90\Omega$
    $X_C = 28\Omega$
    $R = 720\Omega$
    Line $I = 0.39A$

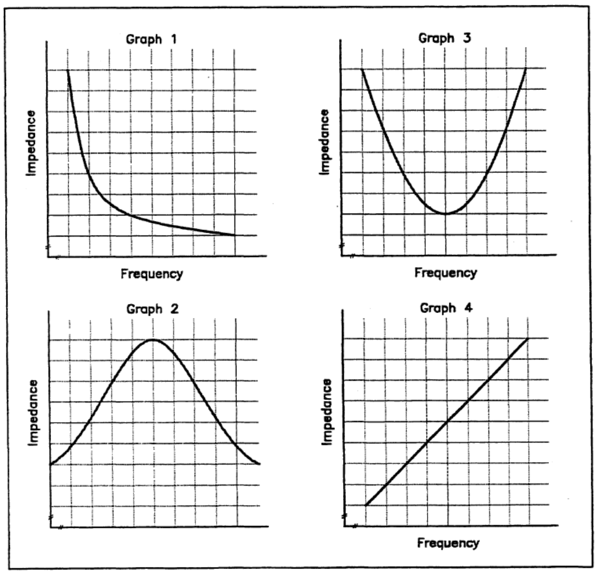
12. What is the voltage across the capacitor in an RLC series circuit if the circuit values are as follows:

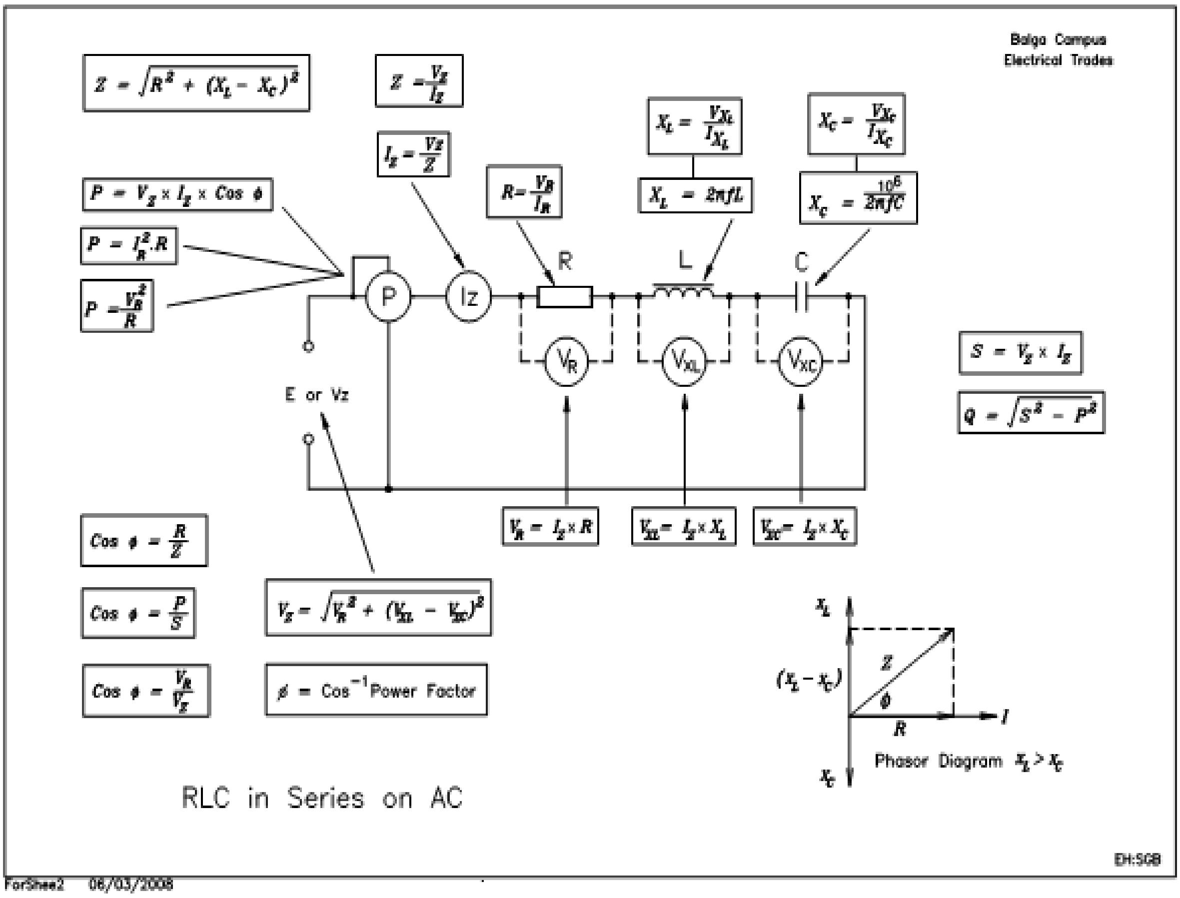
    Line $I = 0.17A$
    $R = 1540\Omega$
    $X_L = 176\Omega$
    $X_C = 29\Omega$

13. What is one advantage and one disadvantage of using an inductor to limit the current in an a.c. circuit compared to a resistor.

14. What two potentially hazardous situations can arise if a 240V RLC series a.c. circuit is operated at its resonant frequency?

15. Which of the following graph represents part of the circuit impedance characteristic of a series RLC circuit on a.c. as the frequency changes?





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Electrical Trades
$Z = \sqrt{R^2 + (X_L - X_C)^2}$
$Z = \frac{V_Z}{I_Z}$
$I_Z = \frac{V_Z}{Z}$
$X_L = \frac{V_{X_L}}{I_{X_L}}$
$X_C = \frac{V_{X_C}}{I_{X_C}}$
$P = V_Z \times I_Z \times \cos\phi$
$P = I_R^2 . R$
$P = \frac{V_R^2}{R}$
$R = \frac{V_R}{I_R}$
$X_L = 2\pi f L$
$X_C = \frac{10^6}{2\pi f C}$
R
L
C
P
Iz
VR
VXL
VXC
E or Vz
$S = V_Z \times I_Z$
$Q = \sqrt{S^2 - P^2}$
$V_R = I_Z \times R$
$V_{XL} = I_Z \times X_L$
$V_{XC} = I_Z \times X_C$
$\cos\phi = \frac{R}{Z}$
$\cos\phi = \frac{P}{S}$
$\cos\phi = \frac{V_R}{V_Z}$
$V_Z = \sqrt{V_R^2 + (V_{XL} - V_{XC})^2}$
$\phi = \cos^{-1}$ Power Factor
X_L
$(X_L - X_C)$
Z
ϕ
R
I
X_C
Phasor Diagram $X_L > X_C$
RLC in Series on AC
EH:SGB
ForShee2 06/03/2008

NOTES

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 6 Project 1	G102A JW/JD DEC 2013

An Inductor on A.C.

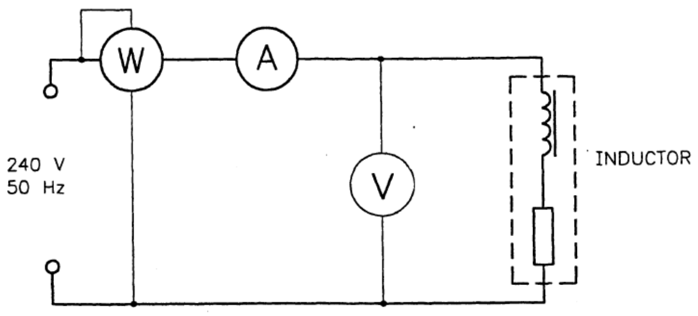
Objective

To verify the relationships between the values in an a.c. circuit consisting of an inductor with internal d.c. resistance.

Equipment

240V, 50Hz a.c. supply
An inductor (40W fluorescent choke or similar)
0-100W single phase analogue wattmeter or similar
0-1A a.c. ammeter
Multimeter
Single phase power board
Connecting leads

Circuit Diagram



Procedure

DANGER TAG PROCEDURE REQUIRED

1. Zero the multimeter on the ohms x 1 range, then measure the d.c. resistance of the inductor. Record the resistance in the Results Table.

2. Connect the circuit according to the circuit diagram given above (note that the resistor shown simulates the internal d.c. resistance of the inductor).

3. Check for short circuits with a multimeter set on the ohms x 1 range. Switch the multimeter off after the check.

4. Have your connections checked by your Lecturer.

5. Connect the circuit to the 240V, 50Hz supply. Measure line voltage, line current and power, and record your results in the Table.

6. Switch the circuit off, remove the plug from the outlet, attach your danger tag to the plug top.

7. Draw a phasor diagram showing the relationship between the resistance, inductive reactance and impedance in the circuit.

8. Calculate the values necessary to complete the table headed 'Calculations' (show all working on a separate sheet).

9. Have your results and calculations checked by your Lecturer.

10. Disconnect your wiring and return all of the equipment to its proper place.

Measurements

Results Table

Resistance of inductor	
Line voltage	
Line current	
Power	

Phasor Diagram

Calculations

Impedance	
Inductive reactance	
Inductance	
True Power	
Power Factor	
Apparent Power	
Reactive Power	
Angle of lag	
Current on d.c.	

Questions

1. Why was the current drawn on a.c. different from the current which would be drawn by the same inductor on d.c.?

2. List four factors which govern the current drawn by an inductor if it is supplied from a constant voltage a.c. supply

3. Does the d.c. resistance of the inductor have a significant effect on the current drawn by the inductor on a.c.?

4. How much of the line current is doing useful work in the circuit?

5. What is the resonant frequency of the test circuit?

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Resistance, Inductance and Capacitance in Series

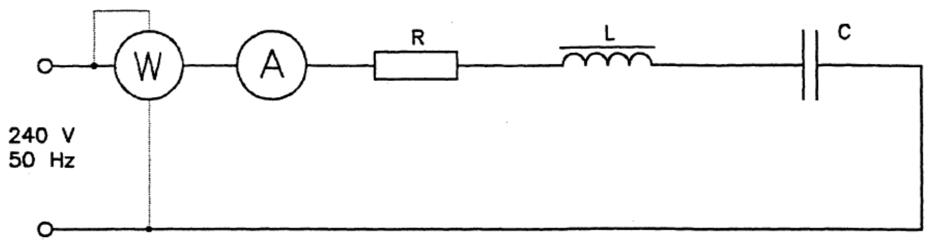
Objective

To observe the effects of connecting resistance, inductance and capacitance in series in an a.c. circuit.

Equipment

240V, 50Hz a.c. supply
480Ω resistor (1A)
3µF paper capacitor or similar
An inductor (36W fluorescent ballast or similar)
A 0-150W single phase analogue wattmeter or similar
One 0-1A a.c. ammeter
Multimeter
Single phase power board
Connecting leads

Circuit Diagram



Procedure

DANGER TAG PROCEDURE REQUIRED

1. Connect the circuit according to the circuit diagram given above.

2. Check for short circuits with a multimeter set on the ohms x 1 range. Switch the multimeter off after the check.

3. Have your connections checked by your Lecturer.

4. Connect the circuit to the 240V, 50Hz supply. Measure the voltage across each component with a multimeter, and record the reading in the Measurements Results Table. For each voltage reading, set the multimeter on the highest available a.c. range first.

5. Switch the circuit off, remove the plug from the outlet and attach your danger tag to the plug top.

6. Calculate the values necessary to complete the Calculations Results Table, and draw a phasor diagram of the circuit. Disregard the internal resistance of the inductor.

7. Have your results checked by your Lecturer.

8. Disconnect your wiring and return all of the equipment to its proper place.

Results

Results Tables - RLC in Series

Measurements					
I_Z	V_Z	V_R	V_L	V_C	P

Calculations							
R	L	X_L	X_C	Z	S	Q	Cos Φ

Phasor Diagram

Questions

1. Did the sum of the voltages across the components in this circuit add up to the line voltages? Explain your answer.

2. What dangerous condition could exist if the inductive reactance and the capacitive reactance were equal in a series a.c. circuit? What is the name of this condition?

3. Use your results to show that the only power dissipated in this circuit is the power dissipated by the resistor.

4. Use your results to determine whether the power factor of the circuit was lagging or leading. What is the value of the angle of lag or lead in this circuit?

5. What is the minimum value of power factor according to the WA Distributions Connections Manual?

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Power Factor Improvement

Task:

To describe the principles of power factor improvement and make use of the principles to improve the power factor in an industrial installation.

Why:

Power factor is an important consideration in any alternating current installation because it can result in excessive currents in parts of a circuit if it is not managed correctly. You need to understand the principles of power factor and power factor improvement so that you can ensure that appropriate measures are taken to reduce the effects of poor power factor.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a written assessment.
2. You must satisfactorily complete the set laboratory tasks
3. You must achieve 100% in a final practical assessment.

Equipment:

A.C. Theory Project Boards
LV A.C. Power Supply
A.C. Ammeters
A.C. Voltmeters
Multimeters
Scientific Calculator

References

- Electrical Principles for the Electrical Trades (6th ed.) Jenneson & Harper
- WA Electrical Requirements
- AS/NZS3000:2018 Wiring Rules. Standards Australia

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Power Factor Improvement

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

   Electrical Principles for the Electrical Trades (6th ed.)

   Vol. 1: 9.7 Power in a.c. circuits
   Vol. 2: 11.8 Power and energy meters

   WA Electrical Requirements

   Section 1.4 Power Factor

   AS/NZS 3000:2018 – Wiring Rules

   Clause 4.15 Capacitors

2. Read the Summary and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheet. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Complete the projects in this workbook.

5. Submit your answers to the Work Sheet and your completed project reports to your Lecturer for discussion and assessment.

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POWER FACTOR IMPROVEMENT

A.C. Power

1. There are various types of power in an a.c. circuit – TRUE power (P), measured in watts (W), APPARENT power (S), measured in volt amps (VA), and REACTIVE power (Q), measured in volt amps reactive (VAr). Power factor is the ratio between true power and apparent power in any circuit.
2. True power (P) is the power which is doing useful work in a circuit – usually converting electrical energy into heat energy, as in a heating element, or converting electrical energy into mechanical energy as in an electric motor. True power is the power measured on a wattmeter.
3. Apparent power (S) is the product of the line voltage and the line current (V times I) on a.c. Apparent power cannot be measured directly it can only be calculated from other circuit measurements.
4. Reactive power (Q) is the power stored in an a.c. reactive component (as a magnetic field in an inductor or as an electrostatic field in a capacitor) and returned to the mains during part of each half cycle. Reactive power is not usually measured directly but it can be calculated from other circuit measurements. Reactive power is sometimes referred to as 'wattless' power and the related current is called 'wattless' current.

Power Triangle

5. The relationship between the various types of power can be shown on special phasor diagram known as a 'power triangle', in which the true power is shown as a horizontal phasor pointing from left to right. A power triangle (see Figure 1) is similar in shape to an impedance triangle.

True Power = Energy Used

Apparent Power = Energy Supplied

Reactive Power = Energy Wasted

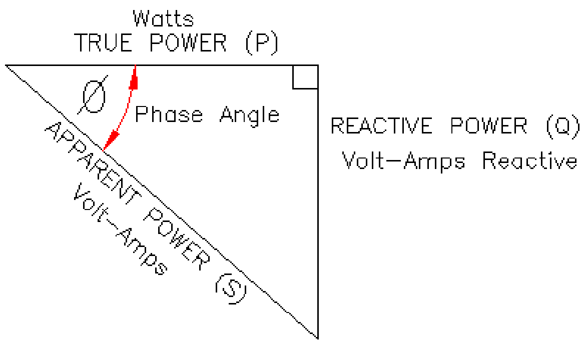


Figure 1 – A power triangle

6. The instruments necessary to measure the required values to construct a power triangle are shown on Figure 2.

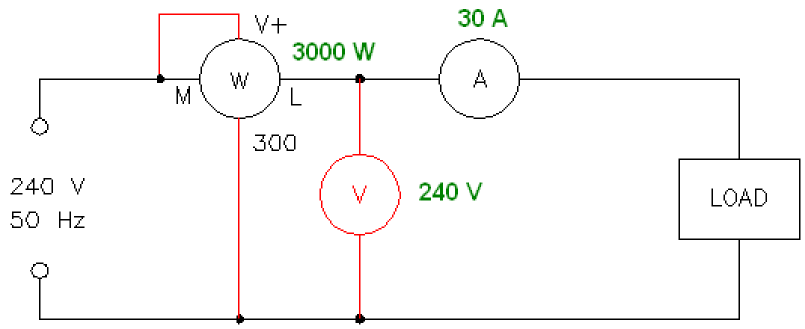


Figure 2 – Measuring a.c. power

7. In a typical power triangle, the only power doing useful work is represented by the horizontal line (the true power); the apparent power and the reactive power include power which is stored in the reactive component (an inductor or capacitor) and returned to the mains during part of each cycle.

