Government of Western Australia
North Metropolitan TAFE

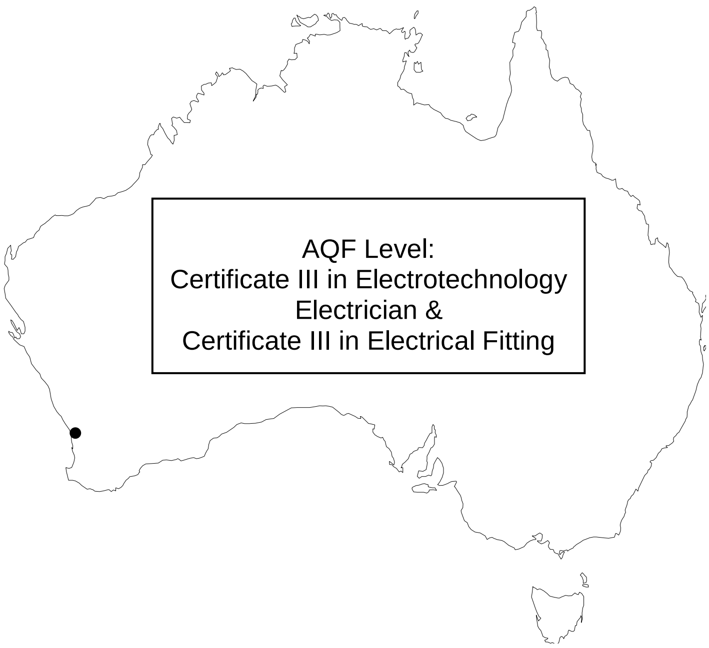
UEE 11 Training Package Support Material
(Non-Endorsed Component)

Based on:
National Electrotechnology Industry Standards

Resource Book

UEENEEG006A

Solve problems in single and three phase low voltage machines.



AQF Level:
Certificate III in Electrotechnology Electrician &
Certificate III in Electrical Fitting

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

It is intended for NMTAFE students only.

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UEENEEG006A – Solve problems in single and three phase low voltage machines.

C O N T E N T S

Competency Standard Unit Elements and Performance Criteria UEENEEG006A

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	
Single and three phase transformers KS01 – EG006A				
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Section 1 Activity Sheet 2	Connections Transformer Secondaries Series Aiding/Opposing			
Section 1 Activity Sheet 3	Connecting Single Phase Transformers in Parallel			
Section 2 Work Sheet	Specialised Transformers			
Section 2 Activity Sheet	Current Transformer Connections			
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Alternating current rotating machines KS02 – EG006A				
Section 6 Work Sheet 1	Three Phase Motor Construction and Connections			
Section 6 Activity Sheet 1	Three Phase Motor Construction			
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Section 7 Activity Sheet 2	Capacitor Start Motor – Component Identification			
Section 7 Activity Sheet 3	Split Phase Motor Connections			
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Section 7 Activity Sheet 7	Series Universal Motor Construction			
Section 7 Activity Sheet 8	Series Universal Motor Connections			
Section 8 Work Sheet	Motor Protection			
Section 9 Work Sheet	Alternators – Synchronous Motors			

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)
- Code of Practice – Safe electrical work on low voltage electrical installations
- WA Electrical Requirements

Competency Standard Units

UEENEEG006A – Solve problems in single and three phase low voltage 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.

UEENEEE102A – Fabricate, assemble, dismantle utilities industry components.

UEENEEE104A – Solve problems in D.C. circuits.

UEENEEE105A – Fix and secure electrotechnology equipment.

UEENEEE107A – Use drawings, diagrams, schedules, standards, codes and specifications.

UEENEEG101A – Solve problems in electromagnetic devices and related circuits.

UEENEEG102A – Solve problems in low voltage A.C. circuits.

UEENEEG106A – Terminate cables, cords and accessories for low voltage circuits.

Elements and Performance Criteria

ELEMENT		PERFORMANCE CRITERIA	
1	Prepare to solve single and three phase low voltage machines 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 machine(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 single and three phase low voltage machines 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 machine problems from measured and calculated values as they apply to single and three-phase low voltage machines.
		2.5	Establish methods for dealing with unexpected situations are discussed with appropriate person or persons and documented.
		2.6	Unexpected situations are dealt with safely and with the approval of an authorised person.
		2.7	Problems are solved without damage to machines, 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 machine 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-EG006A Single and three-phase transformers

Evidence shall show an understanding of single and three phase transformers to an extent indicated by the following aspects:

T1 Transformer construction encompassing:

- types of lamination style and core construction used in single-phase, three phase, double wound, auto transformers and instrument transformers.
- identification of different winding styles/types used in transformers.
- methods used to insulate low and high voltage transformers.
- construction of transformer tanks for distribution transformers.
- transformer auxiliary equipment. (Bushings, surge-diverters, tap-changers, hot oil & winding indicators, breather, Buchholz relay and conservator).
- function of transformer auxiliary equipment.
- types of information stated on transformer nameplates.
- application of transformers.
- performing basic insulation resistance, continuity and winding identification tests.

T2 Transformer operation encompassing:

- principles of mutual induction of a transformer.
- factors that determine the induced voltage in a transformer winding.
- determining the value of a transformers secondary voltage and current given one winding's electrical details and turns ratio.
- identification of voltage and current components of a phasor diagram for a transformer on no-load.
- principles of power transferred from the primary to secondary when a load is connected using a phasor diagram neglecting impedance drops.
- selecting transformers for specific application/s.
- safety features specified in AS/NZS3000 with respect to transformers and isolating transformers.

T3 Transformer losses, efficiency and cooling encompassing:

- power losses which occur in a transformer.
- tests which allow the power losses of a transformer to be determine.
- determination of transformer losses and efficiency using test results.
- relationship between transformer cooling and rating.
- methods used for natural and forced cooling of transformers.
- properties of transformer oil.
- tests conducted on transformer oil.

T4 Transformer voltage regulation and percent impedance encompassing:

- voltage regulation as applicable to a transformer.
- reasons for voltage variation in the output of a transformer.
- determine the voltage regulation of a transformer from voltage and percentage impedance values.
- percentage impedance as applied to transformers.
- determine the percent impedance by using test results.
- determine percent impedance of a transformer by calculation.

T5 Parallel operation of transformers and transformer auxiliary equipment encompassing:

- determine polarity markings for an unidentified single phase double wound transformer.
- need for parallel operation of transformers.
- conditions/restrictions required before two transformers can be connected in parallel.
- connecting transformers in parallel to supply a single load (loading on transformers operating in parallel).
- the consequences/effect of an incorrect connection.

T6 Auto-transformers and instrument transformers encompassing:

- identification of auto-transformers, voltage transformers and current transformers from their winding diagrams.
- determining voltage and current in the windings of an auto-transformer by calculation.
- advantages and disadvantages of an auto-transformer.
- AS/NZS3000 requirements with respect to transformers.
- construction of voltage transformers.
- ratings of voltage transformers.
- construction of current transformers.
- ratings of current transformers.
- precautionary measures taken to connect and disconnect instrument transformers.
- connection diagrams for instrument transformers.
- applications for auto-transformers and instrument transformers.

KS02-EG006A Alternating current rotating machines

Evidence shall show an understanding of alternating current rotating machines to an extent indicated by the following aspects:

T1 Operating Principles of three phase induction motors encompassing:

- determining circuit operating characteristics by using the right hand (grip) rule for conductors and solenoids and Fleming's left and right hand rules.
- characteristics of the magnetic field produced by a single, two and three-phase windings.
- speed of rotation of a rotating magnetic field.
- relationship between the rotor speed, slip and rotor frequency.
- basic principle of operation of an induction motor.
- reversing the direction of rotation of a three phase induction motor

T2 Three phase induction motor construction encompassing:

- basic component parts of a three-phase induction motor.
- types of rotors used in three-phase induction motors.
- connecting three-phase induction motor in both star and delta.
- dismantling three-phase induction motors.
- testing insulation resistance of a three-phase induction motor prior to connection to the supply.
- testing winding resistance (ohmic value and continuity) of a three-phase induction motor prior to connection to the supply

T3 Three phase induction motor characteristics encompassing:

- relationship between torque, speed, and power and interpretation of speed/torque curves of induction motors.
- squirrel cage motors operating characteristics conditions necessary for an induction motor to produce maximum torque.
- operating characteristics of an induction motor from name plate information and by measurement.
- induction motors efficiency and minimum energy performance standards (MEPS).
- full load efficiency and power factor of induction motors.

T4 Single phase motors – split phase encompassing:

- common types of single phase motor.
- principles of operation of a split phase induction motor.
- construction and basic characteristics of a split phase induction motor.
- applications of split phase induction motors.
- connecting, running and reversing a split phase induction motor.

T5 Single phase motors – capacitor and shaded pole types encompassing:

- identification of single phase induction motors including capacitor start, capacitor start/capacitor run, permanent split capacitor (PSC) and shaded pole
- principles of operation of each motor type listed above.
- operating characteristics and typical applications of each motor type listed above.
- connection and running each type of motor listed.
- reversing the direction of rotation of each of the capacitor type motors.

T6 Single phase motors – universal encompassing:

- principles of operation of a series universal motor.
- identification and functions of each of the basic parts of a series universal motor.
- operating characteristics and typical uses for a series universal motor.
- connecting, running and reversing a series universal motor.

T7 Motor protection encompassing:

- reasons why motor protection is required.
- requirements of the AS/NZS3000 Wiring rules with regards to motor protection.
- types of motor overload protection.
- operating principles of microtherm devices, thermal and magnetic motor protection devices.
- electrical features of motor protection HRC fuses.
- effects of under voltage and over voltage on motors and motor circuits.
- effects of repetitive starting and/or reversing on motors.
- special requirements for motor protection, in high humidity or moist environments, high temperature areas and corrosive atmospheres.
- operating principles of phase failure protection.
- selecting suitable protective devices for a given motor and starter combination.

T8 Three phase synchronous machines- operation principles and construction encompassing:

- power transfer diagram of an a.c. synchronous machine.
- need for the generation of a sinusoidal waveform.
- principles of operation of a synchronous alternator.
- principles of operation of a synchronous motor.
- principles of operation of an asynchronous generator (induction generator).

- identification of main parts of a synchronous alternator/motor.
- methods used to provide the excitation of a synchronous alternator/motor.
- block diagram of an alternator voltage regulator.
- advantages gained by the parallel operation of alternators.
- starting methods of synchronous motors.

T9 Alternators and generators encompassing:

- effects on the generated voltage of variations in excitation.
- effects on generated voltage of variations in load.
- identification of characteristic curves of an alternator.
- types of prime movers used with single and three phase portable/standby alternators.
- manual operation of single and three phase portable/standby alternators.
- ratings of single and three phase portable/standby alternators.
- applications of single and three phase portable/standby alternators.
- construction details of single and three phase portable/standby alternators.
- common faults found in portable/standby alternators.

G006A Work Performance Tasks – (Q Tracker tasks):

100 hours of on-the-job training

UEENEEG006A – Solve problems in single and three phase machines

1. Performance requirements:

1a. Related to the following elements:

1. Prepare to solve single and three phase low voltage machine problems.
2. Solve single and three phase low voltage machine 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:

Group No	**The minimum number of items on which skill is to be demonstrated**	**Item List**
A.	At least four of the following:	**Problems in single and three phase low voltage machine and circuits**. • Determining the operating parameters of existing machines • Altering an existing machine circuit to comply with specified operating parameters. • Developing machine circuits to comply with a specified function and operating parameters. • Determine the cause of low efficiency in an existing machine. • Determining the problems in existing machines to malfunction (electrical and mechanical problems) • Determine conditions causing an existing machine/circuit to be unsafe.

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.

UEENEEG006A – Solve problems in single and three phase machines.

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 UEENEEG006A Recognition of Prior Learning of CSU	Resource Book
2	7 hours	Section 1 – Single Phase Transformers	Resource Book
3	4 hours	Section 2 – Specialised Transformers	Resource Book
4	4 hours	Section 3 – Single Phase Transformer Testing	Resource Book
5	12 hours	Section 4 – Three Phase Transformer Principles	Resource Book
6	4 hours	Section 5 – Transformer Characteristics	Resource Book
7	4 hours	**PART A Written Assessment and Observed Practical Assessment**	**KS01-EG006A Single and three-phase transformers**
8	12 hours	Section 6 - Three Phase Induction Motors	Resource Book
9	16 hours	Section 7 – Single Phase Motors	Resource Book
10	2 hours	Section 8 – Motor Protection	Resource Book
11	2 hours	Section 9 – Synchronous Machines	Resource Book
12	4 hours	**PART B Written Assessment and Observed Practical Assessment**	**KS02-EG006A Alternating current rotating machines**
	Total 72 hours		

I acknowledge that I have received and read this Learning and Assessment Plan Student Name:______________________ Signature: ___________________ Date: __________		
Lecturer Name	Lecturer Signature	Date

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 UEENEEG006A. 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.

Danger Tag Procedure

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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.

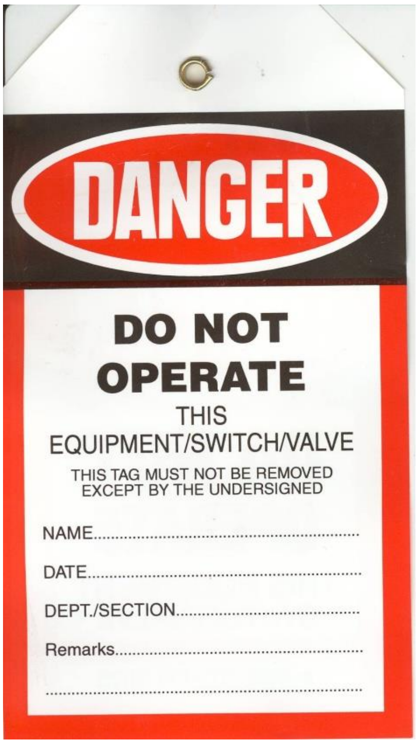


Photo © NMTAFE

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 – UEENEEG006A

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 storeperson.
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 single phase and three phase low voltage machines**	Section 1 Introduction	G006A SGB 02/2010

Single Phase Transformers

Task:

To describe the characteristics and principles of operation of basic single phase double wound transformers.