8. The power factor (Cos Θ) is always the ratio between the true power and the apparent power (P/S or watts/volt amps). In a practical circuit the power factor must be greater than zero and less than or equal to 1.

9. **Example 1** A particular inductive a.c. circuit has a true power of 2400 watts, a line current of 12.5 amps and a line voltage of 240 volts. Determine the power factor (Cos Θ) and the angle of lag.

$$\text{Power factor } (\cos\Theta) = \frac{\text{True Power}}{\text{Apparent Power}} = \frac{P}{S} = \frac{P}{V \times I}$$

$$= \frac{2400}{12.5 \times 240}$$

$$= \frac{2400}{3000}$$

$$= 0.8 \text{ (lagging)}$$

The phase angle is that angle which has a cosine of 0.8

$$\cos^{-1} 0.8 = 36.87° \text{ (lagging)}$$

(The phase angle is lagging because the circuit is inductive)

10. If the power factor in a single phase a.c. circuit is known the true power can be found using the equation:

$$P = V \times I \times \cos \Theta \times Eff\%$$

Where: V = The LINE voltage

I = The LINE current

Cos Θ = The angle of lag or lead

Eff% = The efficiency of the consuming device

11. In resistive a.c. circuits at power frequencies (around 50Hz) the inductance of the resistor is usually insignificant and can be ignored, so the true power is equal to the apparent power and the power factor is 1 (or unity).

12. If an a.c. circuit has a low power factor it means that some of the current being supplied to the circuit is being returned to the mains during part of each cycle, therefore it does no useful work. However, the current must be supplied to the device in the first place – the supply authority alternator has to generate the current, the circuit cables have to be able to carry it, and the switches and contactors in the circuit need to be large enough to handle low or poor power factor. Low power factor has the following disadvantages:

    a. Larger circuit cables
    b. Larger switch or contactor contacts
    c. Larger fuses
    d. More volt drop in cables
    e. Increased copper losses in cables and consuming devices
    f. Lower alternator efficiency
    g. Higher electricity production and distribution costs.

13. Inductive devices such as electric motors and transformers usually operate at their highest designed efficiently when they are on full load, but it is not always possible to operate all devices at full load.

Power Factor Correction

14. Since the current in a capacitor is out of phase with the current in an inductor by 180 degrees, it is possible to connect a suitable capacitor in parallel with inductive consuming devices to cause the power factor to be closer to 1 or unity. This process is called ‘improving the power factor’ or ‘power factor correction’.

15. The general principle of power factor correction can be shown by examining a power triangle for an inductive device with and without a power factor correction capacitor as shown in the following example.

16. **Example 2** A particular single phase transformer draws 10 amps from the 240 volt mains and a wattmeter connected in the circuit indicates a true power of 1200 watts – as shown in Figure 3.

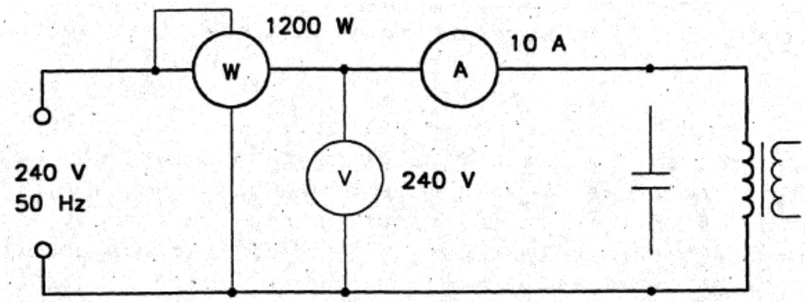
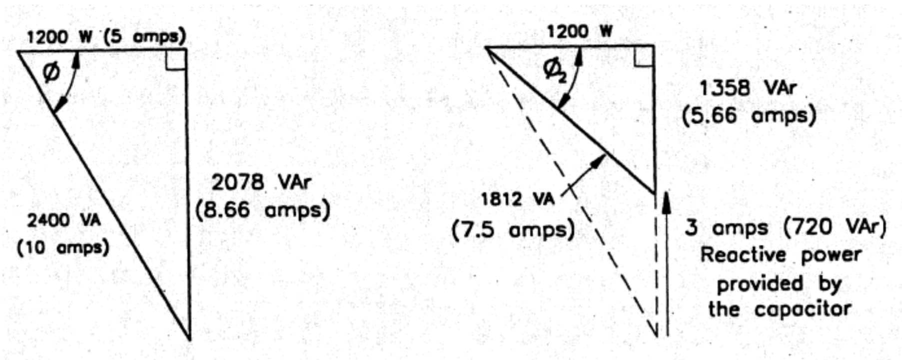


Figure 3 – Power factor correction

17. A suitable capacitor with a current rating of 3 amps (720 VAr on 240 volts) is connected in parallel with the primary of the transformer. A power triangle for each condition is shown in Figure 4. The reactive power (volt amps reactive or VAr) required to be supplied by the capacitor is indicated on the diagram.



Without the capacitor With the capacitor

Figure 4 – Power triangles

18. With the power factor correction capacitor connected in parallel with the consuming device, the line current is reduced from 10 amps to 7.5 amps without any significant increase in true power. (The only increase in true power would be the power loss in the capacitor, but this is low enough to be ignored in most practical situations.)

19. If too large a capacitor is used for power factor correction the power factor would be leading and the same disadvantages would apply as if the power factor was lagging (i.e. higher currents in the supply cables and control equipment).

20. Correcting the power factor to a particular device only reduces the line current on the LINE or supply side of the capacitor – the current and power factor within the machine itself remains unchanged. Therefore power factor correction capacitors should be connected as close to the corrected load as possible.

21. A typical single 240 volt 36 watt fluorescent luminaire has a line current of around 0.2 amps with a 3.5 microfarad power factor correction capacitor (as supplied by the manufacturer), but the line current rises to around 0.4amps if the capacitor is disconnected (without any change to the light output or the cost of operating the luminaire). Disconnecting faulty power factor correction capacitors without replacing them can lead to severe overloads in the associated supply cables and control equipment.

22. The WA Connections Manual Clause10.8.2: Western Power - Power Factor Limits- The Technical Rules prescribes the power factor range for loads of less than 1 MVA connected to the distribution system to be 0.8 lagging to 0.8 leading. Where necessary to ensure the satisfactory operation of the distribution system, a different power factor range may be specified in the relevant connection agreement.

23. Western Power may permit a lower lagging or leading power factor where this will not reduce system security and/or quality of supply, or require a higher lagging or leading power factor to achieve the power transfers required by the load. The Wiring Rules requirements relating to capacitors are contained in Clause 4. The 3.5 microfarad power factor correction capacitor in a typical 240 volt a.c. 36 watt fluorescent circuit, for example, requires a discharge path – usually a 1 megohm resistor connected across the capacitor terminals. In some cases the resistor is connected inside the capacitor casing and is not visible from outside.

24. Power factor in single or three phase circuits can be improved by:

    a. Operating motors and transformers on full load

    b. Connecting suitable capacitors in parallel with inductive circuits

    c. Using special machines called rotary capacitors

25. The power factor of a circuit can be measured directly with a power factor meter. A power factor meter is usually marked ‘Power Factor’ or ‘Cos Θ’ and it is of the ‘centre zero’ type so that it can indicate either leading or lagging power factor. The connections for a typical single phase analogue power factor meter are shown in Figure 5 – the connections are similar to those on an analogue wattmeter.

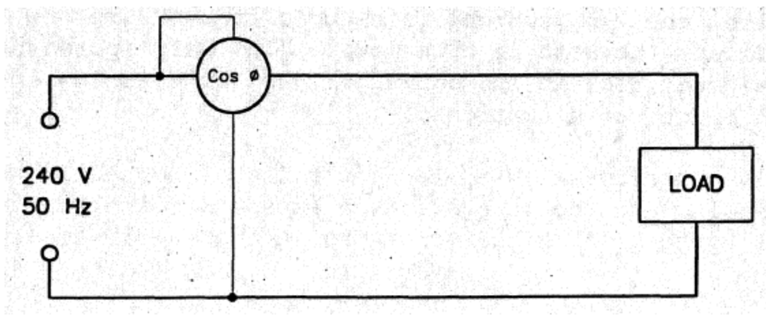


Figure 5 – Power factor meter connections

Resonant Circuits

26. In a series or parallel resonant circuit the reactive components cancel each other out so the power factor is always 1.

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Power Factor Improvement

1. An a.c. circuit has a line current of 10 amps, a line voltage of 240 volts and a wattmeter reading of 1000 watts. What is the value of APPARENT POWER in the circuit?
2. An a.c. circuit has a line current of 20 amps, a line voltage of 240 volts and a wattmeter reading of 2000 watts. What is the value of TRUE POWER in the circuit?
3. An a.c. circuit has a line current of 30 amps, a line voltage of 240 volts and a wattmeter reading of 3000 watts. What is the value of REACTIVE POWER in the circuit?
4. Draw a typical POWER triangle for a series or parallel RLC a.c. circuit?
5. How is the ‘POWER FACTOR’ of an a.c. circuit usually defined?
6. What is the maximum possible value of power factor in a sinusoidal a.c. circuit?
7. What would be the power factor of an a.c. circuit which had pure reactance (s) but no resistance?
8. What three common measuring instruments are required to determine the power factor of an a.c. circuit (not including a power factor meter)?
9. What common single phase measuring instrument has the same external connections as a power factor meter?
10. An inductive a.c. circuit has a line current of 20 amps, a line voltage of 240 volts and a wattmeter reading of 4000 watts. What is the power factor of the circuit?
11. What is the ‘MAIN’ undesirable effects of operating a circuit at a low power factor?
12. What are six undesirable effects of operating a circuit at a low power factor?
13. What is the most common method of improving the power factor of an inductive a.c. circuit?
14. A single phase inductive component draws a current of 20 amps from a 240 volt 50 Hz supply, at a power factor of 0.5. Calculate the reactive power required to correct the circuit power factor to 0.8 lagging. Show the results on a power triangle.
15. Does operating a circuit at a low power factor significantly increase the cost of operating the circuit?
16. What safety precaution should be taken before working on a large power factor correction capacitor which has just been disconnected from the mains?

17. What is the lowest permissible power factor in circuits connected to Western Power's Distribution System according to the WA Connections Manual?

18. Why should a power factor correction device be connected as close to the corrected device as possible?

19. What is the capacity of the largest capacity power factor correction capacitor which may be installed without a discharge path according to AS/NZS3000:2018? State the Clause number.

20. What effect does it have on the power factor of a three phase circuit if several three phase induction motors are operated with light loads?

NOTES

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Power Factor in a Single 36 W Fluorescent Circuit

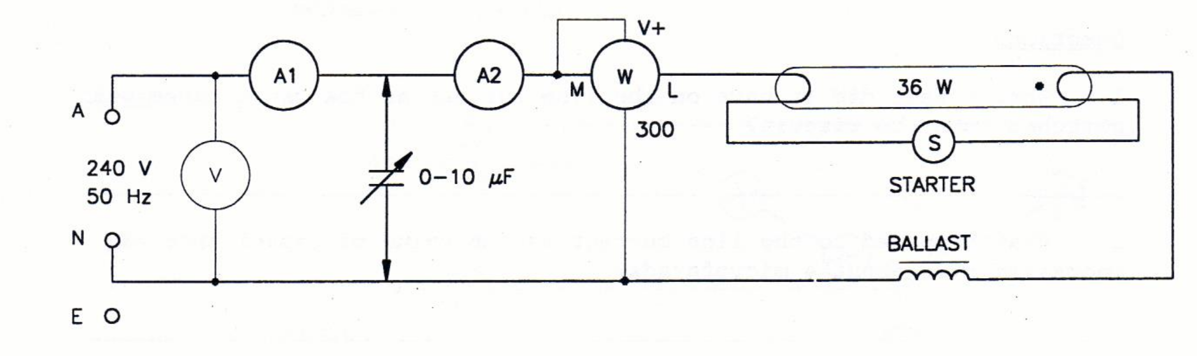
Objective

To observe the effects of changing the capacitance in a standard single 36 watt fluorescent circuit.

Equipment

240 volt 50Hz a.c. supply
One single 36 (or 40) watt fluorescent unit
A variable 240 V switchable paper capacitor bank (about 2 to 10 µF).
A 0-100 W single phase analogue wattmeter or similar
Two 0 – 1 amp a.c. ammeters
Multimeter
Single phase power board
Connecting leads

Circuit Diagram



Procedure

DANGER TAG PROCEDURE REQUIRED

1. Connect the circuit according to the circuit diagram given above. Make sure that the settings on the variable capacitor bank are such that there is no capacitance connected in the circuit.

2. Check for short circuits with a multimeter set on the ohms times 1 range. Switch the multimeter off after the check.

3. Have your connections checked by your Lecturer

4. Switch the circuit on and record the meter readings in the Results Table.
5. Switch the capacitance into the circuit in increments of about 2 microfarads and record the meter readings for each setting.
6. Switch the circuit off, remove the plug from the outlet and attach your danger tag to the plug top
7. Have your results checked by your Lecturer
8. Disconnect your wiring and return all of the equipment to its proper place

Results Table

	µF	Line E	Line I	I_2	Power	Cos Θ
No Capacitance	0 µF					
Setting 1						
Setting 2						
Setting 3						
Setting 4						
Setting 5						

Questions

1. What effect did it have on the line current as the capacitance was switched into the circuit?

____

2. What happened to the line current as the value of capacitance was increased over about 4 microfarads?

____

3. What happened to the reading on the wattmeter as the capacitance was switched into the circuit?

____

4. What happened to the reading on ammeter I_2 as the capacitance was switched into the circuit?

____

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Three Phase Systems

Task:

To describe the principles of the production and local distribution of a three phase alternating current supply system, to perform simple power and energy calculations relating to star and delta circuits and to determine the out of balance current in the neutral conductor of a three phase four wire distribution system.

Why:

The basic system of distributing electrical energy to consumers in Australia is via a three phase four wire distribution system. You need to understand the characteristics and behaviour of such a distribution system in order to be able to connect components correctly and monitor their performance in an installation.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a written assessment.
2. You must satisfactorily complete the set laboratory tasks
3. You must achieve 100% in a final practical assessment.

Equipment

Three Phase Theory Project Boards
LV A.C. Power Supply
A.C. Ammeters
A.C. Voltmeters
kWh meters
Multimeters
Scientific Calculator

References

- Electrical Principles for the Electrical Trades (6th ed.) Jenneson & Harper
- AS 3000:2018 Wiring Rules.

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Three Phase Systems

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades (6th ed.)

Vol. 1: Chapter 10 Three - phase alternating current

Vol 1: 8.11 Harmonics

AS/NZS 3000:2018 Wiring Rules

Clause 3.5.2. Neutral conductor (minimum size)

2. Read the Summaries and practise answering the questions provided on the Work Sheets. Refer to other relevant texts if you feel it is necessary.
3. Answer the questions given on the Work Sheets. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time
4. Complete the projects in this workbook
5. Submit your answers to the Work Sheets and your completed project reports to your Lecturer for discussion and assessment.

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 8 Summary	G102A JW/JD Dec 2013

Three Phase Systems

Generation of AC

1. If a single coil of insulated winding wire is rotated at a constant speed through a two pole magnetic field, an EMF is induced in the coil. If the coil is connected in such a way that a closed circuit is formed a current flows in the coil. The resulting output from such an arrangement is known as a SINGLE PHASE sine wave or sine curve, or the output is said to be sinusoidal. A common name for a device which produces a sinusoidal single phase output is a single phase alternator.

2. The initial mechanical energy required to rotate the rotor and produce electrical energy is supplied from a prime mover, typical types of prime mover include:

   a. Diesel engines
   b. Petrol engines
   c. Steam turbines
   d. Wind driven propellers
   e. Gas turbines (jet engines)
   f. Water turbines (hydro)

3. The output from a single phase alternator is governed by:

   a. The speed of rotation – in general, the higher the speed the higher the output voltage, and the higher the frequency of the sinusoidal output.

   b. The strength of the magnetic flux – in general, the stronger the magnetic flux the higher the output voltage.

   c. The number of turns on the coil – in general, the higher the number of turns the higher the output voltage

   d. The angle at which the coil cuts the magnetic flux. The induced voltage is zero when the coil is moving parallel to the flux and maximum when it is cutting the flux at 90 degrees, so the output voltage varies sinusoidally between zero and maximum to produce one complete sine wave (or cycle) for every revolution (for a two pole machine).