Why:

Transformers are one of the most common a.c. electrical devices. You need a good understanding of single phase double wound transformers in order to be able to understand the principle of operation of other common electrical devices such as a.c. induction motors.

To Pass:

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

Equipment:

Sample single phase double wound transformers
Sample single phase double wound transformer cores
A.C. ammeters
A.C. voltmeters
Multimeters

References:

* Electrical Principles for the Electrical Trades (6th ed.),Jenneson, J.R, Harper, B & Moore, B.

Safety:

You must demonstrate safe working practices at all times.

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 1 Study Guide	G006A SGB 02/2010

Transformers

Suggested Self-Study Guide

1. Study the following section in the recommended references: Electrical Principles for the Electrical Trades 6th Edition Volume 2 Chapter 2 Transformers

2. Read the Summary and practice 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 the Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

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

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 1 Summary	G006A SGB 02/2010

Single Phase Transformers

1. A transformer is a stationary device used to increase or decrease the voltage of an a.c. supply with very low losses.

2. A transformer has at least two windings wound on a magnetic core. The winding connected to the input is called the PRIMARY and the winding connected to the output is called the SECONDARY. Many variations of the coil arrangement are possible.

3. The core is usually made from a high quality laminated stalloy or ferrite, to reduce iron losses such as eddy currents and hysteresis. Many small to medium sized transformers use grain oriented 'C Cores' instead of laminations.

4. The two main core shapes are 'core type' and 'shell type'.

Typical core shapes and winding styles are shown in Figures 1 and 2.

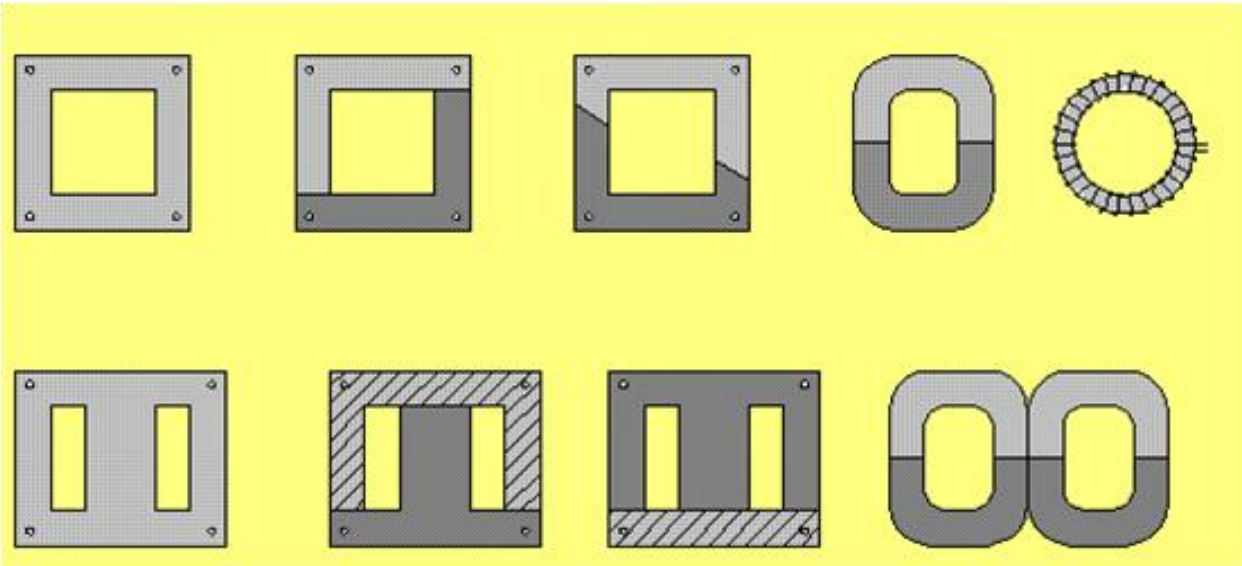


Figure 1 - Typical single phase core shapes

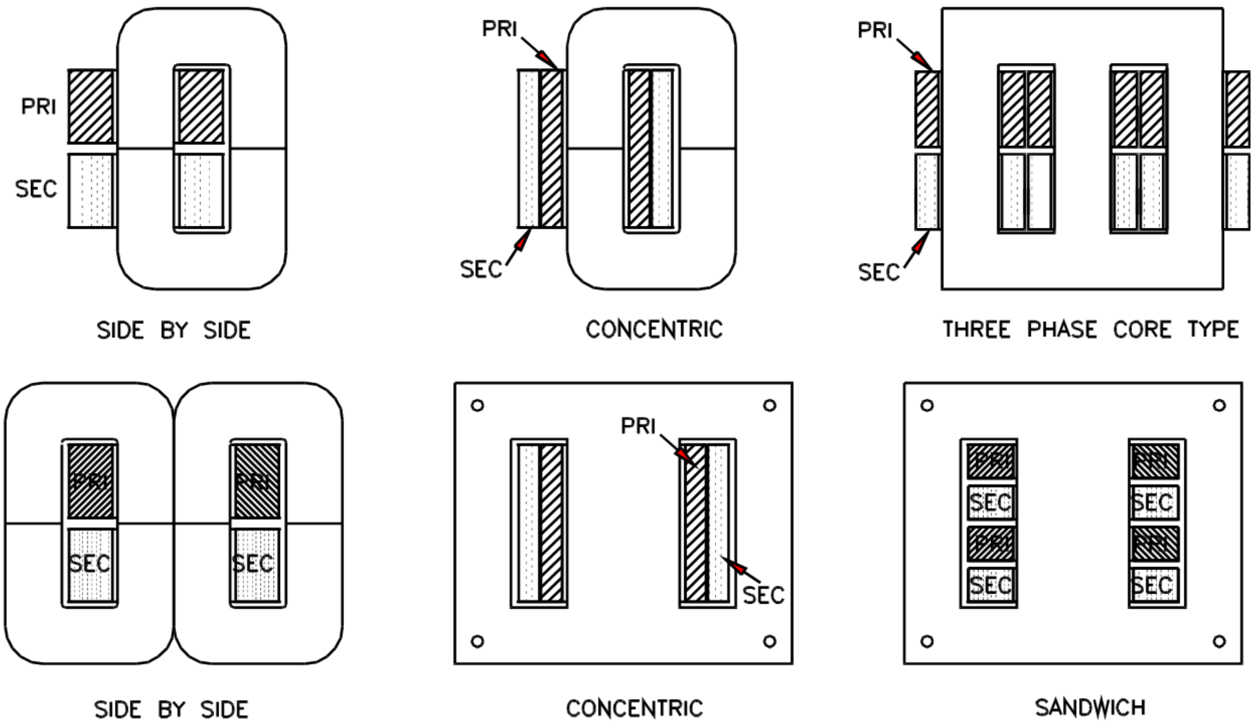


Figure 2 - Typical winding styles – The top 3 diagrams are examples of Core type construction and the bottom 3 diagrams are examples of shell type construction.

5. Electrical insulation in the form of an oxide, a powder, or a thin mylar film is provided between laminations. This insulation should not be damaged. Ferrite is a very good magnetic conductor but it is a very poor electrical conductor.

Double Wound Transformer

6. In this type, the primary and secondary windings are insulated electrically, but they are connected magnetically (by mutual induction). The symbol for a double wound transformer is shown in Figure 3:

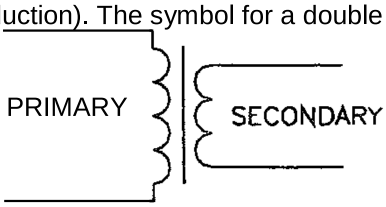


Figure 3 - Single phase transformer symbol.

If the output voltage is higher than the input, it is a STEP UP transformer. If the output voltage is lower than the input, it is known as a STEP DOWN transformer.

In a step DOWN transformer the resistance of the primary winding is usually higher than the resistance of the secondary winding and visa versa because the winding with the lowest voltage is usually wound with a heavier gauge wire. Some transformers have 'tapped' primary or secondary windings to allow for more than one primary or secondary voltage.

Double Wound Transformer Construction

8. Figure 4 shows a typical layout and construction for a double wound single phase shell type transformer which has one primary winding and one secondary.

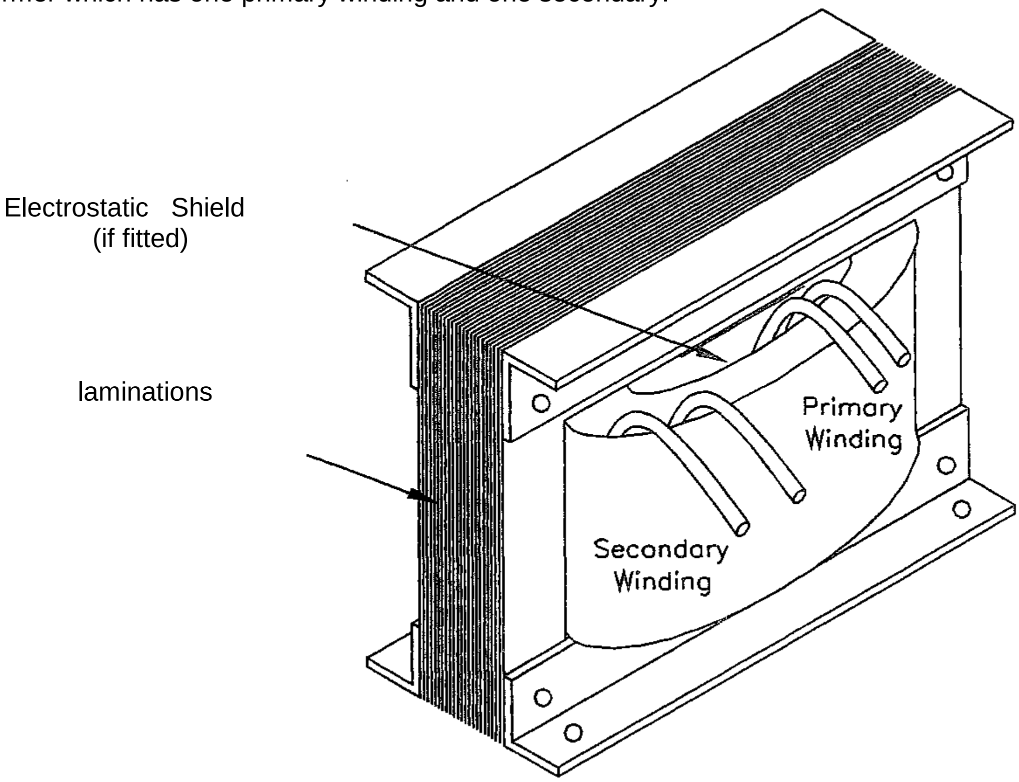


Figure 4 - Shell type transformer

Transformer Operation

9. No Load Condition. When a supply voltage Vl is applied to the primary winding a self-induced voltage V1' is produced (Lenz's Law) in the primary winding and opposes the applied voltage Vl.

10. On no-load, voltage Vl practically equals voltage Vl' and the no-load current or excitation current is usually about 1% to 3% of the rated full- load current.

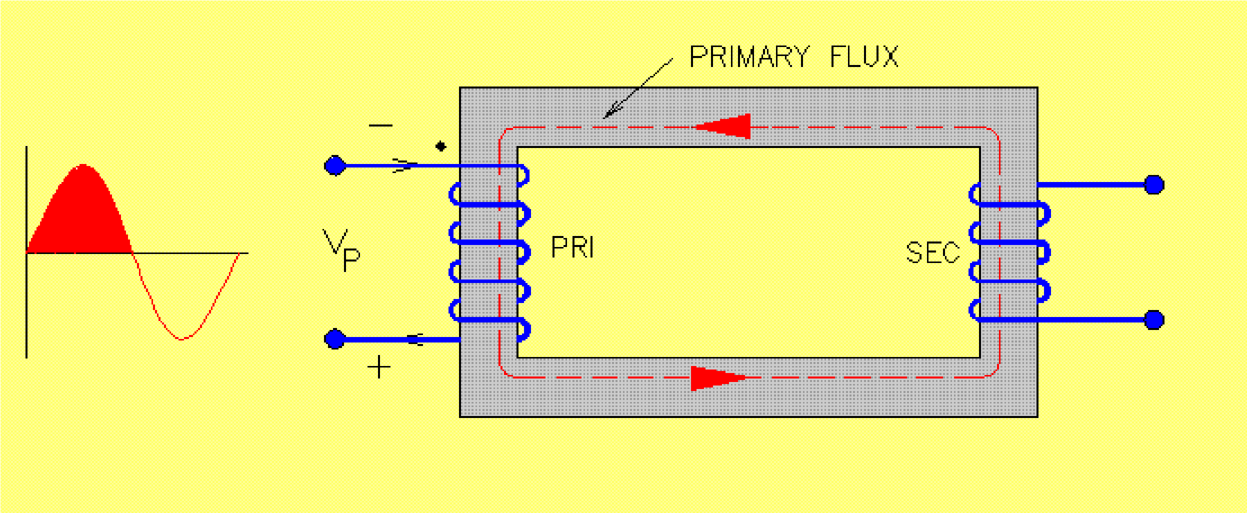
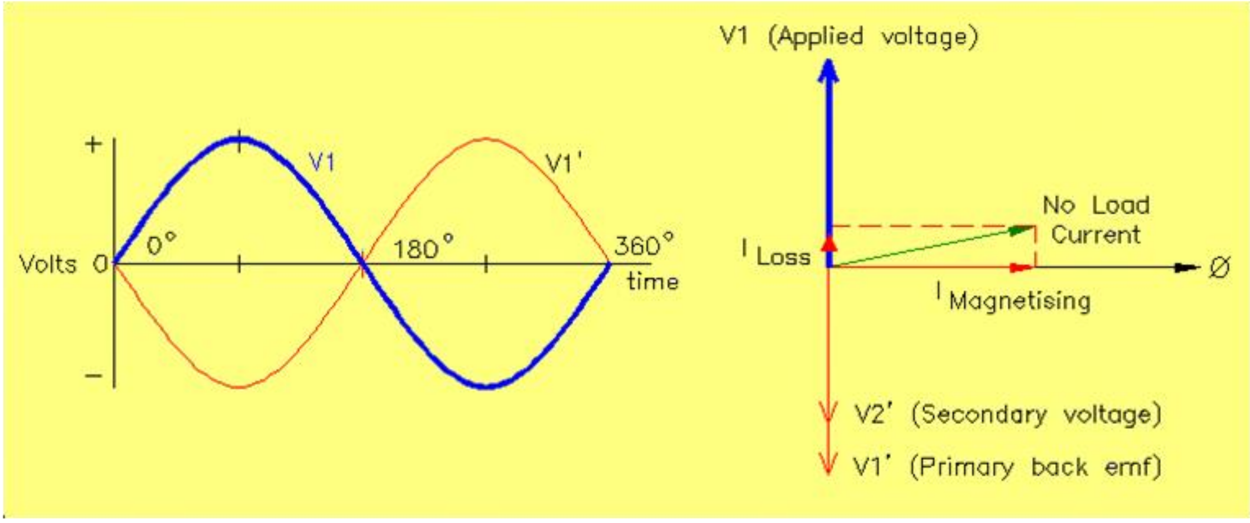