Three Phase Generation

4. A simple three phase alternator operates on the same basic principle as a single phase alternator, but there are three coils on the rotor instead of one, and the three coils are physically arranged so that they are at 120 mechanical degrees to each other.

5. In some alternators the a.c. coils are wound in the stationary stator and the permanent magnet or d.c. coils which produce the initial magnetic field are on the rotor; in either case the output is the same.

6. Alternators must be run at a constant speed to produce a constant output frequency. The customary frequency in Australia is 50 Hz, but in some American installations 60Hz is used.

7. The peak output voltage from one revolution of a three phase alternator which has three coils rotating in a two pole magnetic field is shown in Figure 1. The rms value for each phase is 0.707 of the peak value.

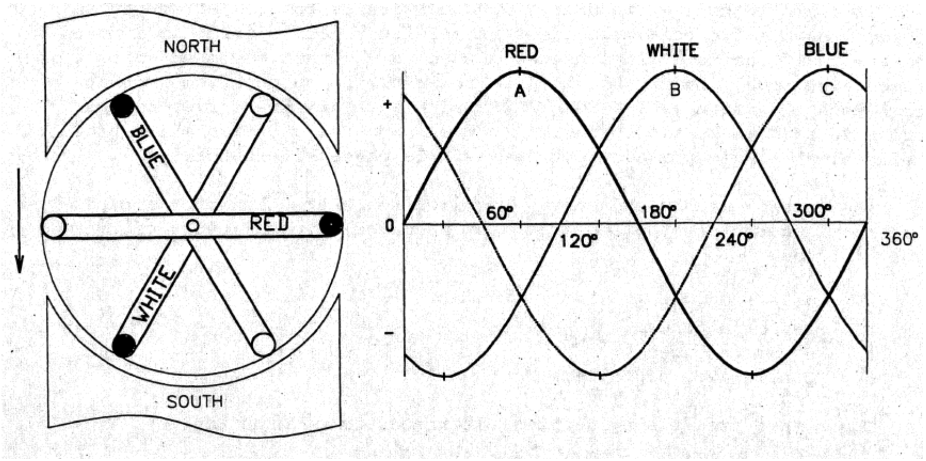


Figure 1 - Three phase sine wave

8. You can see from Figure 1 that one revolution of the two pole alternator produces three sinusoidal voltages – each separated by a phase angle of 120 electrical degrees. Each sine curve reaches a maximum value twice in each cycle (one positive and one negative), and for any given point in time, there is always current flowing in at least two of the three phases. Also, for any given point in time, the instantaneous sum of all three values is zero. For every point in time on a three phase sine curve the current is in one direction in two of the phases and in the opposite direction in the other phase (except when the current in one phase is zero).

9. You can also see from Figure 1 that the phases reach their maximum value in a particular sequence (separated by 120 degrees) – in this case Red, White and then Blue (or ABC). This is known as the phase sequence, or phase rotation, and this governs the direction of rotation of three phase motors; if the current in any two phases is reversed the phase sequence is reversed – it becomes ACB.

10. A phasor diagram of the output voltages from a three phase alternator is shown in Figure 2. These voltage are usually expressed as rms values.

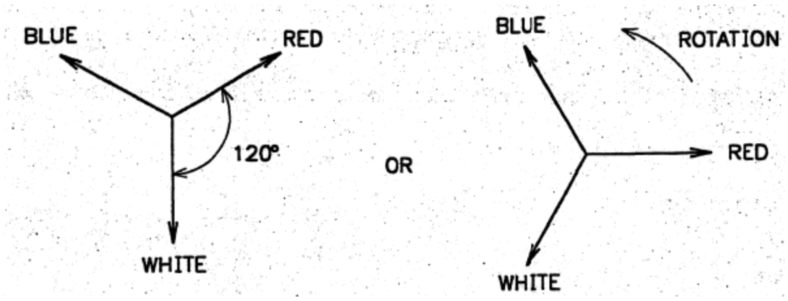


Figure 2 – Phasor representation of a three phase output.

11 Most supply authorities generate and distribute electrical energy using the three phase system. The main advantages of a three phase distribution system compared to a single phase system include:

a. Two operating voltages are available to consumers; 240 volts rms for lighting and small power applications and 415 volts rms for large motors and other high power applications.

b. Three phase machines can be smaller and more efficient than single phase machines for the same power output.

c. The three phase squirrel cage induction motor is one of the simplest and most reliable motors available.

d. The torque produced by a three phase motor is more constant than the torque produced by a single phase motor, so there is less vibration.

e. A three phase distribution system requires less copper in the transmission lines than a single phase system with the same power transmission capability.

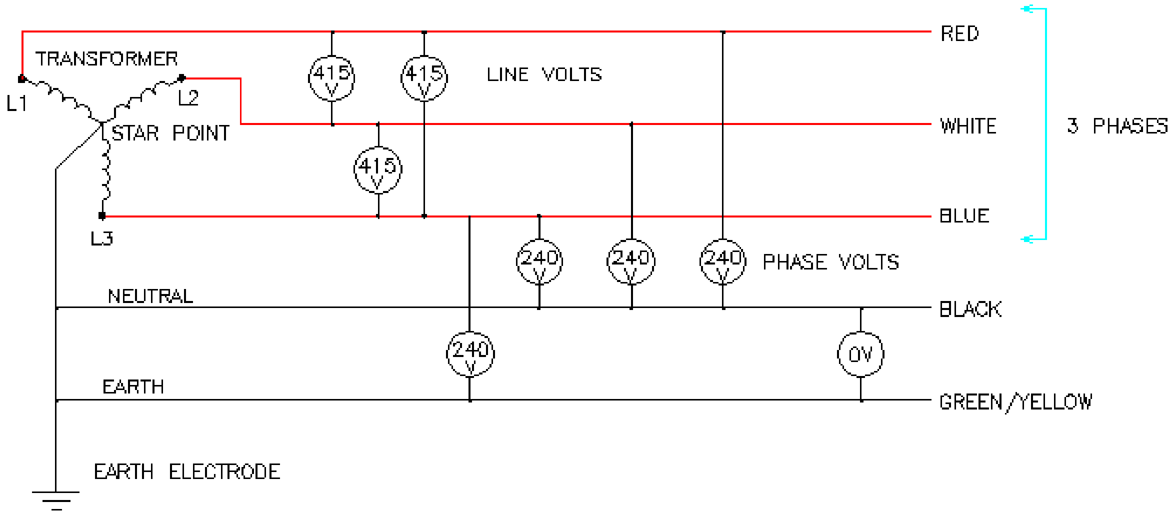
12 Various names are given to the three phases, depending on the application – typical names are:

a. Red phase, White phase and Blue phase
b. Line 1 (L1), Line 2 (L2) and Line 3 (L3)
c. A Phase, B Phase and C Phase
d. R, S and T (on some European equipment)

13 A three phase distribution system allows electricity to be distributed to consumers over what is known as a 'three phase four wire distribution system'. A three phase four wire distribution requires four wires in the distribution system – three actives and one neutral or return wire, but five in each installation (the fifth being the earthing conductor). The voltages available in the three phase four wire distribution system in W.A. are shown in Figure 3. The voltage between any two phases is nominally 415 volts rms and the voltage from any phase

to neutral (or earth) is nominally 240 V rms. The neutral conductor is connected to the earth so the voltage between neutral and earth should be zero.

Figure 3 – Voltages in a three phase four wire distribution system



Star and Delta Connections

14 Three phase devices such as three phase motors, three phase transformers, three phase heating elements require three actives and one earth to be connected to them – they do not require a neutral unless it is required to supply some auxillary 240 volt component associated with the main device (such as indicator lamps, contactor coils or other control circuit components).

15 Three phase devices can be connected in two main ways (also known as 'configurations) – star and delta. In American terminology star is called 'wye' and delta is called 'mesh'. The basic star and delta connections are shown in Figure 4.

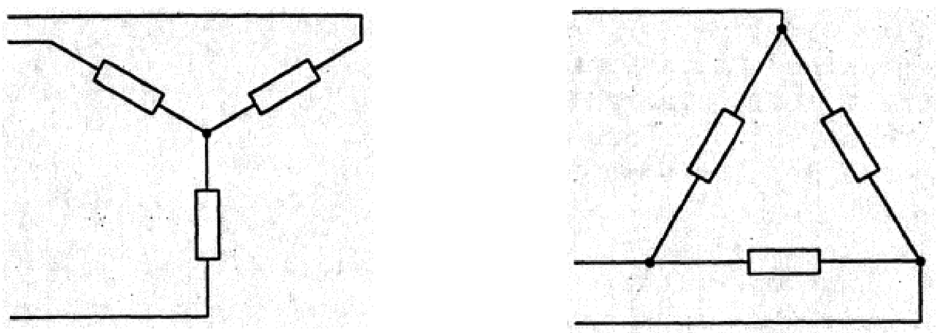


Figure 4 – Basic star and delta connections

16 The voltage across each 'leg' of a star or delta connection is known as the 'phase voltage (V_P)' (or 'coil voltage) and the incoming three phase voltage is known as the 'line voltage (V_L)'.

The star Connection

17 In the three phase star connection the finish of each coil group or heating element is connected to a common point known as a 'star point'. There are several ways of drawing s star connection as shown in Figure 5.

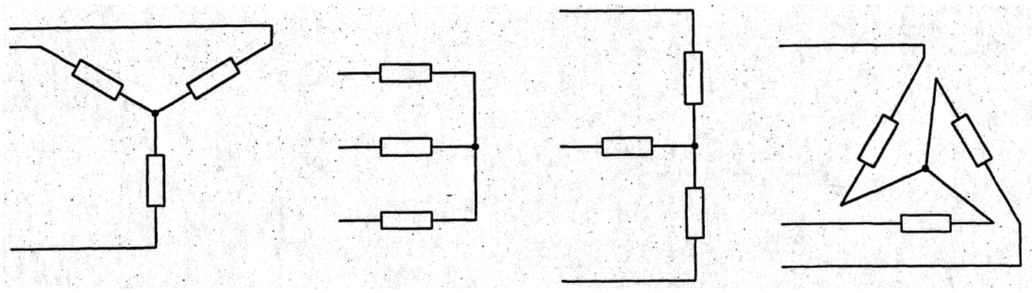


Figure 5 – Methods of drawing a star connection

18 If a 415 volt three phase supply is correctly connected to a star connected device the resulting voltage and current distribution is as shown in Figure 6.

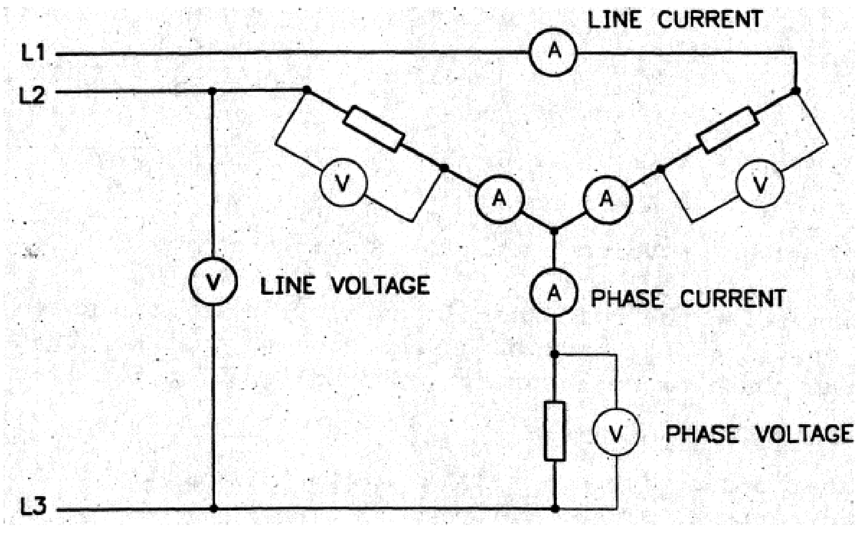


Figure 6 – The voltage and current distribution in a star connection

19 There is a specific mathematical relationship (or ratio) between the phase voltage and the line voltage – in a star connection the phase voltage is less than the line voltage by a factor of $\sqrt{3}$ (1.7321) or 'root 3'.Dividing the line voltage of 415 by $\sqrt{3}$ gives a value of 239.6; for virtually all practical purposes this value is rounded to 240 volts.

Similarly, multiplying the nominal phase voltage of 240 volts by $\sqrt{3}$ gives 415.692 which is known as 415 volts. In a star connection the line voltage leads the phase voltage by 30 electrical degrees.

20 Each of the pairs of coils in a star connection is connected in series across the 415 volt supply, so you might expect that the voltage across the individual coils would be half the line voltage (from Ohm's Law), but this is not so because the phase to phase voltages are 120 degrees out of phase with each other. The voltages across any two legs of the star connection are 120 degrees out of phase with each other, so if each was 240 volts the phasor difference would be 415 volts (or 240 times $\sqrt{3}$). As a general principle, the coil voltage must be less than the line voltage – by a factor of $\sqrt{3}$. The voltage relationships in a star configuration are shown in Figure 7.

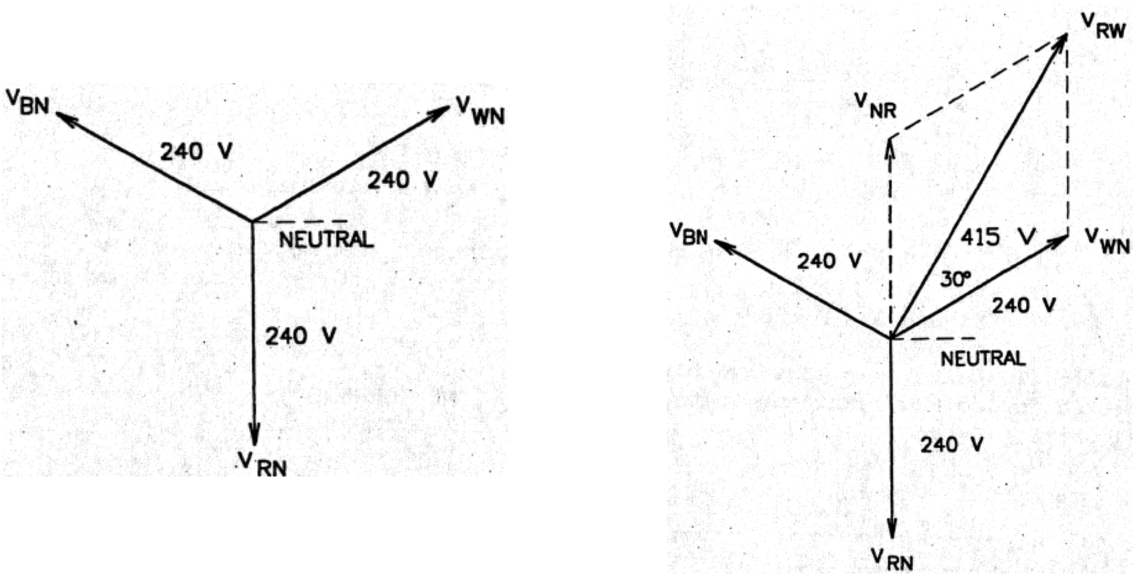


Figure 7 – Voltage relationships in star

21 In a star connection the coils connected between any two phases are in series; there is only one current path so the current must be the same in both, therefore the phase or coil current must be equal to the line current.

22 Thus for a star connection the relationships between the line and phase voltages and currents are as follows:

	Star
Line current = Phase current	$I_L = I_P$
Line voltage = Phase voltage times √3	$V_L = \sqrt{3}\,V_P$
Phase current = Line current	$I_P = I_L$
Phase voltage = Line voltage divided by $\sqrt{3}$	$V_P = V_L/\sqrt{3}$

Line voltage leads phase voltage by 30º electrical

23 If each leg of a star connected device is identical the voltage and current values for each leg will be the same (although they will be out of phase); this arrangement is known as a ‘balanced load’.

24 In a balanced star connection, regardless of the type of load, the voltage between the star point and earth is zero. Three phase transformers which are used in the 415/240 volt electrical distribution system are star connected on the secondary windings, and the star point is the point at which the neutral originates. The star point is also connected to the earth because a three phase distribution is not a balanced load. The effect of unbalanced loads will be covered later in this workbook.

The Delta Connection

25 In the three phase delta connection the finish of each coil group or heating element is connected to the start of the next. There are several ways of drawing a delta connection as shown in Figure 8.