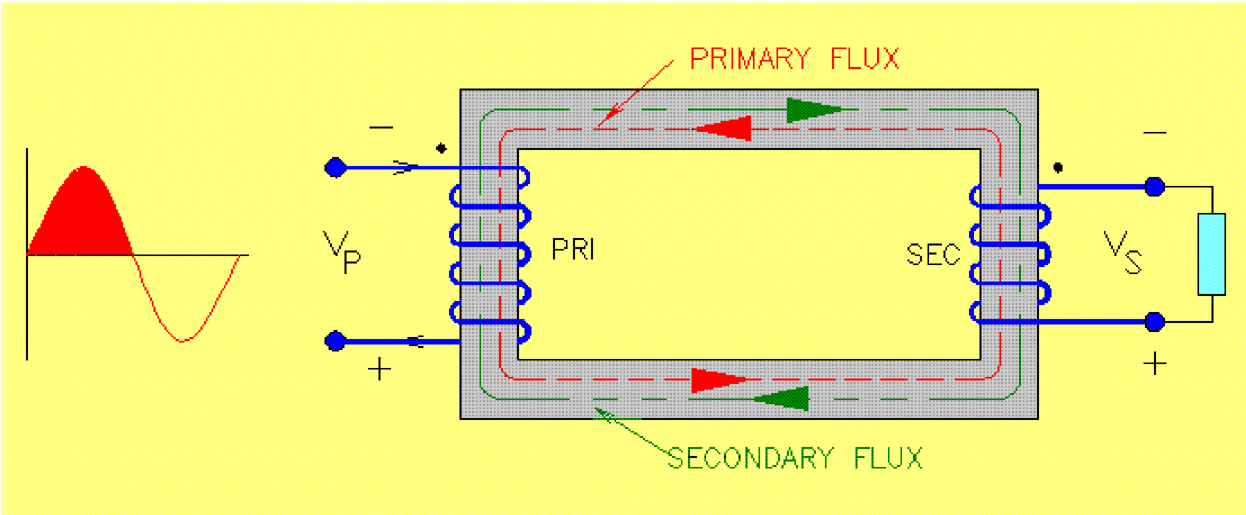
Figure 5 Transformer on no-load

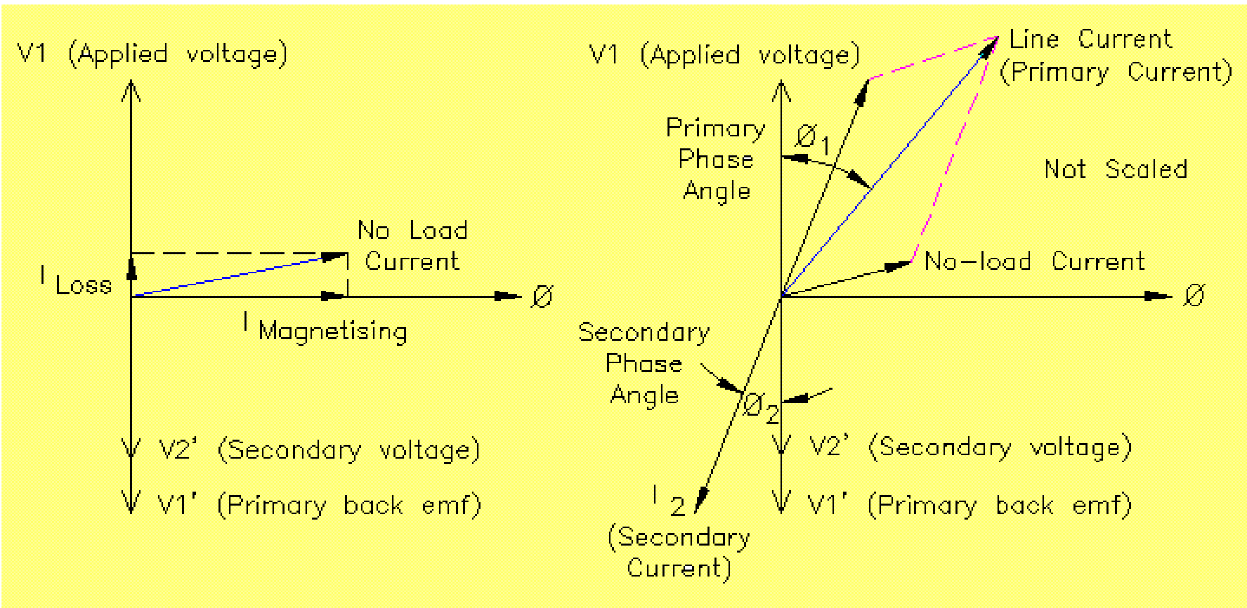
11. The self-induced voltage V1' is 180 degrees out of phase with the primary voltage V1, and the line current is the phasor sum of the magnetising current and the current due to losses as shown in Figure 6. You should note that the RESISTANCE of the primary winding can not be used to calculate the primary current because it is an inductive circuit.



12. On no-load the secondary voltage is also 180 degrees out of phase with the primary voltage V1 but the value of the induced voltage will be governed by the number of turns.

13. Effect on Load When the load is switched on the secondary current produces a demagnetising force. Consequently, the flux is reduced, thus reducing the self induced voltage (or back emf) in the primary. The difference between the back emf in the primary and the supply voltage is increased and more current flows in the primary.
The power factor of a transformer is best when the device is operating at full load.





14. Since the primary current is proportional to the secondary current and the primary voltage is proportional to the secondary voltage:

Primary VA = Secondary VA (neglecting losses)

15. Voltage Ratio. The voltage ratio is the ratio between the primary voltage and the secondary voltage.

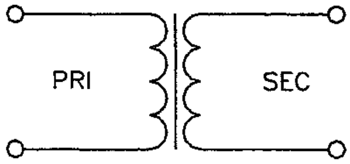
Voltage Ratio = Vp:Vs

16. Turns Ratio. The turns ratio is the ratio between the primary turns and the secondary turns. The turns ratio is the same as the voltage ratio in a transformer.

Turns Ratio = Np:Ns (N is the symbol for turns in a coil). Since the voltage ratio equals the turns ratio:

$$\frac{V_P}{V_S} : \frac{N_P}{N_S}$$

240 V, 4 A
Np = 960 Turns
= 4 Turns/Volt



100 V 9.6 A
Ns = 400 Turns
= 4 Turns/ Volt

e.g: Ns = (Np X Vs)/Vp

960 X 100 / 240 = 400 Turns

17. Example A transformer has 200 turns in the primary winding and 600 turns in the secondary winding. Calculate the turns ratio and the secondary voltage if the primary voltage is 50 V.

Turns ratio
Np = 200, Ns = 600

$$\frac{200}{600} = \frac{1}{3}$$

1 to 3 (step up) To calculate the secondary Volts 3 X 50 = 150 v

18. Any variation of secondary current is accompanied by a proportional variation of the primary current.

Therefore:

$$\frac{V_p}{V_S} : \frac{N_P}{N_S} : \frac{I_S}{I_P}$$

Where: Is = secondary current; Ip = primary current
Vs = secondary voltage; Vp = primary voltage
Ns = secondary turns; Np = primary turns

19. Example A single phase 240:50 V step down transformer supplies 150 amps from the secondary winding. Calculate the primary current.

$$\frac{V_p}{V_S} = \frac{I_S}{I_P}$$

$$I_P = \frac{I_S \quad x \quad V_S}{V_P}$$

$$I_P = \frac{150 \quad x \quad 50}{240}$$

31.25 Amps

Transformer Ratings

20. Transformers and alternators are not rated in kilowatts (kW) because the load drawn from a transformer may have a variable power factor, so they are rated in voltamperes (VA) or kilo voltamperes (kVA) which are derived from the line voltage and the line current.

21. In all transformers, the output kVA from the secondary is equal to the input kVA less any losses in the transformer.

Isolating Transformers

22. An isolating transformer is one in which the primary voltage is equal to the secondary voltage. They are used to isolate the secondary circuit from the earth, because in the MEN supply system the neutral is earthed. Isolating the secondary circuit from earth reduces (but does not eliminate) the possibility of a person receiving an electric shock.

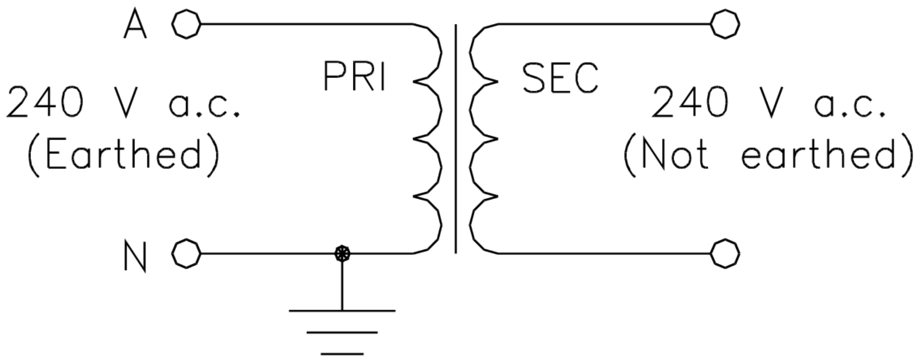


Figure 8

In some cases a non-magnetic shield is installed during manufacture between the primary and secondary windings. This shield is earthed as an added precaution for electrical safety.

Wiring Rules

23. The AS/NZS 3000:2018 Wiring Rules applicable to transformers are in Clause 4.14.

Regulation

24. Regulation is the measurement of the variation between the full load secondary voltage and no load secondary voltage - expressed as a percentage. A typical value of regulation in a power transformer is about 4%.

Voltage Regulation (%) = $\frac{V_{NL} - V_{FL}}{V_{FL}}$ x 100

Transformer Losses

25. **Iron Losses.** The magnetic core of a transformer consists of many thin laminations of high grade silicon steel (Stalloy). The power absorbed by the core of the transformer is called the 'iron loss' and is due to eddy currents and hysteresis. The iron losses remain approximately constant from no load to full load.

26. **Copper Losses.** The windings in a transformer must have resistance. The power lost due to heating of the winding is known as the 'copper loss' (or I^2R loss) and can be calculated using the equation $P = I^2 \times R$ for each winding.
Copper loss is proportional to the square of the current in a winding. Copper losses can be minimised by winding the coils with the largest possible wire (so that they have the least possible resistance).

27. **Eddy Current Losses**. If a transformer had a solid iron core it would act as a conductor. Movement of the magnetic field through the solid core would generate a voltage in the iron and a high current would flow, causing the core to heat up. These currents are called eddy currents and they should be reduced to a minimum for the transformer to operate as efficiently as possible.

28. Eddy currents are reduced by using a laminated or ferrite powder iron core instead of a solid block of iron as shown in Figure 9.

Laminations

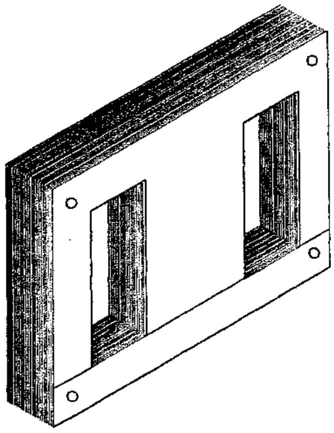


Figure 9 - A stack of core laminations

29. All transformers have laminated or ferrite cores because an alternating current flowing in the windings will generate eddy currents in a solid iron core.

Hysteresis Losses

30. Hysteresis losses occur because the iron of an a.c. electromagnet does not lose all of its magnetism as soon as the magnetic force is removed. A small amount of power has to be used after each half cycle to overcome this residual magnetism (or remanence), before the core can be re-magnetised with the opposite polarity. Hysteresis loss is usually expressed in watts of loss per kilogram of core. A typical hysteresis loop is shown in Figure 10.

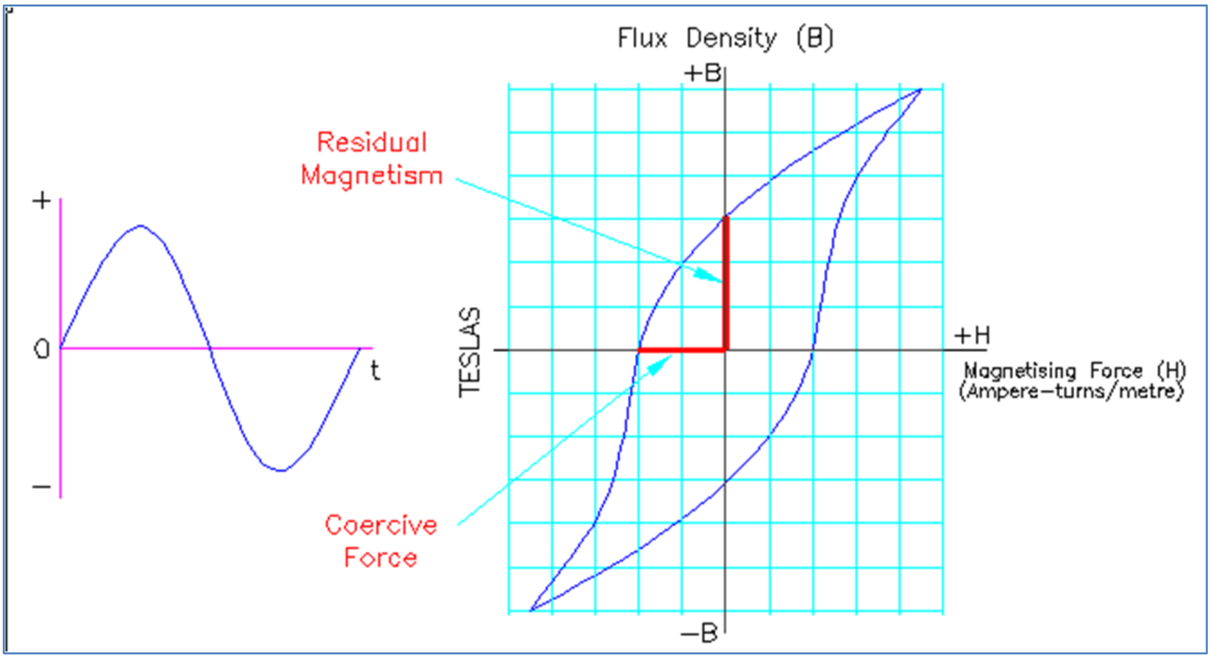


Figure 10 - Hysteresis loop

31. The value of the loss is directly proportional to the area of the hysteresis loop.

32. Hysteresis losses can be reduced by using a better quality iron, which has less residual magnetism or remanence, but higher quality irons are expensive, so most manufacturers use a lower quality iron and allow for losses in the design of the device.

Transformer Efficiency

33. The efficiency of a transformer can be calculated using the equation:

η = **Output/ Input = Output/ (Output + losses)**

$$\eta = \frac{V_S \quad I_s \quad \lambda_S}{V_S \quad I_S \quad \lambda_S + P_{Cu} + P_{Fe}}$$

Where:

V_S = Secondary Voltage
I_S = Secondary Current
λ_S = Secondary Power factor
P_{Cu} = Copper losses
P_{Fe} = Iron losses

34. A single phase transformer is delivering 120 volts at 9.6 amps at a power factor of 0.8 lagging, with an input of 240 volts at 5 amps at a power factor of 0.8 lagging. If the total copper loss is 24 watts and the total iron loss is 15 watts, the efficiency of the transformer is:

$$\eta = \frac{V_S \quad I_s \quad \lambda_S}{V_S \quad I_S \quad \lambda_S + P_{Cu} + P_{Fe}}$$

$$\eta = \frac{120 \quad 9.6 \quad 0.8}{120 \quad 9.6 \quad 0.8 + 24 + 15}$$

$$\eta = \frac{921.6}{921.6 + 24 + 15}$$

$$\eta = 0.959$$

Efficiency.% = **96%**

Transformer Winding Polarity

35. Relative Polarities - The relative polarities of instantaneous primary and secondary voltages can be shown on a diagram by using a DOT marking, or by using a letter code. A dot over a terminal indicates that terminal is the same polarity (at any instant) as the other terminal which has the dot, if the windings are on the same iron core. Figure 11 illustrates the use of the dot marking and the 'a' letter code.

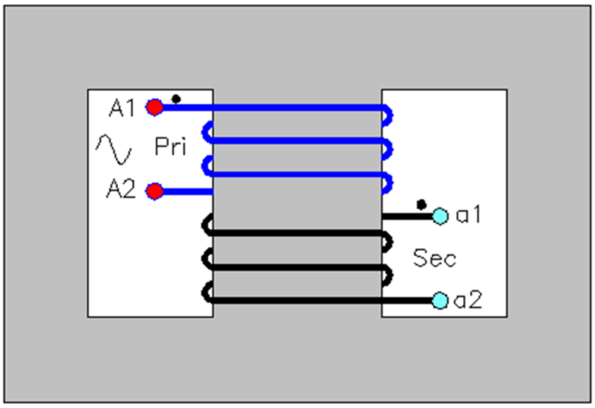
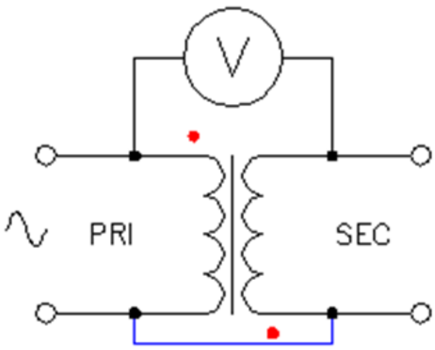
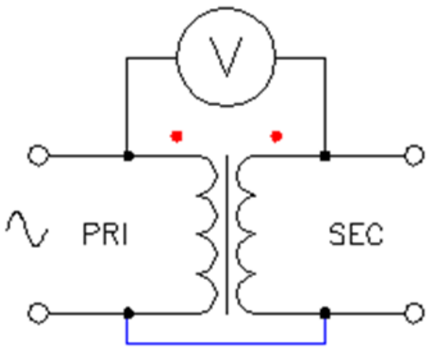


Figure 11 - Dot markings for instantaneous polarities

36. Checking Polarity - If the polarity of a transformer is not known, it may be determined by connecting the winding as in Figure 12 and Figure 13.



Additive figure 12



Subtractive figure 13

37. If the voltmeter reading is greater than the supply voltage, the transformer is said to have an 'additive polarity' and dissimilar ends of the transformer are joined as shown in Figure 12. If the voltmeter reading is less than supply voltage mark the transformer as in Figure 13.

Windings Connected in Series Aiding and Series Opposing

38. Figure 14 shows the effect of terminals of unlike and like polarity being connected together this is known as a 'series aiding' connection.

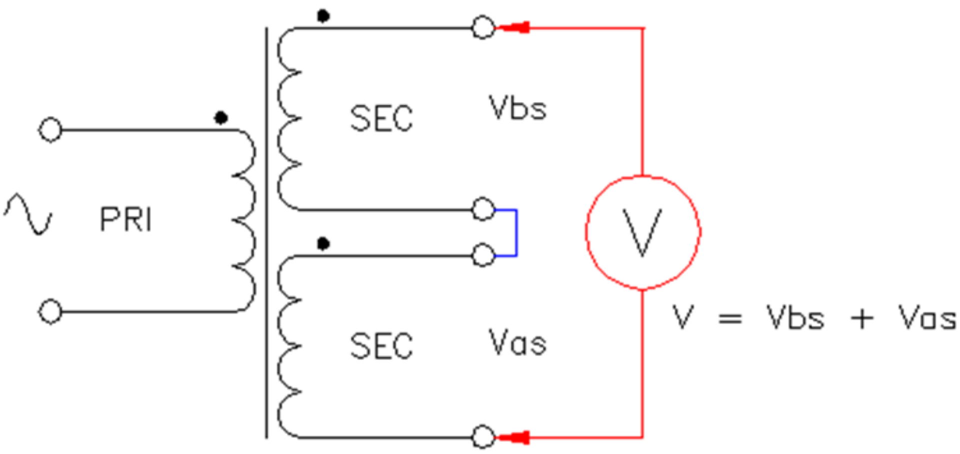


Figure 14 - Series aiding

39. With the two secondary windings connected as SERIES AIDING the output secondary voltage will be:
V = Vbs +Vas

40. With the two winding connected as SERIES OPPOSING the output secondary voltage will be: V = Vbs - Vas

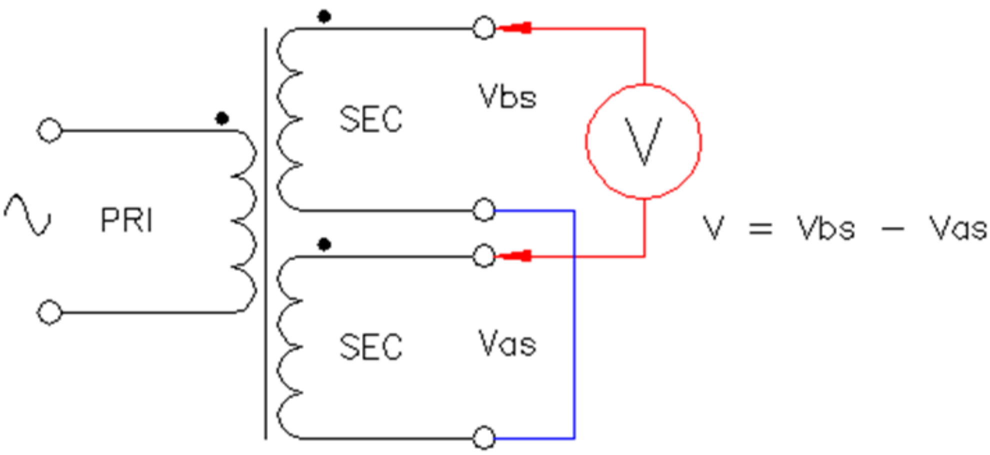


Figure 15 - Series opposing

Paralleling Single Phase Transformers

41. It is possible to connect single phase transformers in parallel provided that the output voltages are the same and the regulation is the same in each. However, since the secondary voltage of a transformer is 180 degrees out of phase with the primary voltage, the two transformers must be connected so that the instantaneous voltage is the same polarity in each.

42. Check Before Paralleling - Before two small transformers are connected in parallel a voltmeter should be connected as shown in Figure 16. If the reading is zero the connection is correct. If the reading is double the normal secondary voltage the connection is incorrect. To connect it correctly, reverse the output terminals from the secondary of one of the transformers.

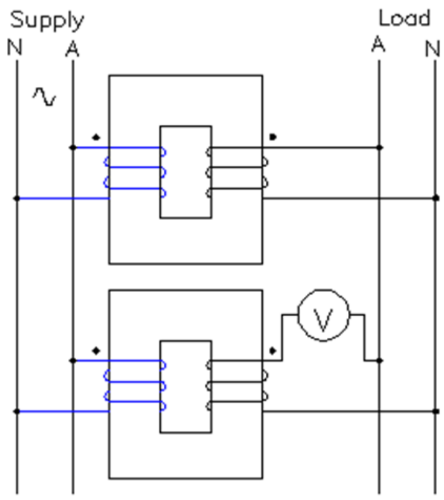


Figure 16 - Paralleling single phase transformers

Applications in Industry

43. Transformers are widely used in industry.
Typical applications include:
a. Power supplies.
b. The power supply for equipment which requires voltages other than 240/415 volts a.c.
c. Supply authority substations - high voltage for power transmission.
d. Arc welding machines.
e. Isolating transformers - for electrical safety.
f. Impedance matching - electronic circuits.

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 1 Worksheet	G006A SGB 02/2010

Single Phase Transformers

1. Can typical single phase transformers be used to raise or lower d.c. voltages?
2. What are the names given to the two windings on a basic single phase step-down transformer?
3. Which winding on a basic single phase step-down transformer has the lowest d.c. resistance?
4. What is the phase relationship between the primary and secondary voltage in a single phase double wound transformer?
5. What name is given to a basic transformer in which the primary and secondary windings are electrically separate from each other?
6. To which winding in a single phase double wound step-down transformer is the input voltage normally connected?
7. From which winding in a single phase double wound step-down transformer is the output voltage normally taken?
8. What name is given to a transformer in which the secondary voltage is greater than the primary voltage?
9. From what material is the core of a power transformer normally made?
10. What is a trade name of a common material used to manufacture the core of a 1 kVA single phase power transformer?
11. What are the names given to the two basic types of single phase transformer core?
12. What is the phase difference between the primary voltage and the secondary voltage of a transformer?
13. Laminated steel is commonly used in the construction of a power transformer. What other type of material is used for the same purpose in very small transformers?
14. What are three advantages of grain-oriented C cores compared to transformer cores which have stacked laminations?
15. What is the name given to the type of transformer secondary coil which is able to deliver more than one output voltage without changing the connections or voltage to the primary winding?
16. What are the two main losses in a power transformer?
17. What type of transformer loss remains relatively constant over the full output range of a power transformer?
18. What is the minimum number of complete grain oriented C cores required to make a single phase SHELL type transformer core?
19. What name is given to a transformer in which the input voltage is the same value as the output voltage?

20. Which winding in a single phase step-down transformer is usually wound with the smallest diameter winding wire?

21. What two main factors govern the copper losses in a transformer?

22. What is the main purpose of an isolating transformer?

23. What dangerous situation can arise if the input voltage is accidentally connected to the secondary of a 240/6 volt single phase double wound step-down transformer?

24. The DC resistance of the primary of a particular 240/12 volt double wound step-down transformer is measured and found to be 4 ohms.
How much current would be drawn from the 240 volt supply on no load?

25. A particular single phase transformer has a nominal output rating of 5 kVA at 125 volts. What is the nominal input rating (neglecting losses)?

26. A particular 240 volt single phase step-down shell type transformer has 1200 turns on the primary and 300 turns on the secondary.
What is the output voltage on no-load?

27. If a single phase double wound step-down transformer has a voltage ratio of 6 to 1, what is the turns ratio?

28. When does a double wound transformer operate at its highest operational power factor?

29. A particular 240 volt single phase shell type transformer has 600 turns on the primary and the nominal secondary voltage is 40 volts. How many turns would there be on the secondary?

30. A 240 volt single phase 2.4 kVA double wound transformer has a secondary voltage of 80 volts. What is the maximum current which may be drawn from the secondary winding?

31. How much current would be drawn from the supply by a 240 volt 40 VA double wound transformer on full load?

32. A 240 volt single phase 1.2 kVA double wound transformer has a secondary voltage of 12 volts. What is current ratio?

33. A 240 volt single phase 60 VA double wound transformer has a secondary voltage of 6 volts. What is turns ratio?

34. A single phase transformer has a turns ratio of 6:1. What is the current ratio?

35. A single phase 240:100 volt transformer is delivering 12 amps at a power factor of 0.8 lagging. If the total copper loss is 27 watts and the total iron loss is 13 watts, what is the efficiency of the transformer?