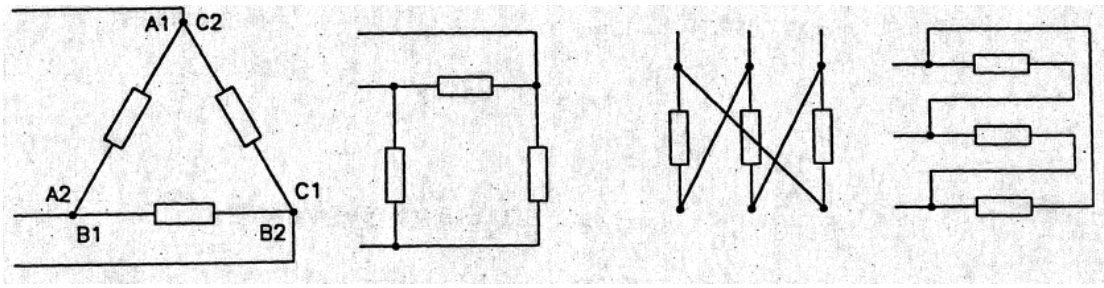


Figure 8 - Methods of drawing a delta connection

26 If a 415 volt three phase supply is correctly connected to a delta connected device the resulting voltage and current distribution is as shown in Figure 9.

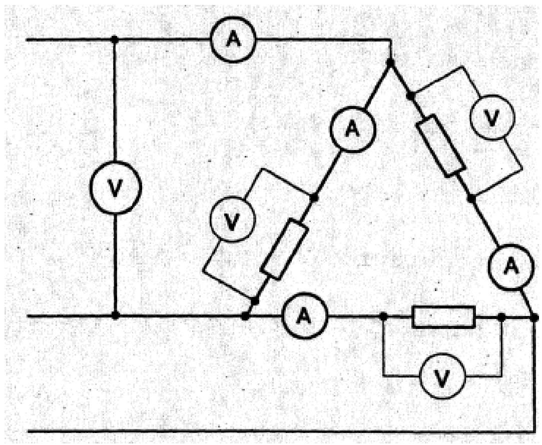


Figure 9 - The voltage and current distribution in a delta connection

27 The relationships between the currents and voltages in a delta connection are similar to those in a star connection in that the factor of $\sqrt{3}$ needs to be considered, but $\sqrt{3}$ is applied to the CURRENTS rather than the voltages, because two out of phase, phase currents contribute to the line current in each phase. In a delta connection the line current lags the phase current by 30 degrees electrical. The current relationships in a delta configuration are shown in Figure 10.

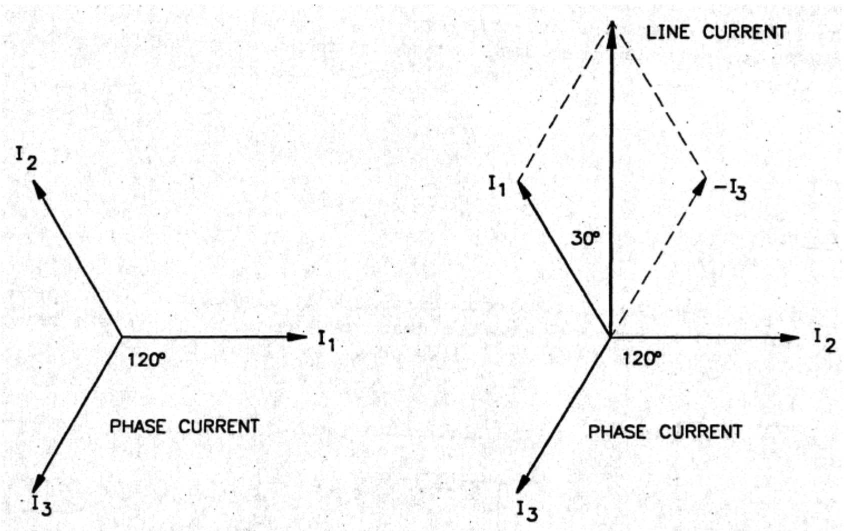


Figure 10 – Current relationships in delta

28 The line current coming into any of the delta connections must divide into two paths, the voltages across which are out of phase. The current in any leg can be found by dividing the line current by $\sqrt{3}$; thus the phase current must be less than the line current by a factor of $\sqrt{3}$

29 Thus for a delta connection the relationships between the line and phase voltages and currents are as follows:

			Delta
Line voltage	=	Phase voltage	$V_L = V_P$
Line current	=	Phase current time √3	$I_L = \sqrt{3}\, I_P$
Phase voltage	=	Line voltage	$V_P = V_L$
Phase current	=	Line current divided by √3	$I_P = I_L / \sqrt{3}$

Line current leads phase current by 30º electrical

Star and Delta Relationships

30 The relationships (or ratios) between the currents and voltages in balanced three phase star and delta circuits are summarised in Figure 11. If you know these relationships you can calculate unknown values if you are given appropriate values of phase or line current or voltage.

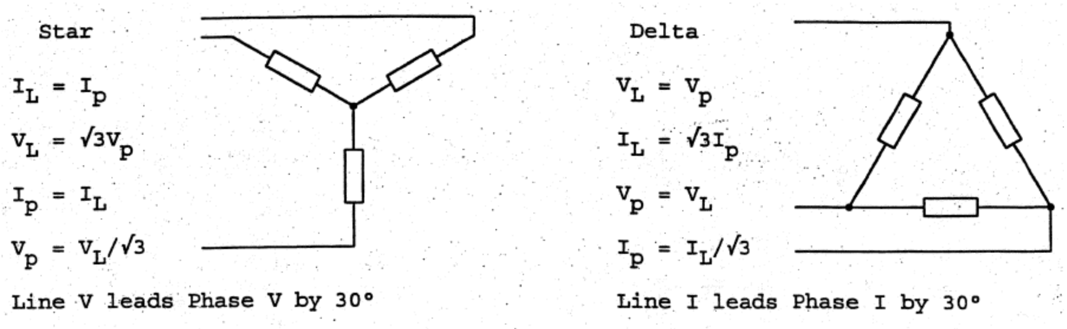


Figure 11 - Summary of star and delta relationships

Exercise

31 Determine the unknown values in the following samples. You should always draw a diagram of the given circuit before you attempt any calculations.

a. **Sample** a three phase star connected heating element has a line voltage of 415 volts and a phase current of 10 amps. Determine the following values:

- Phase voltage ______________________
- Line current ______________________

Sample Solution:

Phase V = Line E / $\sqrt{3}$ (In star)

= 415 / $\sqrt{3}$

= 240 volts (rounded)

===============

Line I = Phase I (In star)

= 10 amps

=========

b. A three phase delta connected heating element has a line voltage of 440 volts and a phase current of 10 amps. Determine the following values:

- Phase voltage ______________________
- Line current ______________________

c. A three phase star connected heating element has a phase voltage of 208 volts and a line current of 10 amps. Determine the following values:

- Line voltage ______________________
- Phase current ______________________

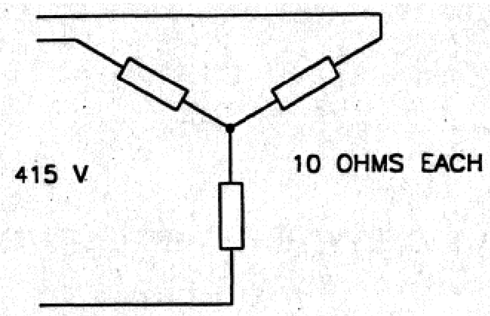
d. A three phase delta connected heating element has a phase voltage of 240 volts and a line current of 10 amps. Determine the following values:

- Line voltage ______________________
- Phase current ______________________

Resistors in Star or Delta

32. If three resistors are connected in star or delta the resulting line current can be found using the appropriate voltage relationships.

33. **Example 1** Find the line current (I_L) if three 10 ohm resistors are connected in STAR to a 415 three phase supply.



$V_L = 415$ volts

So $V_P = 415 / \sqrt{3}$

$= 415 / 1.7321$

$V_P = 240$ volts (approx.)

$I_P = V_P / R$

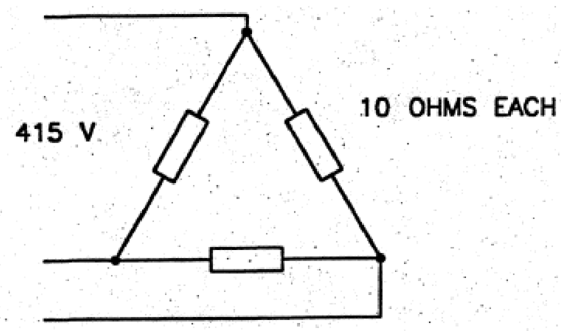
$= 240 / 10$

$= 24$ amps

$I_L = I_P$

So $I_L = 24$ amps

34. **Example 2** Find the line current (I_L) if three 10 ohm resistors are connected in DELTA to a 415 three phase supply.



$V_L = 415$ volts

So $V_P = 415$ volts

$I_P = V_P / R$

$= 415 / 10$

$= 41.5$ amps

$I_L = \sqrt{3} \times I_P$

$= \sqrt{3} \times 41.5$

$I_L = 71.88$ amps

Incorrect Coil Connections

35. Resistive loads such as heating elements can usually be connected without having regard for the starts and finishes of the load elements. However, in magnetic devices such as three phase motors and transformers the correct relationship between starts and finishes of coils and coil groups is critical for correct operation. If one phase winding is reversed, the device will not operate correctly, and excessive currents will usually result in the device overheating and burning out.

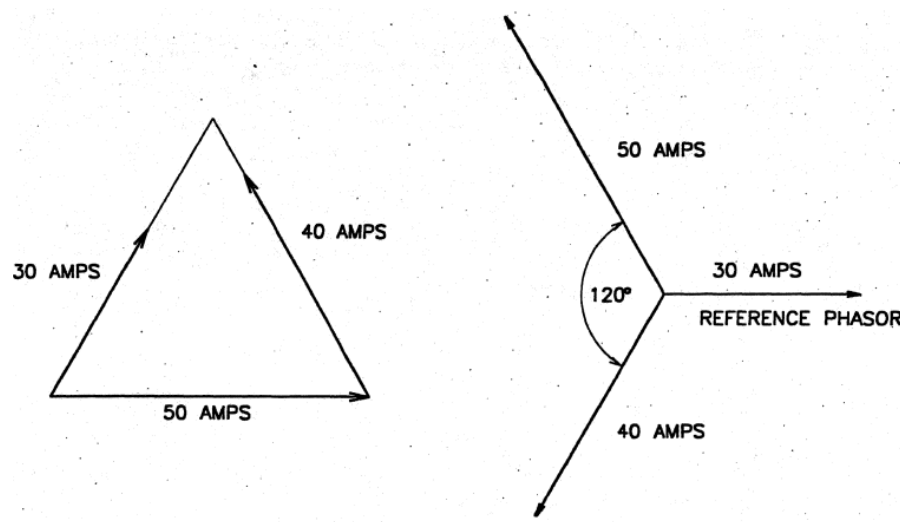
Three Phase Unbalanced Circuits

36. An unbalanced three phase system is one in which the current in each phase is different. In this section we consider the effects of an unbalanced three phase star connected four wire distribution system in which the neutral conductor is connected to the star point of the distribution transformer secondary winding.

37. If the load on each phase of a four wire distribution system is unbalanced, current will flow in the neutral conductor. This current is known as the ‘out of balance current. The out of balance current in the supply neutral conductor of an installation can be reduced by balancing the current in each phase as much as possible.

38. The out of balance current in a neutral can be calculated by finding the phasor sum of the currents in each of the three phases. In a practical circuit the power factor of each phase must be considered, but for the purpose of illustrating the general principle we will assume that the unbalanced load consists of resistive components which have a power factor of unity.

39. Consider a three phase four wire distribution system in which the current in each phase are 30, 40 and 50 amps respectively. If the power factor of each phase is unity the phasor diagram of the circuit can be drawn in two ways as shown in Figure 12.



a. Triangle Phasors		b. 120° phasors

Figure 12 – Phasor diagrams of an unbalanced three phase circuit

40. Having drawn the phasor diagram the out of balance current can be determined by graphical construction or by calculation; we will use the graphic construction method.

a. **Method 1 – Triangle Phasors** Draw an equilateral triangle with sides equal to the largest given value of current (in this case 50 amps) using a suitable scale. Then draw the other two currents (using the same scale) on two of the sides of the triangle. The out of balance current is the distance between the two shorter phasors as shown in Figure 13.

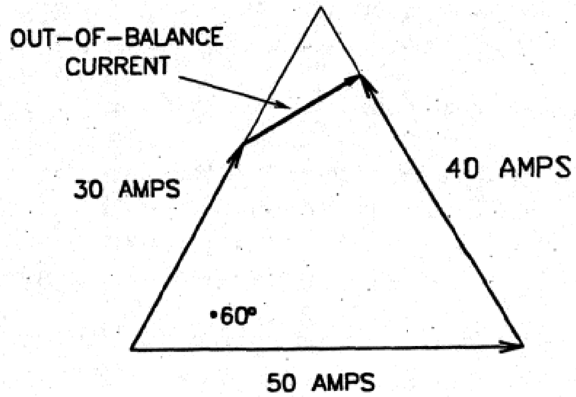


Figure 13 – Construction for Method 1

b. **Method 2 – 120 degree Phasors** Draw the three phasors 120 degrees apart using a suitable scale. Take any two of the phasors and construct their phasor sum. Then construct the phasor sum of the resultant of the first two and the remaining phasor; the resultant is the out of balance current in the neutral as shown in Figure 14.

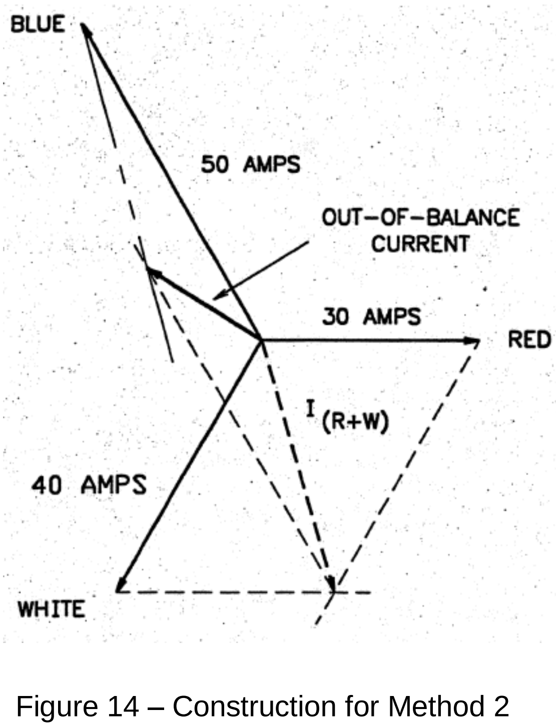


Figure 14 – Construction for Method 2

41. The out of balance current in the neutral as calculated using either of the methods shown above is approximately 18 amps (you could verify this result using trigonometry if you wish).

42. Figure 15 shows a phasor diagram of a balanced circuit in which each of the line currents is 10 amps. Use graphical construction to show that the out of balance in the neutral would be zero.

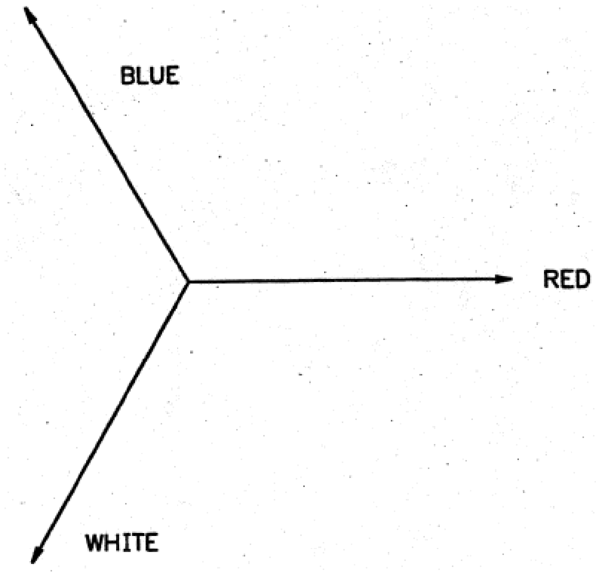


Figure 15 – Phasor diagram for a balanced circuit

43. Now let's consider a more practical circuit in which the currents in the phases have a power factor other than unity. An installation has the following phase currents:

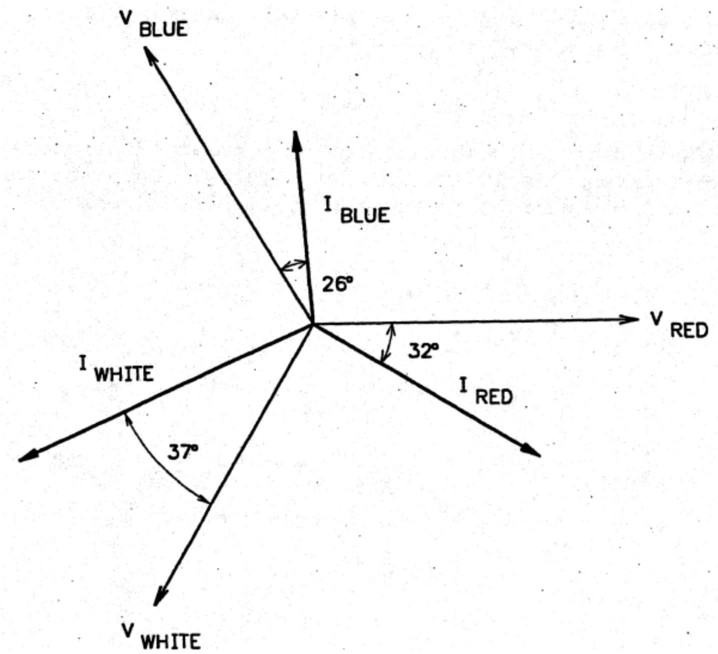
Red Phase:	40 amps at a power factor of 0.85 lagging
White Phase:	50 amps at a power factor of 0.8 lagging
Blue Phase:	30 amps at a power factor of 0.9 lagging

Calculate the current flowing in the neutral conductor.