36. A 240 volt single phase double wound transformer has 400 turns on the primary, giving a secondary voltage of 60 volts. The PRIMARY winding is tapped at 360 and 380 turns. What would be the output voltage if the supply was connected to the 380 turn tapping?

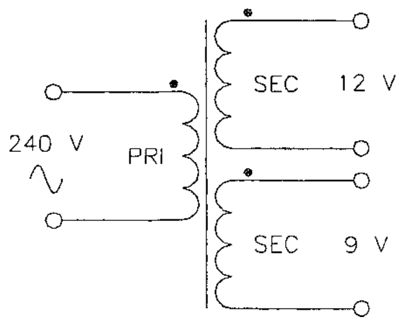
37. What is a typical percentage of regulation in a normal double wound transformer?

38. What is the main reason for using a 240 V to 240 V isolating transformer (in a student laboratory for example)?

39. A single phase double wound transformer has a primary voltage of 240 V and secondary voltage of 32 V. Sketch the connection necessary to use a voltmeter to determine the polarity of the primary to the secondary. Estimate the expected voltage readings.

40. Complete the connections in the following diagram to show how the secondary windings can be connected to give secondary voltages of:

    a. 21 volts.
    b. 3 volts.



41. What two precautions should be taken before attempting to connect the secondaries of two similar single phase transformers in parallel?

42. What will happen if the wrong connection was made when paralleling two identical transformers?

43. Is it possible to parallel two transformers if one has a 240 V primary and a 20 V secondary, and the other has a 240 V primary and a 25 V secondary? Briefly outline the reasons for your answer.

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Single Phase Transformer Connections

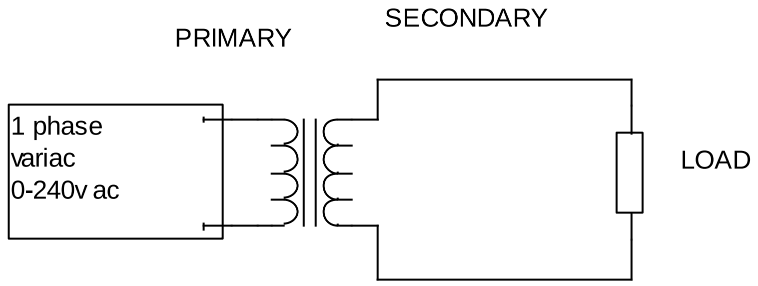
Objective

To verify the voltage relationships in a single phase double-wound step-down transformer.

Equipment

Single phase variable voltage a.c. supply (Variac)
Single phase 240 V double wound step down transformer project board
Load board (60 watt incandescent lamp or similar)
Connecting leads.
Multimeter.

Circuit diagram



Procedure

DANGER TAG PROCEDURE MUST BE FOLLOWED

1. Measure the resistance of the two windings on the double wound step-down transformer and identify the primary winding.
   Record the resistance of both windings in the Results Table.

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

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

4. Have your connections checked by your Lecturer.

5. Set the variable a.c. supply (Variac) to about 25% of its full value and measure the primary and secondary voltages with a multimeter. Record your results in the Results Table.

6. Repeat Step 5 with the Variac set to approximately 50%, 75% and 100% of the supply voltage.

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

8. Have your results checked by your Lecturer.

9. Return all of the equipment to its proper place.

Results Table

Primary Resistance	Ω	Secondary Resistance	Ω
Variac Setting	Primary Voltage	Secondary Voltage	Calculated Voltage Ratio
25% Voltage			
50% Voltage			
75% Voltage			
100% Voltage			

Questions

1. What conclusion can you draw in relation to the ratio between the primary voltage and the secondary voltage for each setting?

___

2. If the primary voltage was set to 100 volts, what would the secondary voltage be?

___

3. If the secondary voltage was set to 100 volts, what would the primary voltage be?

___

4. If there were 500 turns on the primary winding, how many turns would there be on the secondary winding?

___

5. If the primary input current was 1 amp, what would the secondary current be?

___

6. Based on your results, what would the output voltage be if 240 volts was incorrectly applied to the SECONDARY of the transformer?

___

7. What was the VA rating of the transformer used for this project?

___

8. What type of CORE did the transformer have?

____

9. Which winding in the transformer would have the largest diameter winding wire?

____

10. What is the maximum permissible secondary current for the transformer?

____

11. Express the relationship between primary and secondary volts, primary and secondary turns, and primary and secondary current in mathematical terms:

____

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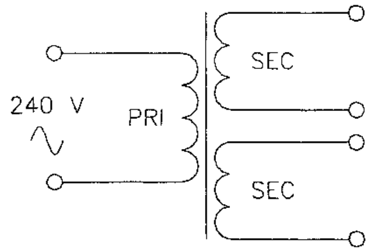
Connecting Transformer Secondaries Series Aiding/Opposing

Objective

To connect the two secondaries of a dual secondary single phase double wound 240 V transformer series aiding and series opposing.

Equipment

A double wound dual secondary transformer (different voltages)
Multimeter
Single phase leads



Circuit

Procedure

Danger Tag Procedure Must be Followed

1. Examine the step down double wound transformer supplied and determine which winding is the primary and which windings are the secondaries using a multimeter where necessary. Record the results in Table 1. Switch the multimeter OFF.

Table 1

Resistance of Primary	Ω	Markings	
Resistance of Secondary 1	Ω	Markings	
Resistance of Secondary 2	Ω	Markings	

2. Connect the circuit so that the secondary output voltages can be measured. Check the circuit for short circuits with a multimeter. Have your wiring checked by your Lecturer.

3. Plug the circuit into a 240 volt single phase outlet and record the primary and secondary voltages in Table 2.

Table 2

Primary Voltage	
Secondary 1 Voltage	
Secondary 2 Voltage	

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

5. Draw a circuit diagram showing how the transformer secondaries must be connected for series aiding output. Calculate the expected output voltage.

Circuit (Series Aiding)

Output Voltage	
Calculated	
Measured	

6. Have your circuit checked by your Lecturer

7. Energise the circuit and measure the total secondary output voltage.

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

9. Draw a circuit diagram showing how the transformer secondaries must be connected for series opposing output. Calculate the expected output voltage.

Circuit (Series Opposing)

Output Voltage	
Calculated	
Measured	

10. Have your circuit checked by your Lecturer

11. Energise the circuit and measure the total secondary output voltage.

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

13. Have your results checked by your Lecturer.

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

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 1 Activity Sheet 3	G006A SGB 02/2010

Connecting Single Phase Transformers in Parallel

Objective

To connect the secondaries of two identical 240 V single phase double-wound step-down transformers in parallel.

Equipment

Two identical single phase double-wound step-down transformers (unmarked). Multimeter.
Single phase 240 V power board.

Procedure

Danger Tag Procedure Must be Followed

1. Examine the two transformers supplied, and identify the primary and secondary windings using a multimeter.

2. Measure the resistance of each winding and record the results in Table 1.

Table 1

	Resistance (T1)	Resistance (T2)
Primary Winding	Ω	Ω
Secondary Winding	Ω	Ω

3. Draw a circuit diagram showing how the transformers must be connected so that the secondary windings are able to operate in parallel.
Identify the secondary closing connection on your diagram.

4. Have your circuit diagram checked by your Lecturer.

5. Connect the transformers in accordance with your circuit diagram, leaving the closing connection open in the secondary circuit.

6. Check your circuit for short circuits using a multimeter. Switch the multimeter off after the test.

7. Have your wiring checked by your Lecturer.

8. Energise your circuit and measure the voltage across the closing connection.

9. If the voltage across the closing connection is not zero, switch the circuit off and remove the plug from the outlet then proceed to Step 10. If the voltage is zero proceed to Step 11.

10. Reverse the connections to either secondary winding and go back to **Step 7.**

11. If the voltage across the closing connection is zero, switch the circuit off and remove the plug from the outlet. Make the closing connection, then re-energise the circuit.

12. Measure and record the primary and secondary voltages.

Primary Voltage:		Secondary Voltage:	

13: Switch the circuit off and remove the plug from the outlet.

14. Have your results checked by your Lecturer.

15. Return all of the equipment to its proper place.

Questions

1. Would it be safe to connect two single phase transformer secondaries in parallel if they were different voltages?

2. Would you recommend connecting two single phase transformer secondaries in parallel if the voltages were the same but the VA ratings of the transformers were different?

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 2 Introduction	G006A SGB 02/2010

Specialised Transformers

Task:

To describe the characteristics and principles of operation of autotransformers, potential transformers and current transformers.

Why:

Autotransformers, potential transformers and current transformers are widely used in industry. You need a good understanding of them to be able to safely use them in a.c. circuits.

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:

Sample autotransformers
Sample current transformers (CT's)
Sample potential transformers (PT's)
A.C. ammeters
A.C. voltmeters
Multimeters

References:

* Electrical Principles for the Electrical Trades (6^{th} ed.), Jenneson, J.R., Harper, B. & Moore, B.

Safety:

You must demonstrate safe working practices at all times.

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 2 Study Guide	G006A SGB 02/2010

Specialised Transformers

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades (6th ed.) Volume 2

Chapter 2 Section 2.9 Special transformers

2. Read the Summaries and practice 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 section of the resource book.
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 single phase and three phase low voltage machines**	Section 2 Summary	G006A SGB 02/2010

Specialised Transformers

Autotransformers

1. The windings of a double-wound transformer are insulated from each other, but the primary and secondary of an autotransformer share one continuous winding.

2. Like the double-wound transformer, the autotransformer can either step up or step down the voltage. The following Figures show a basic double-wound transformer, a step-down autotransformer, a step-up autotransformer and a variable autotransformer.

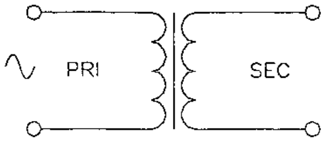


Figure 1 - Double-wound transformer

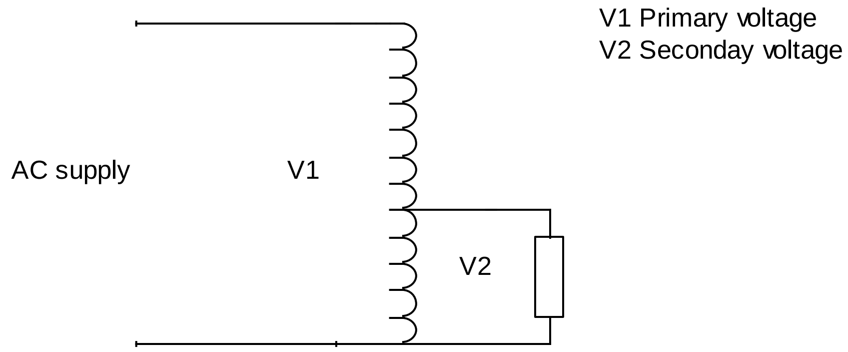


Figure 2 - Step-down autotransformer.

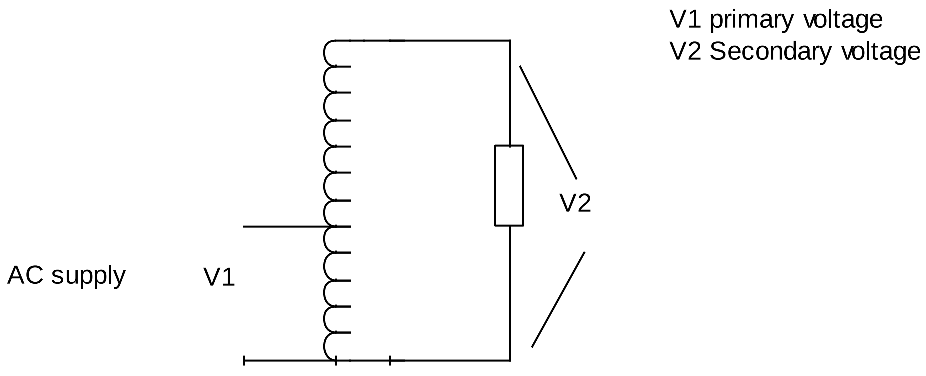


Figure 3 - Step-up autotransformer.

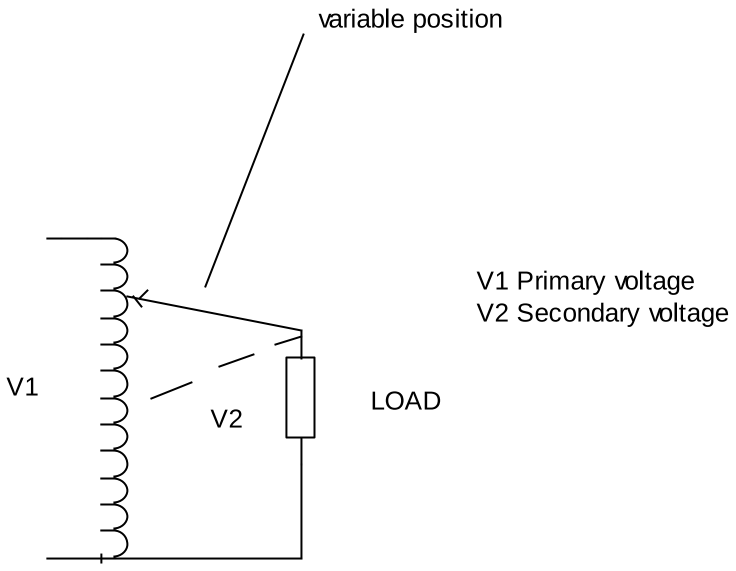


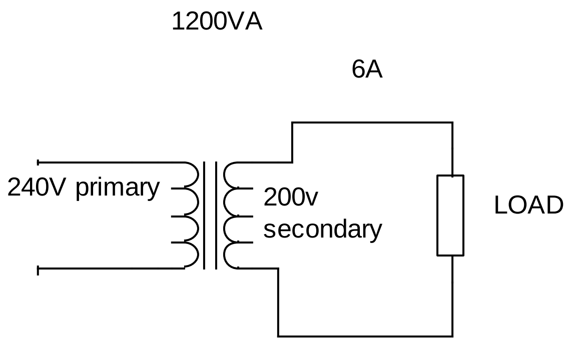
Figure 4 - Variable Autotransformer

3. The main advantages of an autotransformer are:

   a. The shared portion of the winding is only required to carry a current equal to the difference between the input and output currents (neglecting losses) compared to a double-wound transformer of the same VA rating.

   b. The VA rating of an autotransformer is greater than the VA rating of a double-wound transformer of the same core size.