44. The first step is to determine the phase angle for each phase from the power factor. The power factor is the cosine of the angle of lag (or lead), so, suing a suitable calculator:

Red Phase:	$\cos^{-1} 0.85 = 31.79°$ (lagging)
White Phase:	$\cos^{-1} 0.8 = 36.87°$ (lagging)
Blue Phase:	$\cos^{-1} 0.9 = 25.84°$ (lagging)

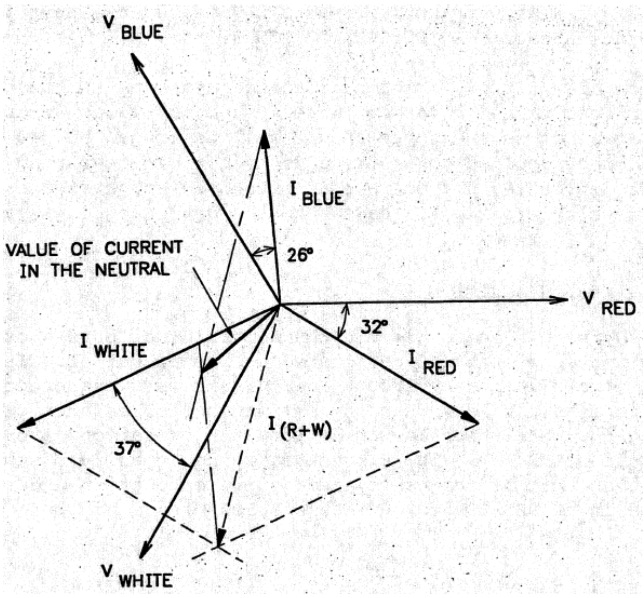
45. Now you need to draw the voltage phasors at 120 to each other, then draw the current phasor for each phase using a convenient scale (you will probably need a drawing protractor). The resulting voltage and current phasors are shown in Figure 16 (using the convention that phasors are assumed to be rotating anticlockwise).



Scale: 1 mm = 1 amp

Figure 16 – Voltage and current phasors, drawn to scale

46. The next step is to complete the parallelogram for two of the currents, then use the resultant and the third current to draw a second parallelogram. The resultant of the second parallelogram is the out of balance current in the neutral as shown in Figure 17.



Scale: 1 mm – 1 amp

The current in the neutral is 18 amps

Figure 17 - Out of balance current in the neutral

Reducing Out-of-Balance Current

47. The out-of-balance current in the neutral of a three phase installation which includes single phase loads can be reduced by balancing the current in each phase and by improving the power factor of individual single phase consuming devices.

Abnormal Operating Conditions

48. In operational three phase installations which include single phase loads, it is essential that the continuity of the neutral conductor be maintained at all times. If the neutral is open circuited, connected devices would not operate correctly. It would be possible for devices to stop operating although the active remains alive – this would create a serious safety hazard because a person may touch the live wire thinking it was dead. This is yet another reason why you must always follow the basic safety procedure of TEST BEFORE YOU TOUCH.

49. If an open circuit or high impedance develops in the neutral conductor of a three phase four wire system supplying an unbalanced load the voltages across the three phases will no longer be 240 volts rms. If the voltage applied to a device is higher or lower than the designed value the device may not operate as intended – significant variations usually result in permanent damage to the device by overheating.

Wiring Rules Requirements

50. In any single phase circuit the neutral must have a current carrying capacity not less than the associated active conductor (Clause 3.5.2 (a)). In a multiphase circuit the current carrying capacity of the neutral must be not less than that determined by: Harmonic currents; Consumers mains, sub-mains and final sub-circuits, maximum out of balance current; and PEN conductors (see Clause 3.5.2 (b)).
    The current carrying capacity of the neutral conductor of multiphase consumer mains, sub-mains or final sub-circuit shall not be less than that of the current-carrying capacity of the largest associated active conductor (AS/NZS 3000:2018 - Clause 3.5.2 (b)(ii).

Using Two Phases

51. Equipment which has a relatively high current rating can be designed for connection to two phases of a three phase supply. Two common examples are:

    a. **Cooking Ranges** If a three phase supply is available the cooking range is supplied with two phases and a neutral. The 240 volt heating elements are arranged so that the current in each phase is as close as possible to the same value, and each element is connected to a common neutral. This type of connection spreads the load over two phases instead of having the entire load on one phase.

    b. **Single Phase Welders** Some arc welding transformers are designed for 415 volt ‘single phase’ operation. The primary of the transformer is connected to two phases – without a neutral, thus providing the required 415 volts. This type of supply is usually known as a ‘single phase 415 volt’ or a ‘two phase’ supply.

Interconnected Star and Delta Devices

52. Three phase transformers are often used to raise or lower the voltage in distribution systems, and to supply local devices at a.c. voltages other than the standard 240/415 volts.

53. Connecting three phase transformers in different configurations results in different output voltages as might be expected, but it can also result in different phase angles between primary and secondary voltages. In general, three phase transformer secondaries can only be connected in parallel if their voltages, phase sequence and phase angles (or phase shift) are the same. The phase relationships between the input and output of four of the main possible connections, is shown in Figure 18.

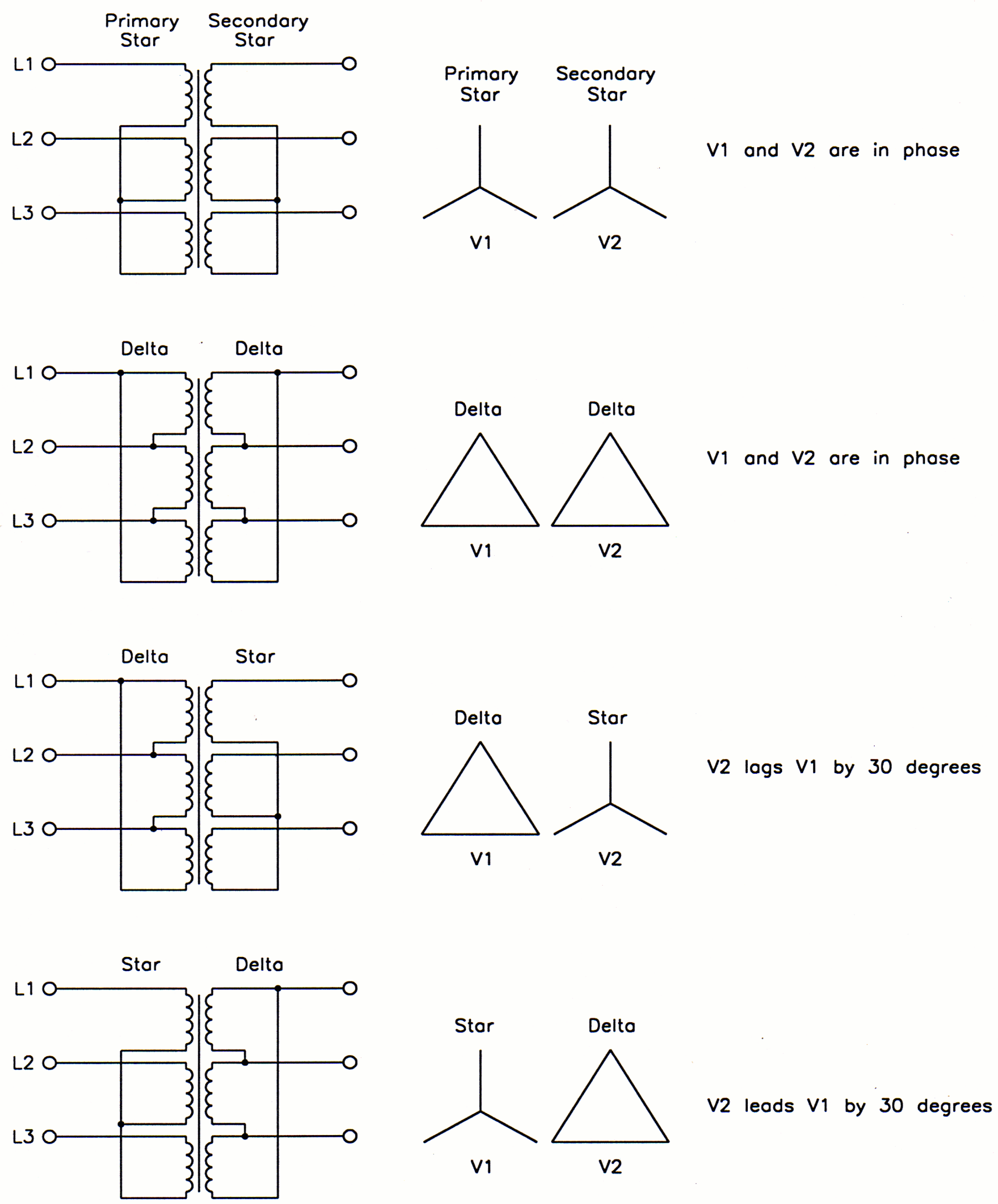


Figure 18 – Three phase transformer connections and phase angles

Harmonics

54. Harmonics are a series of subsidiary waveforms that accompany a primary, or fundamental, waveform. A sinusoidal waveform is made up of a large number of waveforms, each having a frequency which is an integer multiple of the fundamental frequency. A subsidiary waveform which has a frequency of, for example, three times the fundamental frequency is commonly known as a '3rd harmonic'.

55. Figure 19 shows a fundamental sinusoidal waveform, with the 3rd and 5th harmonic.

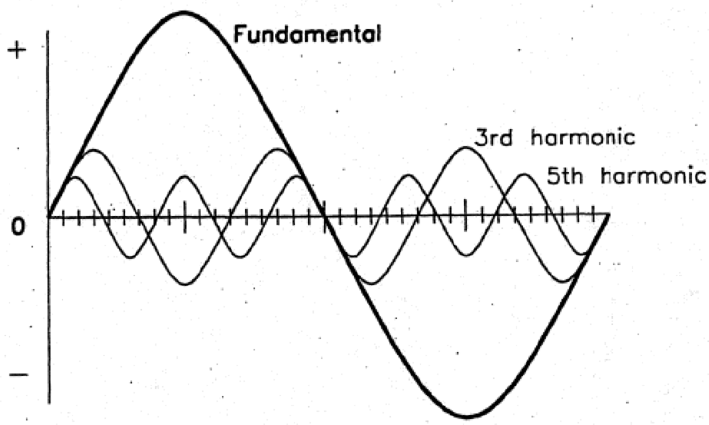


Figure 19 – A fundamental sinusoidal waveform with 3rd and 5th harmonic.

56. Harmonics are caused by any reactive or inductive load, or by any device that uses a rectifier to convert a.c. to d.c. Typical sources of harmonics are electronic lighting equipment, fluorescent ballasts, personal computers, uninterruptable power supply systems, some variable speed motor drives, welders and television sets. See AS/NZS3000:2018 Clause 3.5.2.(b) (i).

57. Harmonics cause problems such as:

a. Distortion of the electricity supply voltage
b. Failure or overheating of transformers and motors
c. Erratic operation of control and protection relays
d. interference in telecommunications systems and equipment
e. Destruction of reactive components in extreme cases
f. Difficulties in calculating power losses
g. Abnormal currents in neutral conductors
h. Nuisance operation of fuses
i High circulating currents associated with power factor correction capacitors

58. One method of reducing harmonic currents is to install specially designed harmonic 'filters' which consist of an appropriate combination of reactors (inductors and/or capacitors) selected to decrease the problems at harmonic frequencies.

59. Analysis and reduction of harmonic currents in single and three phase a.c. supplies and devices is an important but highly complex issue. The role of the electrical tradesperson is to be aware that harmonics exist, and if problems such as those listed above cannot be explained and corrected using his or her theoretical knowledge, refer the matter to a qualified electrical engineer.

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 8 Work Sheet	G102A JW/JD Dec 2013

Three phase Circuits

1. What is the nominal rms voltage between phases in the three phase four wire distribution system in W.A.?

2. What is the nominal rms voltage between each phase and neutral in the three phase four wire distribution system in W.A.?

3. What is the nominal voltage between each phase and earth in the three phase four wire distribution system in W.A.?

4. What is the nominal voltage between neutral and earth in the three phase four wire distribution system in W.A.?

5. What is the phase angle between phases in the three phase four wire distribution system in W.A.?

6. What is the sum of the instantaneous values of voltage or current in a balanced three phase circuit?

7. What are the two basic configurations in which a three phase device may be connected?

8. List two advantages of a three phase distribution system over a single phase distribution system.

9. What is an alternative name for a star connection?

10. What is an alternative name for a delta connection?

11. What is the name given to a three phase circuit in which the load on each of the three phases is identical?

12. What is the voltage between the star point and earth if three identical electrical devices are connected in star?

13. Three identical resistors or windings are connected in STAR. What is the name given to the values of voltage and current with respect to each of the three identical components?

14. Draw a neat circuit diagram showing three identical resistors connected in STAR. Show the three phase supply and include instruments to indicate one of each of the following values:

    Line E   Line I   Phase E   Phase I

15. Draw a neat circuit diagram showing three identical resistors connected in DELTA. Show the three phase supply and include instruments to indicate one of each of the following values:

    Line E   line I   Phase E   Phase I

16. Three identical resistors are connected in star to a 415 volt three phase supply. What is the PHASE voltage in the circuit?

17. If a balanced three phase delta connected circuit has a line current of 60 amps, what is the value of the phase current?

18. If a balanced star connected three phase circuit has a line current of 90 amps, what is the phase current?

19. If a balanced three phase delta connected circuit had a phase current of 70 amps, what is the value of LINE current?

20. If a three phase balanced star connected circuit had a phase current of 20 amps, what is the value of LINE CURRENT?

21. If a balanced star connected three phase circuit has a line voltage of 300 volts, what is the phase voltage?

22. If a balanced delta connected three phase circuit has a line voltage of 400 volts, what is the phase voltage?

23. What is the phase voltage across two resistors in a balanced 415 volt three phase star connected circuit if the supply to the third resistor is safely disconnected?

24. How much current would be flowing in the neutral conductor if the load on each of the three phases in a three phase distribution system was identical?

25. Draw a phasor diagram of the output voltage from a three phase alternator. Indicate the reference phasor and the direction of rotation.

26. Which common balanced three phase connection has the dissimilar ends of each coil winding connected together?

27. Which common balanced three phase connection has the similar ends of each coil winding connected together?

28. What is the relationship between line voltage and phase voltage in a balanced three phase star connected load?

29. Determine the out-of-balance current in the neutral for the following 415 volt 50Hz three phase circuit:

Red Phase:	40 amps at a power factor of 0.8 lagging
White Phase:	50 amps at a power factor of 0.8 lagging
Blue Phase:	60 amps at a power factor of 0.8 lagging

30. How can the out-of balance current in the neutral be reduced in a large industrial installation?

31. A three phase four wire industrial installation has active conductors which have a current carrying capacity of 150 amps. What is the minimum permissible current carrying capacity of the associated neutral conductor? State the Wiring Rules Clause number.

32. When determining the current carrying capacity of the neutral conductor in a three phase four wire installation, is it necessary to take abnormal circuit conditions (such a blown fuse in one phase) into account? State the Wiring Rules clause number.

33. Name two electrical devices which can be designed for operation form two phases of a three phase supply.

34. What effect would it have on the operation of an unbalanced three phase four wire MEN installation if the neutral is open circuited when the circuit is energised?

35. What is the phase relationship between the input voltage and the output voltage of a three phase transformer which is connected delta to star?

36. What is meant by the term ‘Harmonic’ when applied to sinusoidal electrical power systems?

37. Give two possible sources of undesirable harmonics in sinusoidal electrical power systems? How can the effects be overcome?

NOTES

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Three Phase Star and Delta Circuits

Objective

To verify the voltage and current ratios (relationships) in three phase balanced star and delta circuits.

Equipment

Three phase star/delta project board (resistive loads only)
Three phase supply
Tong tester
Multimeter

Circuit Diagrams

Star **Delta**

Procedure

DANGER TAG PROCEDURE REQUIRED

1. Draw a circuit diagram showing how the project board should be connected as a balanced three phase STAR connection. Show how suitable meters would have to be connected to measure line current, phase (or coil) current, line voltage and phase (or coil) voltage for one phase.

2. Connect the circuit according to your diagram. Position the instruments so that the ammeters are together and the voltmeters are together, Have your diagram and connections checked by your Lecturer.
3. Set the variable three phase supply (Variac) to approximately 200 volts.
4. Plug the circuit into a three phase outlet and record all instrument readings in the Results Table.
5. Switch the circuit off and remove the plug from the outlet. Attach your danger tag to the plug-top.
6. Check for zero volts, then repeat Steps 1-5 for a DELTA connection.
7. Have your results checked by your Lecturer
8. Disconnect your wiring and return all of the equipment to its proper place.

Results Table

	STAR	**DELTA**
Line E		
Phase E		
Line I		
Phase I		

Questions

1. Complete the equations to express the ratio between each of the following quantities in a balanced three phase circuit:

Star		**Delta**	
Line E =	____________________	Line E =	____________________
Phase E =	____________________	Phase E =	____________________
Line I =	____________________	Line I =	____________________
Phase I =	____________________	Phase I =	____________________

1 If the line current in a balanced three phase star connected circuit was 10 amps, what would the phase current be?

____

2 If the line current in a balanced three phase delta connected circuit was 10 amps, what would the phase current be?

____

3 If the line voltage in a balanced three phase star connected circuit was 300 volts, what would the phase voltage be?

____

4 If the line voltage in a balanced three phase delta connected circuit was 300 volts, what would the phase voltage be?

____

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 8 Project 2	G102A JW/JD Dec 2013

Out-of-balance Current in the Neutral

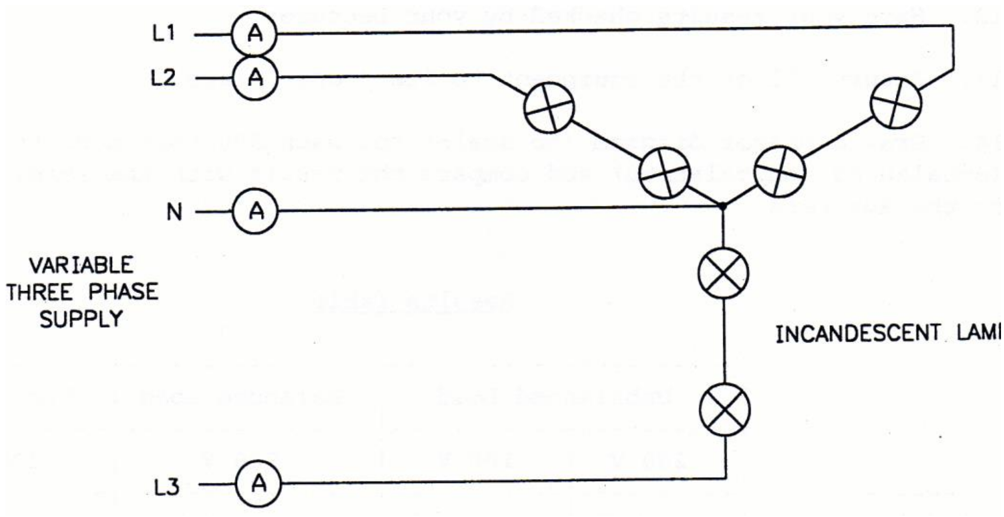
Objective

To measure the out-of balance current in the neutral of a three phase unbalanced and balanced star connected system and verify the results by graphical construction.

Equipment

Three phase star connected unbalanced load project board
Two 15 W 240 volt incandescent lamps
Two 40 W 240 volt incandescent lamps
Two 60 W 240 volt incandescent lamps
0-415 volt a.c. voltmeter
Four 0-1 amp volt a.c. ammeters
Calculator or mathematical tables

Circuit Diagram



Procedure

DANGER TAG PROCEDURE REQUIRED

1 Connect the lamps in STAR, and to a 0-415 volt variable three phase supply (Variac).Set the Variac to the zero volts position.

2 Insert 240 volt lamps in the circuit so that each phase has two IDENTICAL lamps in series, with different wattage lamps in each phase (an unbalanced load).

3 Check for short circuits with a multimeter set on the ohms times 1 range. Switch the multimeter off after the check.

4 Switch the circuit on and increase the setting on the Variac until the output line voltage is 200 volts. Measure the current in Line 1, Line 2, Line 3 and the neutral and record the results in the Results Table.

5 Reduce the setting on the Variac until the output line voltage is 100 volts. Measure the current in Line 1, Line 2 and Line 3 and the neutral and record the results in the Results Table.

6 Switch the circuit off, remove the plug from the outlet and attach your danger tag to the plug top.

7 Re-arrange the circuit so that all six lamps in the circuit are the same power rating (a balanced load)

8 Check for short circuits with a multimeter set on the ohms times 1 range. Switch the multimeter off after the check

9 Switch the circuit on and increase the setting on the Variac until the output line voltage is 200 volts. Measure the current in Line 1, Line 2, Line 3 and the neutral and record the results in the Results Table

10 Remove both lamps from one phase and record all ammeter readings in the Results Table

11 Switch the circuit off, remove the plug from the outlet and attach your danger tag to the plug top

12 Have your results checked by your lecturer

13 Return all of the equipment to its proper place

14 Draw a phasor diagram (to scale) for each 415 volt condition (unbalanced and balanced) and compare the result with the readings obtained on the ammeters

Results Table

	Unbalanced Load	**Balanced Load**	**Two Phases**
	415 V	**415 V**	**415 V**
Line 1	**A**	**A**	**A**
Line 2	**A**	**A**	**A**
Line 3	**A**	**A**	**A**
Neutral	**A**	**A**	**A**

Phasor Diagrams

Questions

1 Were the results obtained by graphical construction identical to those obtained by measurement? If not, how can you account for the difference(s)?

2 Why would it be dangerous to connect two different 240 volt incandescent lamps in series across 415 volt supply?

3 What is the minimum permissible current carrying capacity of the neutral conductor in a three phase supply in which the consumer's mains have a current rating of 100 amps. Give the AS/NZS 3000:2018 Wiring Rules Clause number.

4 A three phase load consisting mainly of individual consuming devices connected between active and neutral has a current of 50 amps in each phase. How much current would flow in the neutral if the circuit was operating normally? How much current would flow in the neutral if the fuse in one phase 'blew'?

5 What two conditions must be met for the current in the neutral of a three phase star connected supply to be zero?

6 Determine the out-of-balance current in the neutral of the following CBA three phase circuit by the Triangle method construction:

Red Phase:	80 amps	0.8 lagging
White Phase:	60 amps	0.8 lagging
Blue Phase:	35 amps	0.8 lagging

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Three Phase Power and Energy Measurement

1 The true power (watts) in a single phase a.c. circuit can be determined by calculation or measurement. The most common method of calculation is using the equation:

$$P = V \times I \times \cos\Theta$$

Where P = True Power
V = The line voltage
I = The line current
Cos Θ = The power factor (for a sinusoidal waveform)

2 If the true power in a single phase circuit is to be measured, a typical connection is as shown in Figure 1. It is essential to check both the voltage rating and the current rating on the wattmeter (individually) to ensure that the ratings are above the expected circuit values.

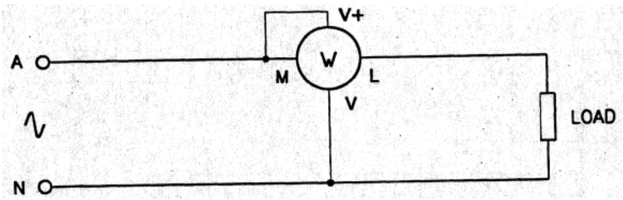


Figure 1. Typical single phase wattmeter connection

Three Phase Power

3 The true power in a three phase circuit can also be calculated or measured. The basic equation for calculating power in a three phase balanced circuit is:

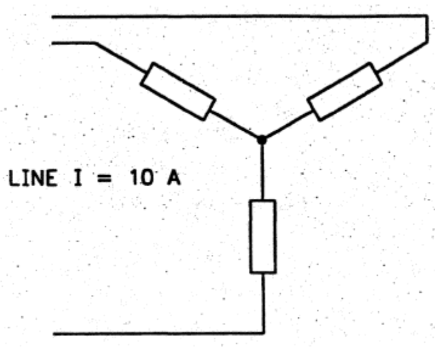
$$\text{Power} = \sqrt{3} \times V \times I \times \cos\Theta$$

Where $\sqrt{3}$ = 1.7321 (a constant)
V = Line voltage
I = Line current
Cos Θ = Power factor (for sinusoidal circuits)

4 **Example 1** Calculate the power consumed by a 415 volt star connected three phase resistive circuit in which the line current is 10 amps.

Solution:

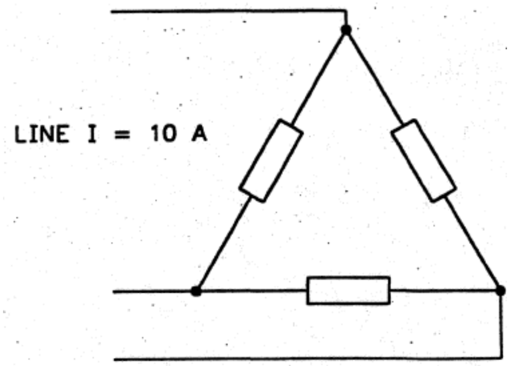
$$\text{Power} = \sqrt{3} \times V \times I \cos\Theta$$
$$= \sqrt{3} \times 415 \times 10 \times 1$$
$$= 7188 \text{ watts or } 7.188 \text{ kW}$$



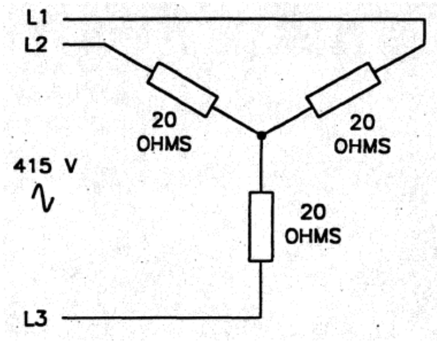
5 **Example 2** Calculate the power consumed by a 415 volt delta connected three phase resistive circuit in which the line current is 10 amps.

Solution

$$\text{Power} = \sqrt{3} \times V \times I \times \cos\Phi$$
$$= \sqrt{3} \times 415 \times 10 \times 1$$
$$= 7188 \text{ watts or } 7.188 \text{ kW}$$



6 **Example 3** Calculate the power consumed by a 415 volt star connected three phase resistive circuit in which the resistance of each of the three resistors is 20 ohms



Solution:

In a star connection Phase volts = Line volts / $\sqrt{3}$

Phase volts = Line volts / $\sqrt{3}$
= 415 / $\sqrt{3}$
= 239.6 volts

The current in each phase is V / R

Phase current = 239.6 / 20
= 11.98 amps

Line current = Phase current
= 11.98 amps

Power = $\sqrt{3}$ x V x I Cos Θ
= $\sqrt{3}$ x 415 x 11.98 x 1

= 8611 watts or 8.611 kW

7 **Example 4** Calculate the power consumed by a 415 volt delta connected three phase resistive circuit in which the resistance of each of the three resistors is 20 ohms.

Solution :

In a Delta connection Phase volts = Line volts

Phase volts = Line volts
= 415 volts

The current in each phase is V/R

Phase current = 415/20
= 20.75 amps

Line current = Phase current x $\sqrt{3}$
= 35.94 amps

Power = $\sqrt{3}$ x V x I x Cos Φ
= $\sqrt{3}$ x 415 x 35.94 x 1

= 25 834 watts or 25.834 kW

7 You may have noticed that the power consumed in the delta circuit is approximately three times the power consumed by the same resistors connected in star; If the calculations were done without rounding decimals the power in delta would be exactly three times the power in star.

Unbalanced Circuits

9 In a three phase unbalanced star connected circuit the total power is the sum of the individual power values in each phase.

10 **Example 1** Calculate the power consumed in a three phase 415 volt unbalanced star circuit (with a neutral) in which the current in the phases are:

A Phase: 10 amps at a power factor of 0.8 lagging
B Phase: 15 amps at unity power factor
C Phase: 20 amps at a power factor of 0.9 lagging

Solution:

A Phase: $P = V \times I \times \cos\theta$
$= 240 \times 10 \times 0.8$
$= 1920$ watts

B Phase: $P = V \times I \times \cos\theta$
$= 240 \times 15 \times 1$
$= 3600$ watts

C Phase: $P = V \times I \times \cos\theta$
$= 240 \times 20 \times 0.9$
$= 4320$ watts

Total Power $= P1 + P2 + P3$
$= 1920 + 3600 + 4320$
$= 9840$ Watts or 9.84 kW

Measuring Three Phase Power

11 There are several methods of measuring three phase power, depending on whether the circuit is three or four wire, or balanced or unbalanced. In the methods described below, one or more standard analogue or digital single phase wattmeters are used. In each case you need to make sure that the expected voltages and currents are within the ratings of the wattmeters you intend to use.

12 One Wattmeter Methods

a. **Three-Wire Circuit** One wattmeter is connected as shown in Figure 2. An artificial neutral is provided by using two impedances which are equal in impedance to the impedance of the voltage coil of the wattmeter. If the circuit is unbalanced, the wattmeter must be connected (or switched) into each phase in turn – the total power is then the sum of each of the three wattmeter readings.

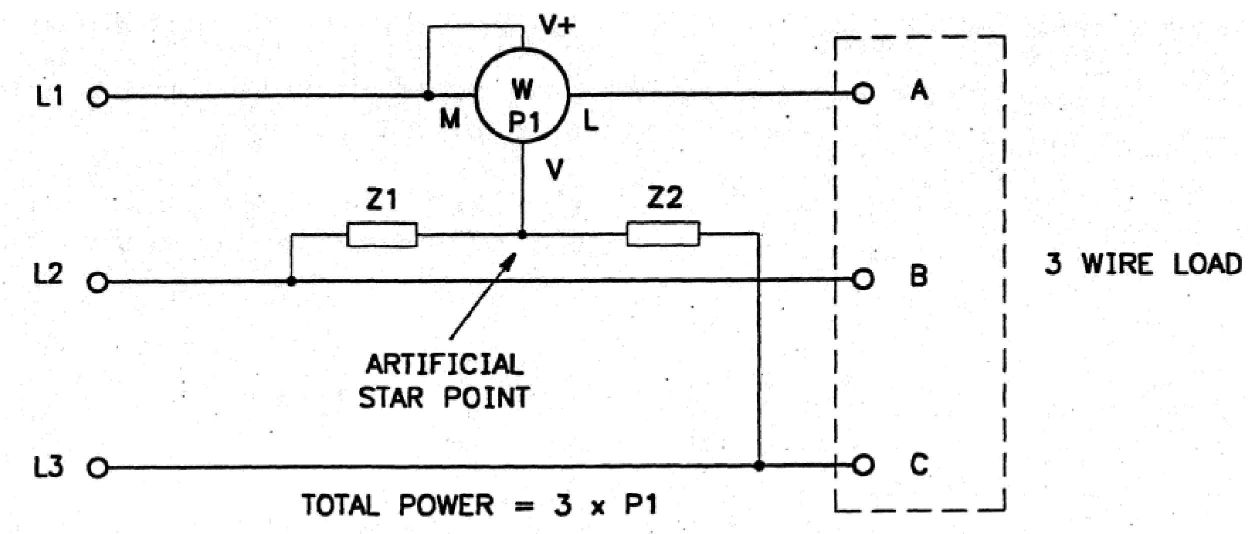
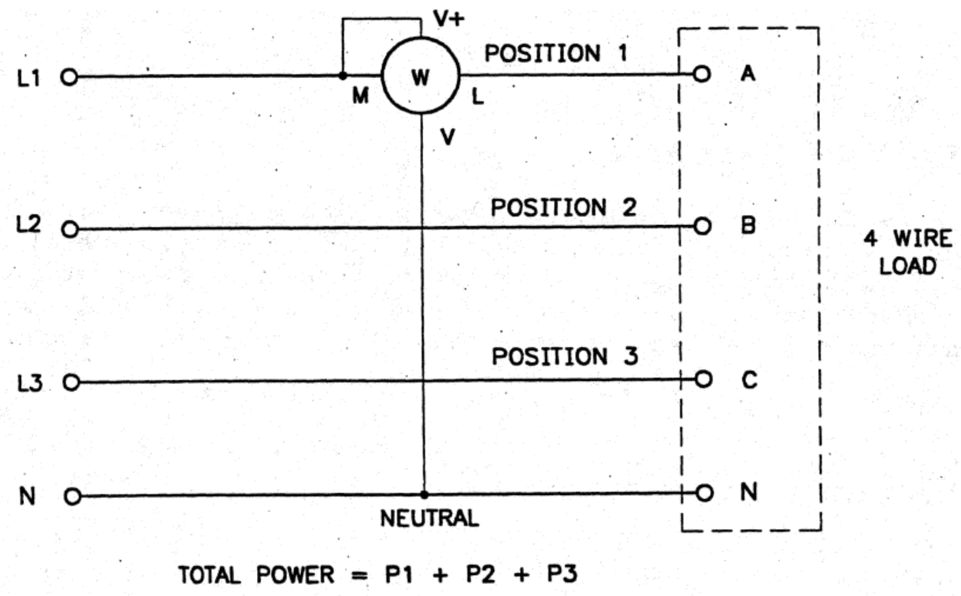


Figure 2 - One wattmeter method - three wire

Advantages	Disadvantages
Only one wattmeter is required Can be used for balanced or unbalanced loads. The wattmeter voltage rating need only be 240 volts.	Requires two special impedances to suit the wattmeter Not accurate if the power varies while while readings are being taken. Wattmeter connections may need to be changed.

b **Four-Wire Circuit** One wattmeter is connected as shown in Figure 3. If the circuit is balanced, the total power is the wattmeter times 3. If the circuit is unbalanced, the wattmeter must be connected (or switched) into each phase in turn – the total power is then the sum of each of the three wattmeter readings.