4. Consider a single phase 1200 VA step-down double-wound transformer with a primary voltage of 240 volts and a secondary voltage of 200 volts.



5. On full load the current in the primary is 5 amps and the current in the secondary is 6 amps. The primary winding wire has to be large enough to carry the full primary current.

6. If the same transformer was connected as a step-down autotransformer the full load line current and output current would be the same as before, but the section of the winding shared by the primary and secondary would only have to carry the difference between the input current and the output current, because the primary and secondary voltages of a transformer are 180 degrees out of phase. See Figure 5

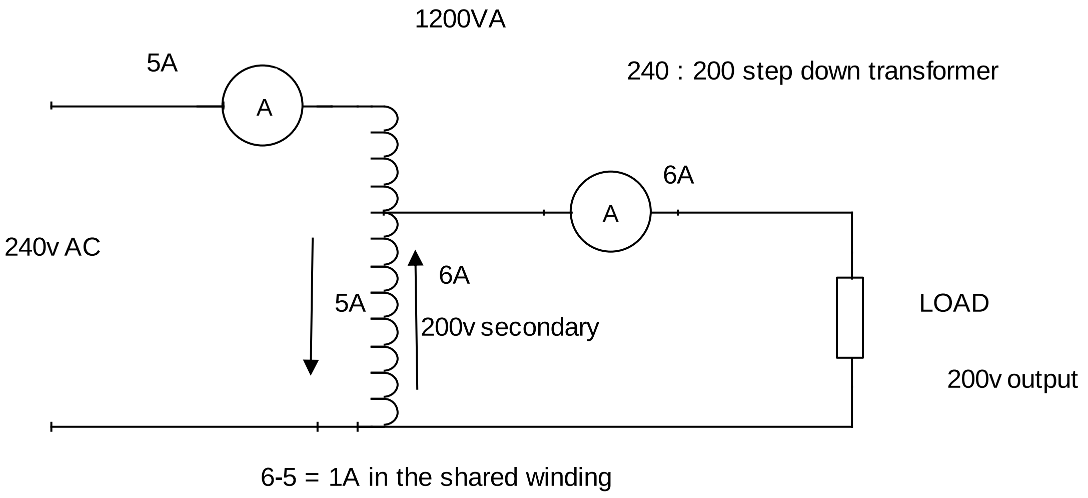


Figure 5 - Currents in an autotransformer.

7. Since the shared portion of the winding is only required to carry 1 amp instead of 6 amps, the size of the winding wire can be significantly reduced, with resulting reductions in cost, weight, space and copper losses. The size of the core could also be reduced, resulting in further savings of cost, weight, space and iron losses for the given VA rating.

8. Although the benefits of using an autotransformer are considerable, there is a significant disadvantage. If the shared portion of the winding was open-circuited during operation, as shown in figure 6, the full line voltage would exist between the open circuit and the neutral- this is usually an extremely hazardous situation.

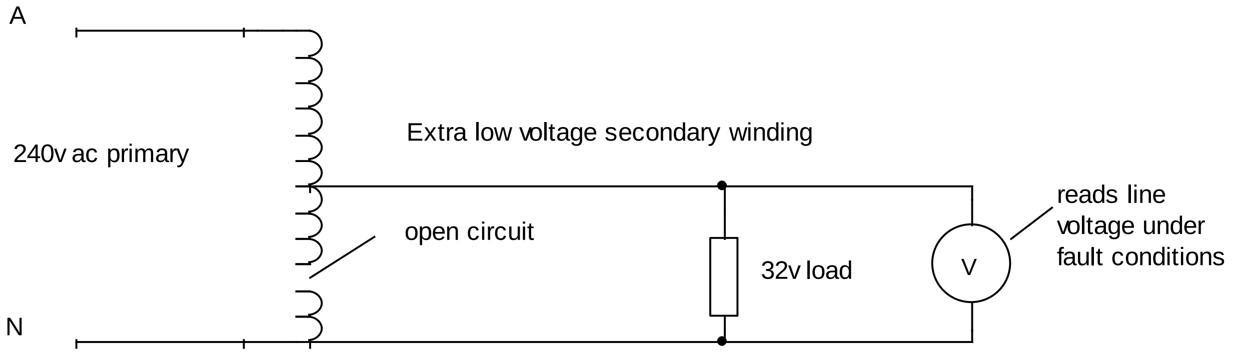


Figure 6 - Autotransformer with an open circuited winding.

9. Clause 4.14.4 of AS/NZS 3000 states that an autotransformer shall not be used to supply electrical equipment, including circuit wiring, having a voltage rating of less than the highest input or output voltage of the autotransformer.

Uses of Autotransformers

10. Low voltage autotransformers are mainly used in starters for induction motors, where they reduce the applied voltage during the starting period. Other uses are; instant- start fluorescent lamp circuits and supplying equipment designed to operate at 220 volts from a 240 volt system.

11. Step-up autotransformers are used as boosters near the ends of long transmission lines where line losses have caused the voltage to drop below the required potential.

12. Variable autotransformers are available to give a controllable a.c. output voltage. One trade name is VARIAC. When a Variac is used to provide a variable supply voltage, the output must always be handled as if it was at the full line voltage, in case an open circuit occurs in the shared portion of the winding.

Instrument Transformers

Potential Transformers (PTs)

13. Potential Transformers are used where the voltage is too high for the instrument or where electrical isolation is required.

14. The principle of a potential (voltage) transformer is similar to that of a power transformer. It contains the usual primary and secondary winding and an iron core.

15. The potential transformer is always a step-down transformer and the maximum secondary voltage is usually 110 volts. The input (primary) voltage could exceed 33000 volts.

16. Most potential transformers are oil-filled for added insulation, but they may be of the dry kind up to approximately 3000 volts.

17. Potential Transformer Connections. The primary of a potential transformer is always connected ACROSS the high voltage supply conductors. The meter is connected directly across the secondary terminals. Usually one of the secondary terminals of a potential transformer is connected to earth.

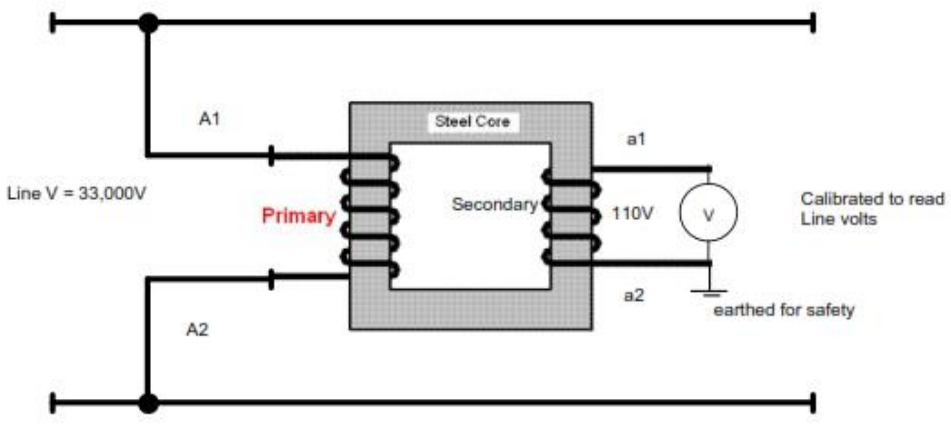


Figure 7 - Potential transformer connections.

18. The terminals of potential transformers must be clearly marked because the polarity must be correct when the potential coils of wattmeters or watt-hour meters are connected.

19. The primary terminals of a single-phase potential transformer are usually marked A1 and A2 and the corresponding secondary terminals are marked a1 and a2. These markings are purely directional and indicate that, at the instant A1 is positive with respect to A2, a1 will be positive with respect to a2.

20. Standard symbol for potential transformers (PT).

Figure 8 - Potential transformer symbol

21. PT Burdens. Apart from a voltage ratio, a PT is also assigned·a load or burden rating. This gives an indication of the full-load secondary current and also the load .placed on the supply source.

22. Example A 330 VA potential transformer at 110 V would make available 3 amps of secondary current for meters.

    110 x 3 = 330 VA

Current Transformers (CTs)

23. Current Transformers have two main functions:

    a. To transform high-load current values so that they can be measured on a low current meter or current sensing· device.

    b. To isolate the metering circuit from the main power circuit, which could be a high-voltage line.

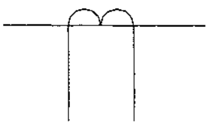
24. Current transformers are normally used where the load current is larger than about 50 amperes. They allow a definite fraction of this current to be metered by a low-capacity ammeter (typically 1 to 5 amperes) which can be calibrated to indicate the load current.

25. If the secondary becomes open-circuit, there will be no secondary flux and so the core flux density increases. The induced voltage at the secondary terminals increases greatly, producing a safety hazard and the possibility of. insulation break-down.

26. Consequently, the secondary of a current transformer MUST NEVER BE OPEN-CIRCUITED while the primary is energised.

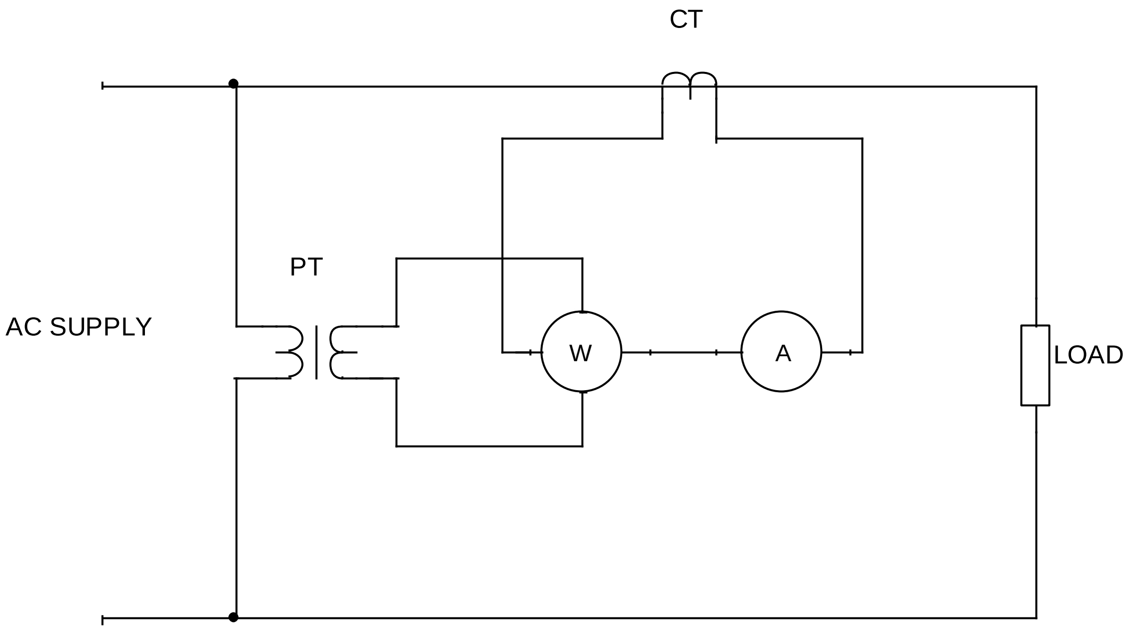
27. The polarity markings of current transformers must be carefully observed, particularly when wattmeters or watt-hour meters are connected. The primary terminals are typically marked Pl and P2 and the secondary terminals are marked Sl and S2.

28. Current Transformer Symbol



Secondary 5A

30. **Instrument Transformer Connections**



Leakage Transformers

30. Leakage transformers or high-reactance transformers produce a comparatively high no-load voltage and a low short-circuit current inducing a magnetic shunt as shown in Figure 10, it allows a low leakage on no-load and a high flux leakage on short-circuit.

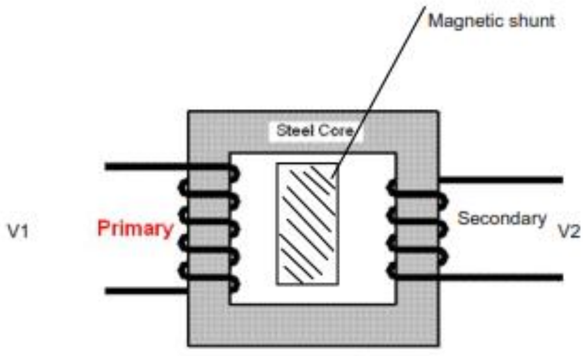


Figure 10 - Leakage transformer.

31. **Principle of Operation** On no load the primary winding produces a flux in the core which cuts the secondary winding, inducing a voltage in it. The leakage flux is reasonably low, because the air gaps in the magnetic shunt circuits produce a reasonably high reluctance in the shunt circuits.

32. When the transformer is loaded, the secondary current produces a secondary flux which tends to oppose the primary flux. Part of the primary flux now passes through the magnetic shunts, reducing the effective flux cutting the secondary winding and reducing the induced voltage.

33. Typical Applications;
    a. Furnace ignition
    b. Gaseous discharge lighting
    c. Welding machines

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Specialised Transformers

1. Which winding on a current transformer (CT) will always have the greatest number of turns?

2. Is it possible to use a current transformer in a d.c. circuit?

3. Which two common measuring instruments often require the use of current transformers?

4. What part of a circuit usually forms the primary winding of a toroidal type of current transformer?

5. What is a typical maximum value of secondary current in a current transformer?

6. What essential safety precaution must be taken when an ammeter is to be disconnected from its associated current transformer {other than switching the power off during disconnection)?

7. List four applications for current transformers.

8. What are the customary terminal markings on the primary and secondary winding terminals of a current transformer?

9. What type of current transformer can have a primary winding which is· not part of the current transformer itself?

10. What is the main use for a 'potential transformer'?

11. What is a typical voltage from the secondary of a potential transformer?

12. What is meant by the term 'burden' of a potential transformer?

13. What is the main characteristic which distinguishes an autotransformer from a double wound transformer?

14. What is the main advantage of an autotransformer over a double wound transformer of the same VA rating?

15. Why would it be dangerous to use a 240/32 step-down autotransformer to provide a 32 volt supply for a portable hand-lamp?