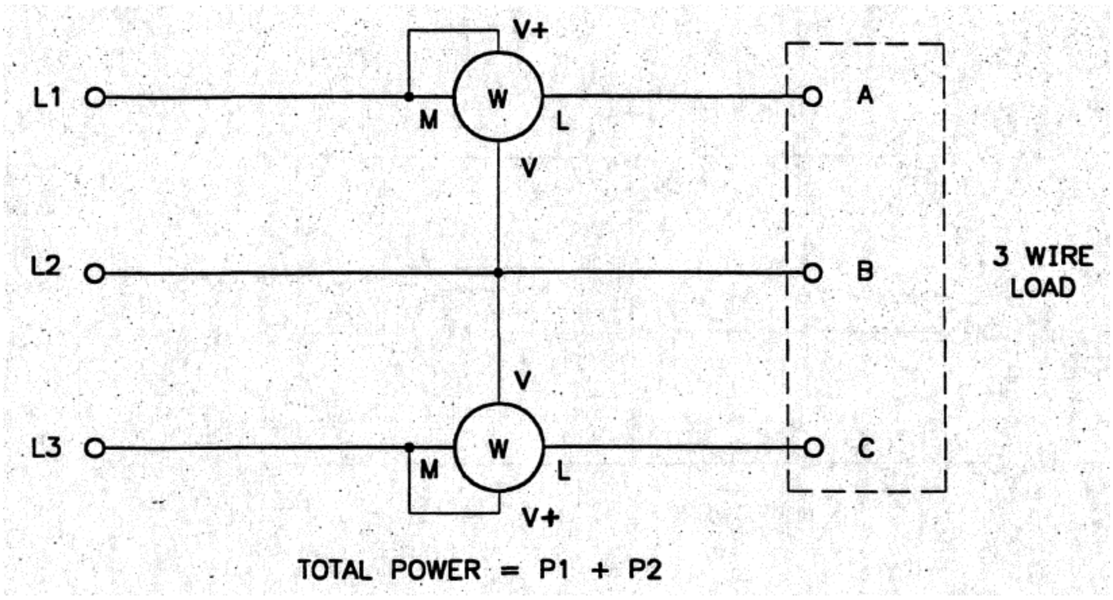


TOTAL POWER = P1 + P2 + P3

Figure 3 - One wattmeter method - four wire

Advantages	**Disadvantages**
Only one wattmeter is required Can be used for balanced or unbalanced loads. The wattmeter voltage rating need only be 240 volts.	Wattmeter connections may need to be changed Not accurate if the power varies while while readings are being taken. A neutral is required

13 **Two Wattmeter Method** This method can be used for THREE wire balanced or unbalanced loads. Two wattmeters are connected as shown in Figure 4. The total power in the circuit is the algebraic sum of the two wattmeter readings.



TOTAL POWER = P1 + P2

Figure 4 - Two wattmeter method – three wire

Advantages	**Disadvantages**
Only two wattmeters are required No neutral is required Suitable for balanced and unbalanced loads.	Not suitable for four-wire loads Care must be taken to ensure that both meters are correctly polarised initially.

14 When using the two wattmeter method the power factor of the circuit affects the direction of movement of the wattmeter pointer. If the power factor is exactly 0.5, one of the meters will read zero and the true power will be the reading on the other instrument. If the power factor is less than 0.5, one of the meters will try to read down-scale (backwards) and the true power will be the difference between the two readings. If the power factor of the circuit is above 0.5, both meters will indicate in the positive direction and the true power will be the sum of the instrument readings.

15 **Three Wattmeter Method** This method can be used for three and four wire balanced or unbalanced loads. Three wattmeters are connected as shown in Figure 5. The total power is the sum of the three wattmeter readings.

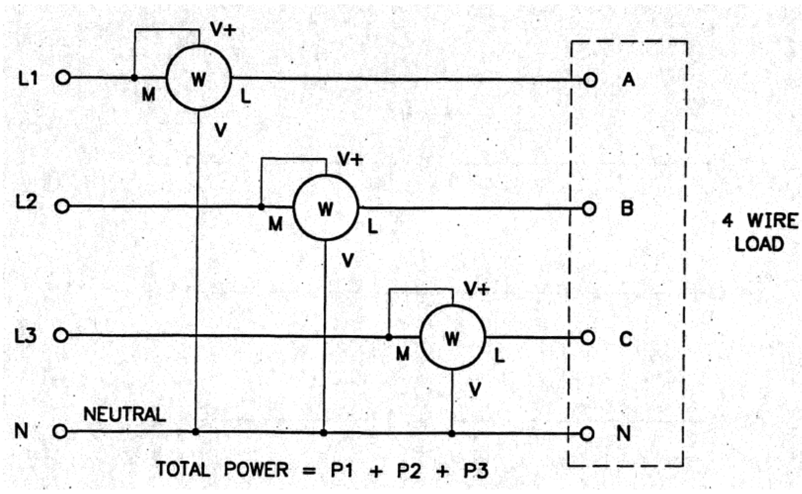


Figure 5 - Two wattmeter method – three wire

Advantages	**Disadvantages**
Suitable for balanced and Unbalanced loads Accurate with changing loads Less chance of errors when interpreting readings	Three wattmeters are required

16 If the circuit is only three wire and the wattmeters are identical, an artificial neutral can be created by joining the three voltmeter 'V' terminals together; the total power is the sum of the three wattmeter readings.

Apparent Power

17 The power indicated on a wattmeter is always true power or the INPUT power to a circuit. The true power cannot be obtained from the line voltage and line current unless the circuit is purely resistive. The power calculated from the line voltage and line current is the APPARENT power – as it is in a single phase a.c. circuit. The apparent power (S) in any balanced three phase circuit can be found from the equation $S = \sqrt{3} \times V \times I$ and the true power can be found by the equation $P = \sqrt{3} \times V \times I \times \cos \Theta$

Energy Measurement

18 Wattmeters measure true power – the rate at which electrical energy is being converted to another form of energy at a particular point in time. The reading on a wattmeter changes as the load changes, so a power measurement cannot be used directly to determine the total amount of electrical energy used over a given period of time.

19 Supply authorities use energy meters to determine the consumption of electricity for the purpose of charging the consumer. Different types of consumers are charged at different rates (known as tariffs). A typical tariff for domestic consumers is 23 cents per kilowatt hour. The general tariff structure used in WA is Section 15 of the WA Electrical Requirements.

20 Energy (E) is power times time (E = P x t). The basic unit of energy is the joule (J) which is 1 watt for 1 second. The joule is too small a unit to be convenient for specifying energy for supply authority purposes so they use a larger unit – the kilowatt-hour (kWh). 1 kilowatt-hour is the energy consumed by a 1 kW load over a period of 1 hour. One kilowatt-hour is also known as one 'Unit'.

21 Typical connections for supply authority kWh meters are shown in Figure 6

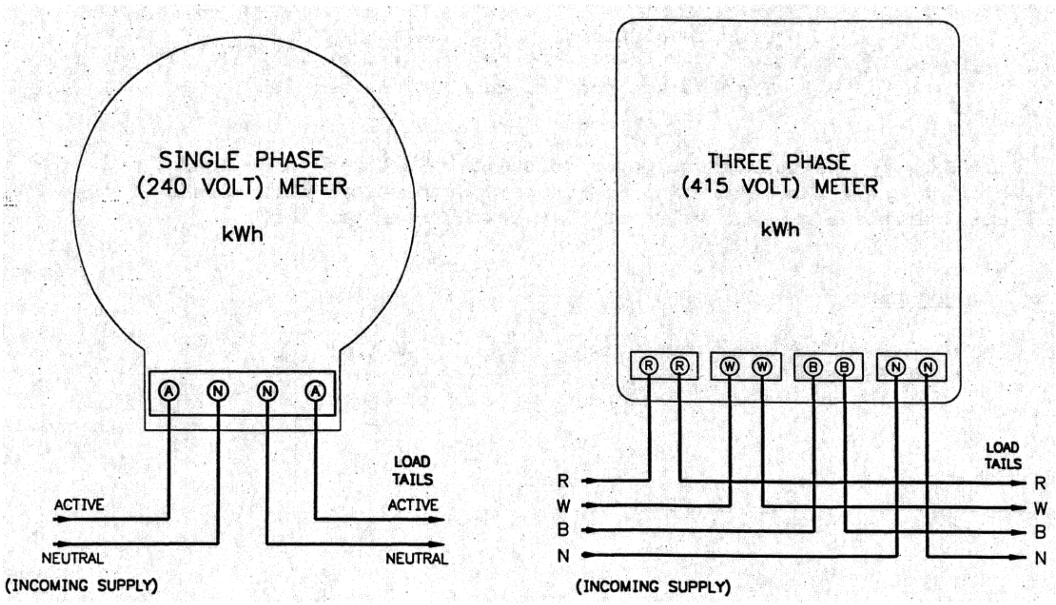


Figure 6 - Typical kWh meter connections

22 The cost of operating a single or three phase fixed load for a given time can be calculated using the following equation:

Total cost = Kilowatts x hours x Cost per kilowatt-hour

23 **Example** Calculate the costing of operating a three phase water reticulation motor for 2 hours if the motor power was 1.5 kW and the cost was 23 cents per unit.

Solution:

Total cost = Kilowatts x Hours x Cost per kilowatt-hour

= 1.5 x 2 x 23
= 23 cents

24 A typical supply authority kWh meter has an internal rotating disc mechanism which is used to measure the energy – the readout can be via a series of dials or in a digital format. If the number of disc revolutions per kWh is shown on the nameplate, the power consumed by a particular device can be calculated. One method is to count the number of seconds in some convenient time and apply the equation:

$$\text{Power in kW} = \frac{\text{Disc revolution}}{\text{Time in seconds}} \times \frac{3600}{\text{Revolutions per kWh}}$$

25 **Example** Calculate the power consumed by a three phase load which causes a kWh meter disc to rotate 2 revolutions in 1 minute if the meter nameplate gives a value of 66.6 revolutions per kWh.

Solution:

$$\text{Power in kW} = \frac{\text{Disc revolution}}{\text{Time in seconds}} \times \frac{3600}{\text{Revolutions per kWh}}$$

$$= \frac{2}{60} \times \frac{3600}{66.6}$$

$$= 1.8 \text{ kW}$$

Maximum Demand

26 Maximum demand is a term used in the AS/NZS 3000: 2018 Wiring Rules to refer to the **maximum current** expected in mains or final sub circuits for the purpose of determining the size of cables for that part of an installation under normal operating conditions. There are four methods of determining maximum demand, as specified in Clause 2.2.2.

27 The most common method of determining maximum demand in small installations is by calculation (covered in UEENEEG107A), but in larger installations it is possible to determine the maximum demand by measurement in consultation with the supply authority (see Clause 2.2.2 (c).

Notes

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Three Phase Power and Energy Measurement

1. What is the basic unit in which true power is expressed in any electrical circuit?

2 What is the QUANTITY symbol for true power?

3. What is the UNIT symbol for the basic unit of true power?

4. Name the measuring instrument which can be used to measure the true power in an AC circuit.

5. Name the electrical quantity which is calculated by multiplying line voltage by line current in a single phase AC circuit.

6. What is the QUANTITY symbol for apparent power?

7. What is the UNIT symbol for the basic unit of apparent power?

8. Calculate the total power dissipated in an unbalanced three phase circuit consisting of the following loads:

Red Phase	240 volts	15 amps	unity power factor
White Phase	240 volts	20 amps	0.8 lagging power factor
Blue Phase	240 volts	10 amps	0.5 lagging power factor

9 Calculate the true power being dissipated in the following balanced star connected three phase circuit:

Line E	415 volts
Line I	25 amps
Power factor	0.85 lagging

10 Calculate the true power being dissipated in the following balanced delta connected three phase circuit:

Line E	415 volts
Line I	25 amps
Power factor	0.85 lagging

11 Calculate the approximate full load LINE current drawn by a 415 volt 50 kW three phase SCI motor which is operating at a power factor of 0.8. Neglect motor efficiency.

12 A three phase 415 volt star connected instantaneous hot water system has a line current of 18 amps per phase when operating normally. Calculate the total POWER output if the unit was operated on two phases instead of three.

13 How many connecting terminals would there be on a typical single range 240 volt single phase wattmeter? How would the terminals be marked?

14 What corrective action can be taken if the pointer on a single phase analogue wattmeter indicates in reverse?

15 Why is it particularly important to check the maximum voltage and current ratings of the load against the maximum ratings of the wattmeter before connecting the instrument in a circuit?

16 If a ‘Press to Read’ button is to be connected to a single phase analogue wattmeter, to which part of the meter circuit should it be connected? How should it be connected?

17 The power in an unbalanced three phase circuit has been measured using the two wattmeter method. Both instruments indicate in the positive direction and readings are 1200 and 1000 watts. What is the total power in the circuit? What can be said about the power factor of the circuit?

18 The power in an unbalanced three phase circuit has been measured using the two wattmeter method. One of the instruments shows a reverse deflection although it is connected correctly. What does this condition indicate?

19 What type of measuring instrument is used to measure the electrical energy used over a given period of time?

20 Calculate the cost of operating a 415 volt three phase instantaneous hot water system heating element for half an hour if the line current is 18 amps and the cost of electrical energy is 23 cents per unit.

21 In what units is ‘maximum demand’ expressed to the Wiring Rules?

NOTES

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THREE PHASE POWER MEASUREMENT

Objective

To measure the total true power in a three phase balanced resistive load using the ‘two wattmeter’ method

Equipment

Three phase unbalanced load project board (resistive loads only)
Two wattmeters to suit the load
Three phase 415 volt power board

Circuit Diagram

Procedure

DANGER TAG PROCEDURE REQUIRED

1 Draw a circuit diagram showing how the true power can be measured in a three phase three wire unbalanced load using the two wattmeter method.

2 Connect the circuit according to your diagram. Have your diagram and connections checked by your Lecturer.

3 Switch the circuit on and record the wattmeter readings in the Results Table 1.

4 Switch the circuit off and remove the plug from the outlet. Attach the danger tag to the plug-top.

5 Have your results checked by your Lecturer

6 Disconnect your wiring and return all of the equipment to its proper place.

Table 1 (Two Wattmeter Method)

Wattmeter 1	
Wattmeter 2	
Total Power:	

Questions

1 What condition is indicated if the wattmeters are connected correctly, but one instrument tends to read down-scale instead of up-scale? What corrective action should you take to obtain a correct power reading?

2 What condition is indicated if the wattmeters are connected correctly, and one instrument indicates zero watts?

3 What condition is indicated if the wattmeters are connected correctly, and both instruments have exactly the same reading?

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Voltage Drop and Earth Fault-loop Impedance

Task:

To perform voltage drop and earth fault loop impedance calculations using AS/NZS 3008.1.1 Tables of Cable Reactance and AC Resistance.

Why:

The selection of cables for alternating current circuits requires a knowledge of the methods of calculating voltage drop and fault loop impedance.

To Pass:

4. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a written assessment.
5. You must satisfactorily complete the set laboratory tasks
6. You must achieve 100% in a final practical assessment.

Equipment:

Scientific Calculator

References:

- Electrical Wiring Practice (7th ed.). Pethebridge & Neeson
- AS/NZS 3000:2018 Standards Australia
- AS/NZS 3008.1.1:2017 Standards Australia

Government of Western Australia North Metropolitan TAFE	**Solve problems in low voltage a.c. circuits**	Section 10 Study Guide	G102A JW/JD July 2014

Voltage Drop and Earth Fault-loop Impedance

Suggested Self Study Guide

1. Study the following sections in the recommended references:

Electrical Wiring Practice (7th ed.) Vol. 2

Section 5.6 Selection of minimum cable size based on voltage drop and earth fault-loop impedance (EFLI) limitations. Page 143

Section 5.3 Factors affecting cable selection. Page 119

AS/NZS 3008.1.1:2017

Section 4.3 Determination of voltage drop from circuit impedance.

AS/NZS 3000:2018

B4.5 Calculation of earth fault-loop impedance.

2. Read the Summary and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.
3. Answer the questions given on the Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.
4. Complete the projects in this workbook.
5. Submit your answers to the Work Sheet to your Lecturer for discussion and assessment.

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Voltage Drop and Earth Fault-loop Impedance

Voltage Drop

1. Electrical supply authorities try to maintain the voltage at the consumer's terminals as near as possible to the specified voltage. However, some allowance must be made for the drop in electrical pressure between the start and finish of a cable run of wiring. This drop in electrical pressure is known as 'volt drop' or 'fall in voltage'.

2. In a domestic installation it is usually the electrical worker's responsibility to ensure that the voltage drop is within the limits imposed by the Wiring Rules.

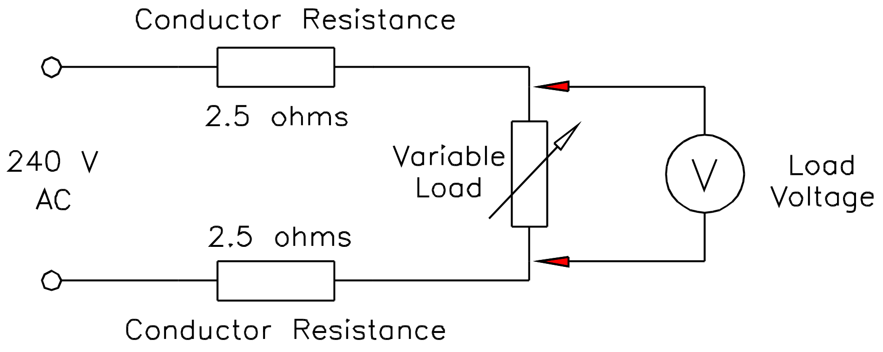
Principles

3. Voltage drop can only occur in a circuit when current is flowing. So, using Ohm's Law:

Volt Drop = Current in a circuit x Impedance of the circuit.

$V = I \times Z$

4. **Exercise** Calculate the volt drop in the circuit below if a constant voltage of 240 volts a.c. is applied and the load is varied to allow 1, 5,10 and 20 amps to flow respectively. Note that it is a series circuit, so the voltage across each component is directly proportional to the impedance of the component.



5. **Solution**

Load of 1 A:	Load of 10 A:
Vd = I.Z	Vd = I.Z
= 1 x 5	= 10 x 5
= 5 V	= 50 V
Voltage at the load = 240-5	Voltage at the load = 240-50
= 235 V	= 190 V
=======	=======
Load of 5 A:	Load of 20 A:
Vd = I.Z	Vd = I.Z
= 5 x 5	= 20 x 5
= 25 V	= 100 V
Voltage at the load = 240-25	Voltage at the load = 240-100
= 215 V	= 140 V
=======	=======

6. You can see from the example above that as the current in the circuit is increased, the voltage drop increases - i.e. the voltage at the load falls from 240 volts on no load to 140 volts on the full load of 20 amps.

7. The voltage drop in a circuit can be reduced by reducing the impedance of the circuit or the current flowing in it (V = I.Z).

Maximum Allowable Voltage Drop

8. Wiring Rules Clause 3.6.2 requires that the volt drop between the point of supply and any point of a 240 or 415 volt installation shall not exceed 5% of the nominal supply voltage. Since 5% of 240 is 12 volts, this means that the voltage measured at any point in the installation must never be less than 240-12 or 228 volts.

9. In a three phase circuit 5% of 415 V is 20.75 V, so the minimum permissible voltage at any point is 415-20.75 or 394.25 V.

10. Limiting the volt drop to 5% of the supply voltage ensures that:

a. There is sufficient voltage to provide satisfactory operation of any equipment being supplied.

b. Under short circuit conditions the cable impedances, including that part of the earthing conductor, are sufficiently low to operate the circuit protection device.

Reducing Voltage Drop

11. The voltage drop in a circuit can be reduced by reducing the resistance of the circuit or the current flowing in it. This can be done by:

a. Increasing the cable size or connecting additional cables in parallel. Note that the Wiring Rules places restrictions on connecting cables in parallel; mainly that cables must be 4 mm^2 or more and they must be made of the same material and same cross-sectional area - see AS/NZS 3000 Clause 3.4.3.

b. Reducing the current flowing in the circuit by reducing the load (not usually practical).

c. Reducing the length of the cable run (this is not usually practical).

Determination of Voltage Drop from Circuit Impedance

12. AS/NZS 3008.1.1 Section 4 provides information on how to determine the minimum permissible size of cable for a specific run without exceeding the maximum permissible voltage drop. AS/NZS 3008.1.1 provides a detailed treatment using several different methods. The circuit impedance method of determining voltage drop in AS/NZS 3008.1.1 works on conductor length rather than cable length. To account for this we can multiply Zc by 2.

The AS/NZS3008.1.1: 2017 provides information on calculating the voltage drop in a cable operating on an a.c. system using the formulas:

$$V_d = \frac{I \quad L \quad (2\,Z_c)}{1000}$$ AS/NZS3008.1.1: 2017 4.3.2

Where
v_d = voltage drop in cable, in volts
I = current flowing in cables, in amperes
Z_c = impedance of cables, in ohms

Zc $=\sqrt{(Rc^2 + Xc^2)}$

Where
R_c = cable resistance, in ohms (from tables 34 to 39)
X_c = cable reactance, in ohms (from tables 30 to 33)

Single phase circuits The impedance of the active and the neutral conductors is taken into account by doubling Zc

Exercise: Calculate the voltage drop using the impedance method for a single phase circuit supplying a 16 amp load, 25 metres from the switchboard using 2.5 mm^2 TPS cable. Assume allowable voltage drop of 3%. The mains Vd = 2%.

240 volts X 3% = 7.2V

Zc $=\sqrt{(Rc^2 + Xc^2)}$

Zc $=\sqrt{(9.01^2 + 0.102^2)}$ R_c from Table 35 Col. 4, X_c from Table 30 Col. 9.

Zc= 9.01Ω

$$V_d = \frac{I \quad L \quad (2\,Z_c)}{1000}$$

$$V_d = \frac{16 \quad 25 \quad 2 \quad 9.01}{1000}$$

$V_d = 7.2V$ The maximum route length of 2.5mm^2 cable supplying a 16amp load with an allowable voltage drop of 3% is 25 metres.

Compare this result with the more familiar milli-volts per ampere metre method of calculating voltage drop in cables using AS/NZS3008.1.1 Table 42.

$$V_d = \frac{L \quad I \quad V_c}{1000}$$

$$V_d = \frac{25 \quad 16 \quad 15.6 \quad 1.155}{1000}$$

$$V_d = 7.2V$$

Three phase circuits. In a balanced three phase circuit, no current is flowing in the neutral conductor and at any given instant the current in one active conductor will be balanced by the currents flowing in the two active conductors.

Exercise: Calculate the voltage drop using the impedance method for a three phase circuit supplying a motor drawing 18 amps. The motor is positioned 35 metres from the switchboard. The wiring system used is 4 mm^2 multi-core MIMS cable operating at a maximum temperature of 90°C. Assume allowable voltage drop of 2%.

415 X 2% = 8.3 V

Zc =$\sqrt{(Rc^2 + Xc^2)}$

Zc =$\sqrt{(5.53^2 + 0.0879^2)}$

R_c from Table 38 Col. 5, X_c from Table 32 Col. 3.

$$Z_c = 5.53\Omega$$

$$Vd = \frac{\mathrm{I\ L\ (\sqrt{3}\ Zc)}}{1000}$$ AS/NZS3008.1.1: 2017 4.3.3

$$V_d = \frac{18 \quad 35 \quad (\sqrt{3}\ \ 5.53)}{1000}$$

$$V_d = 6.03V$$

Using 4mm^2 multi-core MIMS cable to supply this motor is acceptable as the calculated voltage drop does not exceed the allowable 2% of the supply voltage.

Compare this result with the more familiar milli-volts per ampere metre method of calculating voltage drop in cables using AS/NZS3008.1.1 Table 49. Col 8

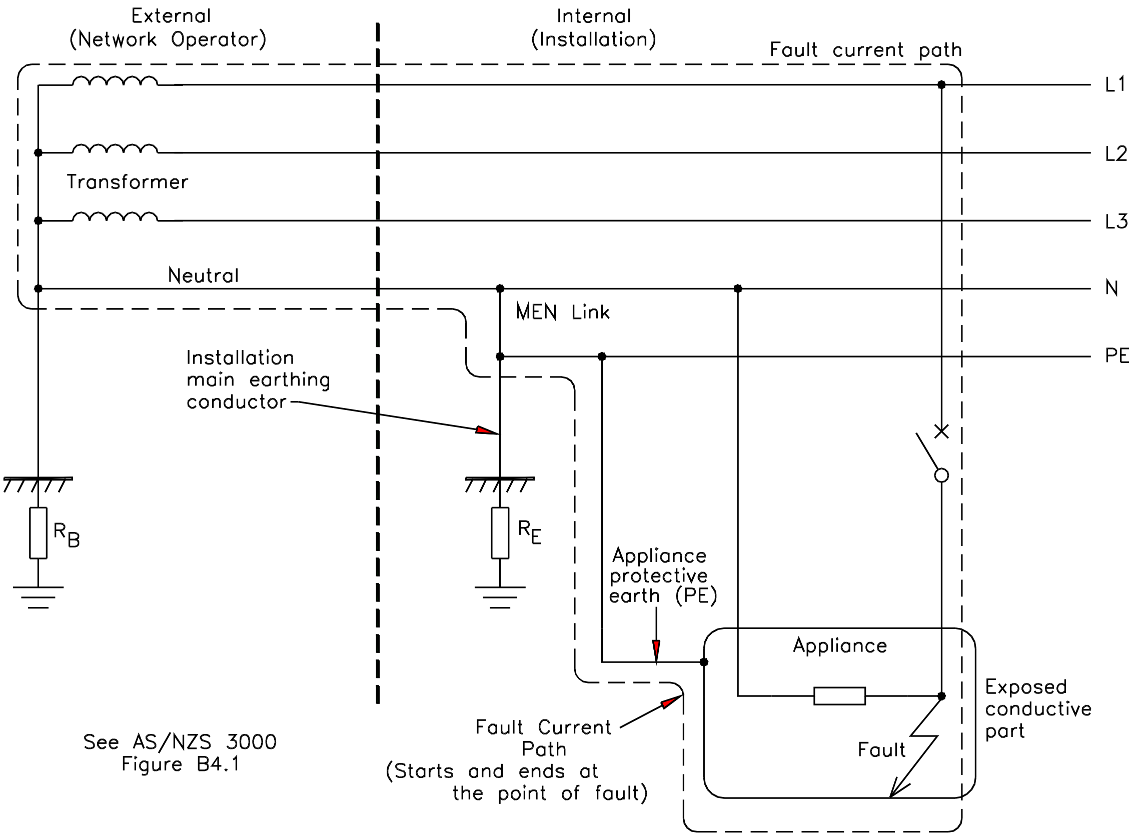
$$V_d \quad = \quad \frac{L \quad I \quad V_c}{1000}$$

$$V_d \quad = \quad \frac{35x \quad 18x \quad 2\,x\,9.52}{1000}$$

$$V_d \quad = \quad 5.99V$$

Earth Fault Loop Impedance

13. Earth Fault-loop impedance is the impedance of the conductors in the series path taken by the current in the event of a fault between an active conductor and an earth fault, starting and ending at the point of the earth fault.



Under an earth fault condition, the impedances of the supply transformer windings, the supply authority’s cables, the supply mains, switchboard wiring, final sub-circuit active, protective earth(PE) and the MEN link, are all part of the fault current loop. The total impedance of this earth fault loop must not restrict the amount of current that is needed to trip the circuit protection device eg a circuit breaker.

14. The maximum value of fault loop impedance (Z_S) can be calculated for circuits protected by circuit breaker using manufacturers' information relating to the approximate mean tripping current for the circuit breaker. The mean tripping current for typical circuit breakers can be taken as:

Type B = 4 times rated current

Type C = 7.5 times rated current (e.g. general purpose loads)

Type D = 12.5 times rated current (e.g. high inductive loads)

See AS/NZS 3000 Clause B4.5 and Table 8.1 – note the 230 V.

Earth fault-loop impedance calculation

15. The earth fault loop impedance (Z_S) for a circuit breaker can be determined using AS/NZS 3000 Clause B4.5 and Table 8.1:

$$Z_S = \frac{U_O}{I_a}$$

Where

Z_S = Earth fault loop impedance

U_O = Nominal phase voltage- 240 V in WA

I_a = The mean tripping current of the circuit breaker

Exercise Calculate the maximum earth fault loop impedance that will cause the automatic operation of a 20 amp Type 'C' circuit breaker. The supply voltage is 240 volts.

$$Z_S = \frac{U_O}{I_a}$$

$$Z_S = \frac{240}{20\ X\ 7.5}$$

$$Z_S = 1.6\Omega$$

Earth fault-loop impedance Measurement

16. The AS/NZS 3000 Clause 8.3.9.2 describes two methods of measuring earth fault-loop impedance.

Where the power supply is not connected, the resistance of each individual circuit may be measured using an ohmmeter. Using this method the results need to be compared with Table 8.2 –Maximum values of resistance.

Where the supply is available, the required impedance should be measured using a test instrument that has the facility for measuring Earth fault-loop impedance. Using this method the results need to be compared with Table 8.1 – Maximum values of earth fault-loop impedance.

Note – Both of these Tables are based on a nominal supply voltage of 230 volts.

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Voltage Drop and Earth Fault-loop Impedance

1. Using the impedance method, calculate the voltage drop in one 240 volt single phase mains 16 mm^2 twin TPS copper cable installed in an underground enclosure. The route length is 25 metres and the maximum demand is 63 amps. Show all working.

2. Using the impedance method, calculate the voltage drop in a three phase 415 volt copper insulated single-core 50 mm^2 aerial wiring system. The maximum demand is 125 amps per phase and route length is 100 metres. Show all working.

3. Calculate the maximum length of a single phase circuit supplying a load of 15 amps using TPS copper cable that has an impedance of 16.5Ω. The allowable voltage drop for this circuit is 7.2 volts. Remember the formula is based on conductor length not length of circuit! Show all working.

4. Calculate the maximum impedance of earth fault-loop that will cause the automatic operation of a 32 amp, Type’C’ single phase circuit breaker. The supply voltage is 240volts.

5. Calculate the maximum earth fault loop impedance that will cause the automatic operation of a 25 amp, Type ‘D’ three phase circuit breaker. The supply voltage is 415 volts.

6. Compare your results from questions 4 and 5 with AS/NZS 3000 Table 8.1

Why are your results different to the values in Table 8.1?

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Earth Fault-loop Impedance Measurement

Objective

To measure the fault loop impedance using fault-loop impedance test instrument.

Equipment

A fault loop impedance test instrument

A dedicated testing circuit for the purpose of testing fault loop impedance

NOTES

References

- Electrical Principals for Electrical Trades – Volumes 1 (6th ed.) Jenneson & Harper
- Electrical Wiring Practice – Volumes 1 & 2 (7th ed.) Pethebridge & Neeson
- AS/NZS 3000 (current edition)
- AS/NZS 3008.1.1 (current edition)
- Code of Practice – Safe electrical work on low voltage electrical installations
- WA Electrical Requirements
- *National Curriculum* - EE-Oz Training Standards Australia