16, What is the trade name of a common type of single or three phase variable voltage autotransformer?

17. What are two common uses for autotransformers?

18. What is the special characteristic of a leakage transformer?

19. What are two common uses for leakage transformers?

20. A voltmeter, ammeter. and wattmeter are connected to a single phase circuit via instrument transformers. Each meter indicates the following measurements:
    a. Voltmeter – 10 800 volts
    b. Ammeter – 95 amps
    c. Wattmeter- 872 kW

    The CT ratio is 100:5 and the PT. ratio is 11 000:110.
    Calculate the actual voltage, current, volt-amps and power in the secondary circuit.

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Current Transformer Connections

, **Objective**

To connect and adjust suitable ammeters to various current transformers.

Equipment
2 kVA· double wound step down transformer
2 current transformers.(CTs) 50/5, 100/5
0 - 5 A a.c. ammeter
2 - ammeter scales to suit CT
2 – a.c ammeters 0 – 100A and 0 – 5A
1 – a.c. tong-tester set on ampere scale
Variable load bank

Procedure

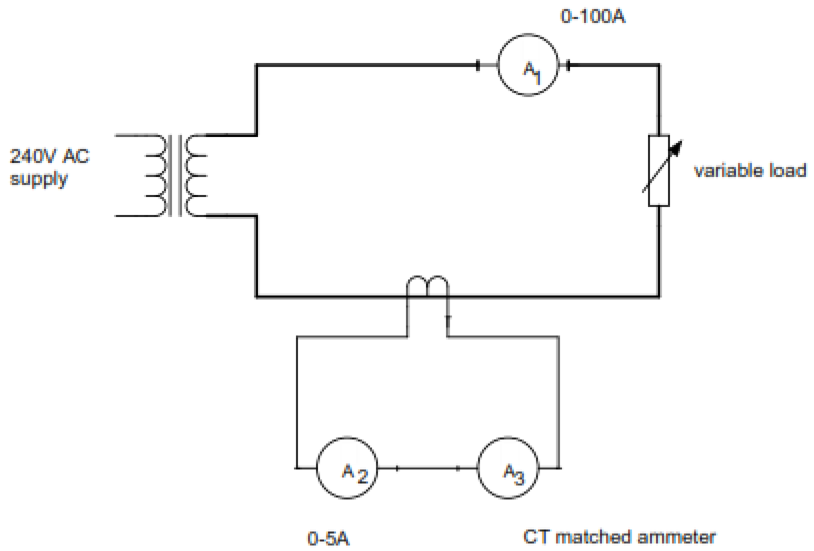
DANGER TAG PROCEDURE MUST BE FOLLOWED

1. Identify the current transformer and record the data below.

Table 1

	VA Rating	Turns Ratio	Burden
Current Transformer 1			
Current Transformer 2			

2. Connect a 50/5 CT into the circuit below. Ensure that the load is disconnected. ·



3. Connect the tong-tester in series with the 0 – 100A Ammeter.

4. Have your circuit checked by your Lecturer.

5. Energise the circuit under the NO-LOAD condition.

6. Increase the load for ammeter A1 to read 50 A.

7. Record ammeter readings A1, A2, A3 and the tong-tester in Table 2 below.

8. Switch the circuit off and remove the plug from the outlet and "Danger Tag" plug.
   Replace the 50/5 CT with a 100/5 CT and repeat steps 2 to 7.
   Change the face-plate to suit the new CT.

Table 2

	Ammeter 1	Ammeter 2	Ammeter 3	Tong-tester
Test 1				
Test 2				

9. Have your circuit checked by your Lecturer.

10. Re-energise the circuit and repeat the test again using TWO turns on the primary and record your results in Table 3 below.

Table 3

	Ammeter 1	Ammeter 2	Ammeter 3	Tong-tester
Test 1				
Test 2				

11. Switch the circuit off and remove the plug from the outlet and "Danger Tag" plug.
    Return all of the equipment to its proper place.

Questions

1. From the results in Table 2 determine the current ratio for each CT and verify your results from Table 1 (show all working).

2. Briefly explain the effect on the output current of a CT when primary turns are increased. How can this method be used to advantage?

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Transformer Testing

Task:

To test transformers for safety and correct operation.

Why:

You need a good understanding of the testing of single phase transformers to be able to avoid damage to equipment and ensure your own safety and the safety of the public.

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

Sample of single & three phase double wound transformers with prepared faults
A.C. ammeters
A.C. voltmeters
High voltage insulation tester
Multimeters

References

* Electrical Principles for the Electrical Trades(6th ed.). Volume 2. J. R. Jenneson.

Safety

You must demonstrate safe working practices at all times.

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Single Phase Transformer Testing

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades (6th ed.) Volume 2: Jenneson, J.R., Harper, B. & Moore, B.

Section 2 Transformers

Section 11 Test Equipment

2. Read the Summaries and practice 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 Resource book.
5. Submit your answers to the Work Sheets and your completed project reports to your Lecturer for discussion and assessment.

	Solve problems in single phase and three phase low voltage machines	Section 3 Summary	G006A SGB 02/2010

Transformer Testing

1. Any transformer must be inspected and tested to verify that it complies with the Australian Standard 2374.

2. The recommended inspection and testing sequence for low voltage transformers is as follows:-

a. Visual Inspection. Many defects may be present in a transformer that cannot be discovered by testing with instruments.
e.g. i. Loose laminations
ii. Oil leaks
iii. Loose terminals
iv. Condition of windings
v. Condition of supports and mounting of windings and auxiliary equipment.
vi Overheating on no-load condition.

b. Continuity of all Windings: - A continuity tester is used to check that a conductor is continuous along the whole of its length. The ohmmeter, which is used for determining the resistance value, will serve as a continuity tester.

c. Insulation: - Insulation resistance is measured with a 500 volt insulation resistance tester (Megger) for winding voltages not exceeding 250 V to earth and must be not less than the minimum permissible value according to the AS/NZS 3000 Wiring Rules.

Check all conductors both primary and secondary are electrically insulated from the metal frame or core.

Check insulation resistance between all primary and secondary windings of the transformer.

d. Primary and Secondary Identification - From the given transformer information the primary and secondary can be identified as follows:

i. Step-down double wound transformer

With an ohmmeter measure the d.c. resistance of each winding. The resistance will be higher in the primary ·winding than the secondary winding

ii. Step- up double wound transformer

The d.c. resistance will be higher in the secondary winding than the primary winding.

e. Overheating - Could indicate shorted turns in the windings caused by circulating currents around the shorted turns. Check the d.c. resistance of all windings and compare with manufacturers data.

Faults and Testing

3. The four main electrical faults that can occur in transformers in service are:

a. Earth faults: Where insulation failure results in a winding or connection shorting to earth. Usually caused by faulty insulation, ingress of moisture and magnetic stress.

b. Inter-winding faults: Where a breakdown of insulation results in the primary winding shorting to the secondary winding. Causes - same as in earth faults.

c. Shorted turns: Where adjacent turns short together.
Mainly due to conductor insulation breakdown caused by overheating, due to overload and poor ventilation, or coil movement resulting from magnetic stress.

d. Open circuit: Where a faulty connection, or joint, breaks the continuity of the windings. Usually caused by poorly made connections or dry joints.

Testing of Transformers

4. The following basic tests can be carried out to identify the faults listed in power transformers.

a. Earth Test	Test with a suitable high voltage insulation tester from the winding terminals to the metal frame of the transformer. Readings should be within specified limits, usually not less than One megohm (1MΩ). Tests should be conducted with an instrument capable of delivering twice the working voltage to earth.
b. Inter-winding Tests	A high voltage insulation tester is again required for this test. Test should be conducted between all windings.
c. Testing for Shorted Turns	An Ohmmeter can be used to give some indication of shorted turns when the d.c. resistance of each winding is checked against manufacture's data. A bridge megger set on the ohms range will provide a more accurate reading of the resistance of each winding.
d. Testing for Open Circuits	An Ohmmeter will indicate an open circuit winding.

Wiring Rules

5. The AS/NZS 3000 Wiring Rules contains a number of clauses relating to transformers. Clause 4.14.1 (Transformers) contains the general requirement for transformers.

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Transformer Testing

1. List the items to look for when carrying out a visual inspection on a transformer.

2. What is meant by good electrical continuity of a winding, and how is this test carried out?

3. Why is it required to use a 500 V insulation tester on equipment rated up to 240 V to earth. State the AS/NZS 3000 Wiring Rules Clause number.

4. The following results were obtained from a single phase double wound STEP-UP transformer.

a. One winding had a d.c. resistance of 90 ohms
b. The other winding had a d.c. resistance of 5 ohms

Which winding would be the primary?

5. List four main electrical faults that could occur in a transformer when in service.

6. Describe one method of testing a transformer winding for short circuited turns.

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Transformer Testing

Objective

To test transformers for open circuit and insulation faults.

Equipment

Double-wound step-down transformer (unmarked).
Insulation tester.
Multimeter or Ohmmeter.

Procedure

DANGER TAG PROCEDURE REQUIRED

1. Examine the transformer supplied, and identify the primary and secondary windings using a multimeter.

2. Measure the resistance of each winding and record the results in Table 1.

Table 1

	Resistances		
Primary			
Secondary			

3. Measure the insulation resistances with a high voltage insulation tester and record the results in Table 2.

Table 2

	Insulation Resistance		
Primary to Frame			
Secondary to Frame			
Primary to Secondary			

4. Have your results checked by your Lecturer,

5. Return all of the equipment to its proper place.

Questions

1. Would it be safe to connect the transformer to the supply?

2. What is the minimum specified value of insulation resistance between the windings to earth of a single phase transformer connected to a 240V supply?

____

3. What type of measuring instrument must be used for testing insulation resistance?

____

4. Were the insulation values obtained in the tests within those specified for transformers?

____

5. Does an ohmmeter give a satisfactory indication of shorted turns of a transformer winding? Give reasons for your answer.

____

____

6. What condition would be indicated if the resistance of a transformer winding was:

   Zero ohms   Infinity ohms

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Three Phase Transformer Principles

Task:

To describe the characteristics, principles of operation and connection of basic three phase double wound transformers.

Why:

Three phase transformers are used in all a.c. distribution systems and most large power supplies. You need a good understanding of their operation and connections to be able to connect, service and maintain them.

To Pass:

1. You must correctly answer the questions on the response sheets provided.
2. You must satisfactorily complete the set laboratory tasks.

Equipment

Sample three phase double wound transformers Sample three phase double wound transformer cores
Sample three phase open delta transformers
A.C. ammeters
A.C. voltmeters
Multimeters

References

* Electrical Principles for the Electrical Trades (6th ed.), J. R. Jennesen.

Safety

You must demonstrate safe working practices at all times.

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 4 Study Guide	G006A SGB 02/2010

Three Phase Transformer Principles

Suggested Self-Study Guide

1. Study the following sections in the recommended references: Electrical Principles for the Electrical Trades (6th Ed.) Volume 2 Section 2 -Transformers

2. Read the Summary and practice 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 the Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

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

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 4 Summary	G006A SGB 02/2010

Three Phase Transformer Principles

Construction

1. The variations in single phase transformer cores also apply to three phase cores, but whereas the single phase transformer construction is mainly of the shell type, the majority of three phase transformers are of the core type design.

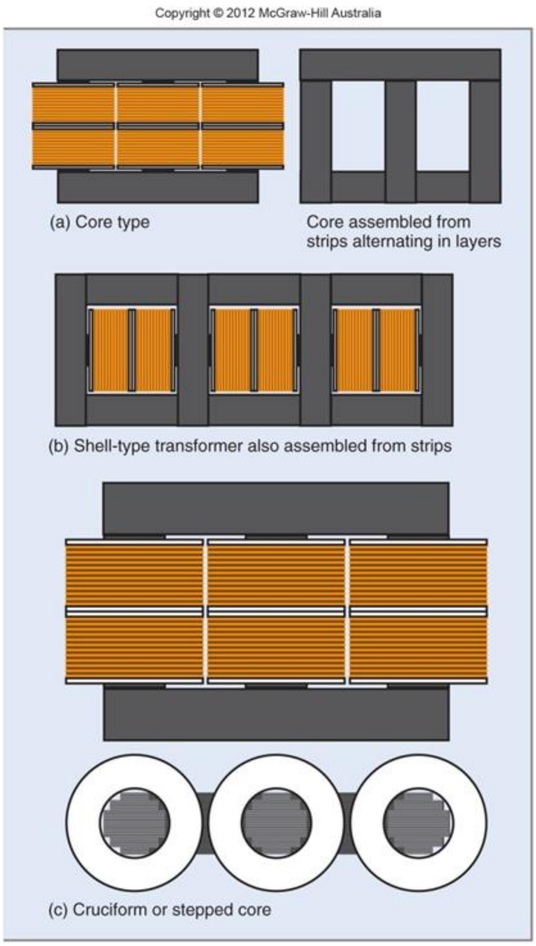


Figure 1

2. A three phase transformer can be obtained by using three identical single phase transformers (Figure 2), but in practice one common core is used with three identical sets of primary and secondary windings mounted on it (Figure 3).

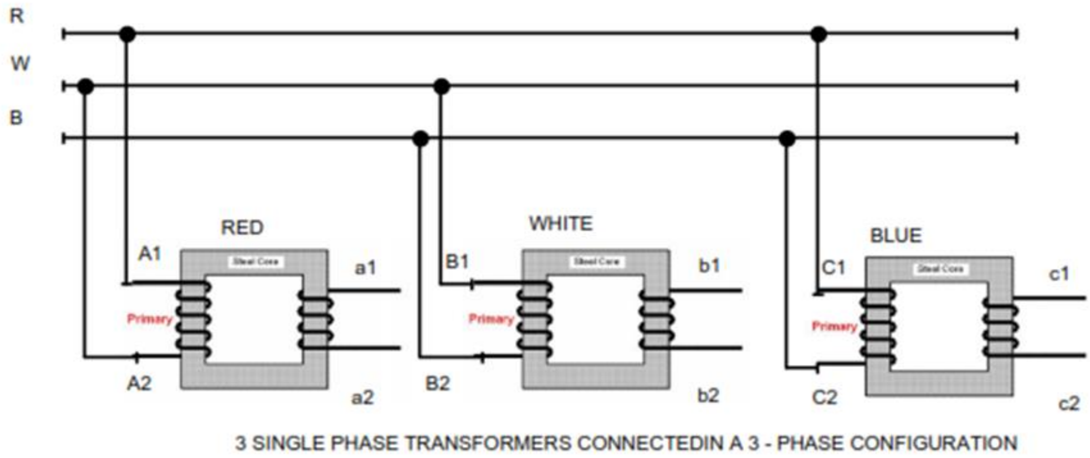


Figure 2 - Three single phase transformers connected in a three phase configuration.

3. Core Type Construction. Although similar in appearance to the single phase shell type, they differ in that each leg of the core is of equal cross sectional area (Figure 3). This is the most common type of core used for three phase transformers.

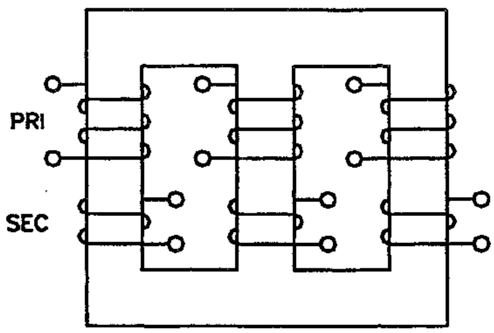


Figure 3 - Three legs of equal cross section.

4. Due to the 120 degree phase displacement of a three phase supply only three legs are required in the core of a three phase transformer as the fluxes established by the three windings do not reach full strength at the same time. For example, if the flux produced by the red phase is at its maximum, the flux in the other two legs is half the value in the opposite direction.

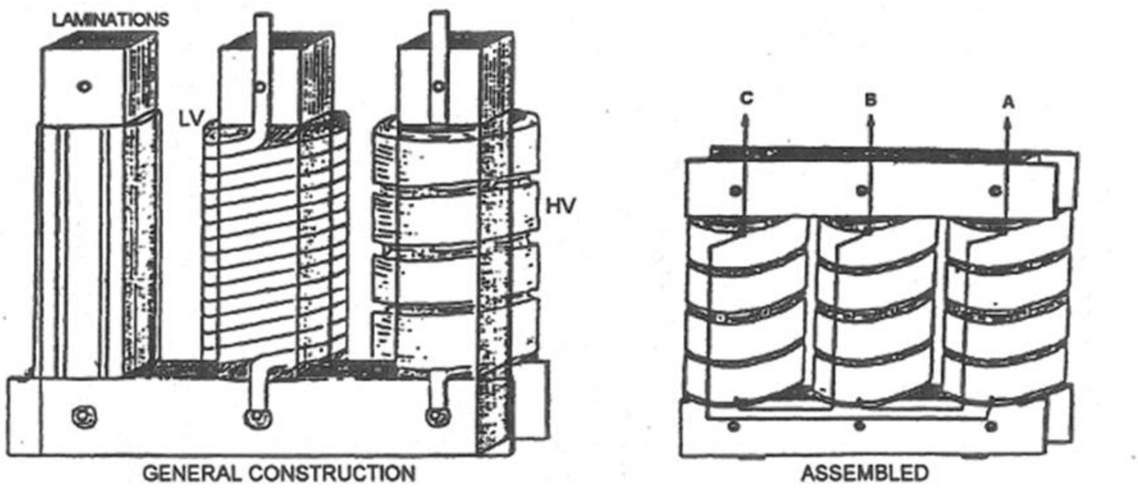
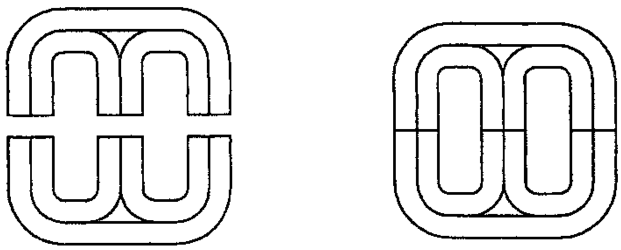


Figure 4 Typical three phase distribution transformer

5. Another type of construction used for three phase transformers cores is the laminated toroidal or 'C core' with machined faces to minimise the air gap.



Three phase ‘C’ core construction

Transformer Cooling

6. Copper and iron losses cause heat to be generated within a transformer when on load. This heat must be dissipated to prevent the transformer overheating and possibly burning out. The operating temperature of a transformer has a significant effect on the life of the internal insulation so it must be kept as cool as possible.

7. A transformer is a static device and has no rotating parts that could produce a ventilating draught, therefore, other means must be provided to remove the heat generated.

8. Small transformers rely on the external surface of the transformer to dissipate the heat by radiation and convection.

9. In large transformers the heat losses are far greater than the surface area can effectively dissipate, additional methods of removing the heat must therefore be provided.

10. The two most common methods used are;

    a. Air Blast Cooling
    b. Oil Cooling

11. Air blast, or, forced draught air cooling, has a safety advantage over the oil cooled transformers. However, air cooling depends on a plentiful supply of cool filtered air. Transformer· design must allow for the free passage of air between the windings, core and housing. The major disadvantage with this method of cooling is that if the air supply failed the transformer would quickly overheat if.it is working anywhere near its capacity.

12. Oil cooling is achieved by immersing a transformer in a tank of special insulating oil. This action alone improves the heat dissipation by increasing the area of radiation surfaces.

13. External tubes added to the transformer tank further increase the radiation surface, as well as providing a thermo-siphon effect, where the oil circulates by convection throughout the windings, tank and tubes. See Figure 5.

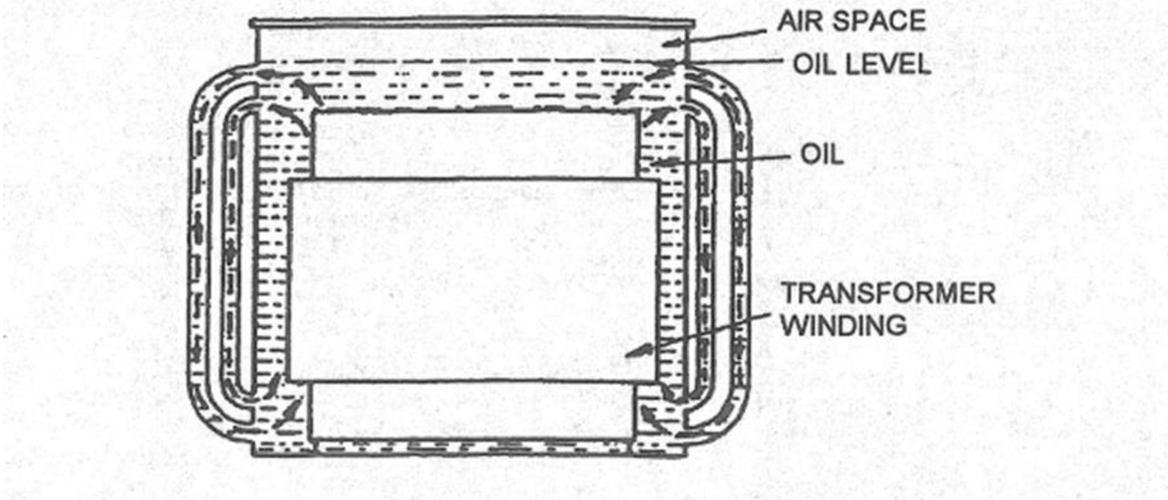


Figure 5 Hot oil rises - Cooled in tubes - Returns to tank bottom

14. To minimise oil contamination, large transformers are often fitted with external oil conservation tanks that reduces the surface area of oil in contact with air, and a chemical breather containing a desiccant such as silica-gel to prevent the ingress of moisture. Transformer oil can be contaminated by gasses which occur during operation, so some transformers are fitted with gas relays (Buchholz relays) to provide a warning if the gasses reach a pre- determined level.
In Figure 6 below shows the conservator tank fitted above the main tank of the transformer. A Buchholz (gas) relay is placed in the pipework between the two tanks. A Buchholz relay monitors the gasses generated by either electrical faults in the windings, tap changers or connections. This relay can warn the transformer operator that there is a problem in the transformer by collecting the gasses being generated by a fault and if there is a surge of oil from the main tank back to the conservator tank, trip (switch off) the transformer from both the HV and LV supplies.

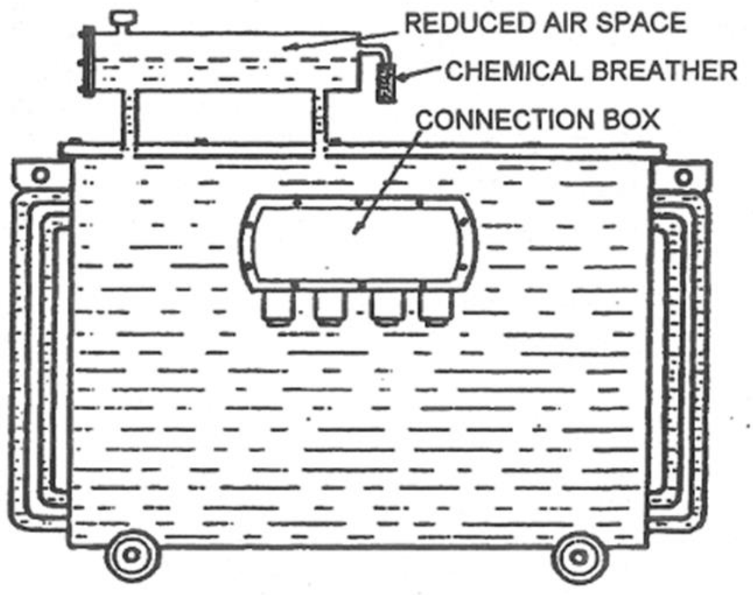


Figure 6.

15. Additional cooling for oil filled transformers may be obtained by further cooling with water filled pipes acting as a heat exchanger within the oil tank. The water is circulated by a pump.

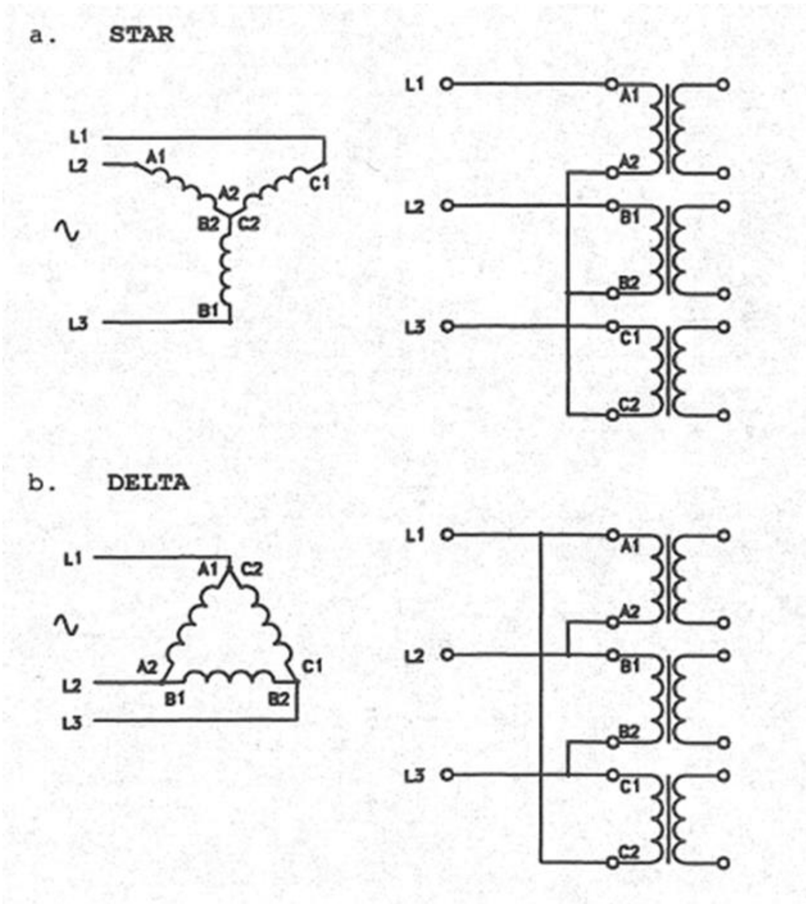
16., Transformer oil is a high quality electrical insulating oil, refined to strict standards. It not only acts as a coolant but also provides good insulating properties. Transformer oil must have special properties such as low sludge value, low acidity, high flash point, low viscosity and high electric strength. Extreme cleanliness is essential when handling transformer oil and it should be kept free of moisture, dirt, acidity and sludge. Transformer oil should be perodically tested for these contaminants during its service life.

17. Since transformer oil is flammable at high temperatures, precautions must be taken to avoid the spread of fire in case of an accidental spillage. Fire-resistant dikes or basins can be required under transformers with an oil capacity over 50 litres (see AS/NZS 3000:2018 Clause 4.16.2).

Winding Configurations

18. Three phase transformers can be connected in various STAR - DELTA configurations to give different output voltages. Care must be taken to connect the starts and finishes of windings correctly. Incorrect connections can give unequal voltages, producing circulating currents, that could result in the transformer burning out.

19. Basic Star and Delta Transformer connections



20. It is important to remember the basic star and delta connections and the relationships between line and coil voltages. It is on these relationships that calculations for voltage and turns ratios are based.

Transformer Ratio

21. The two ratios that are associated with all transformers are:

    a. Voltage Ratio - which is the ratio between primary and secondary voltages.
    Voltage Ratio = $V_P : V_S$.

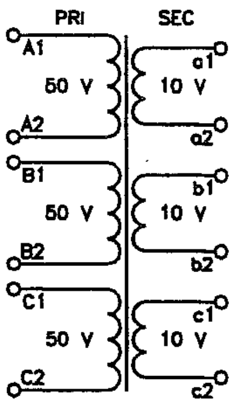
    b. Turns Ratio - which is the ratio between primary and secondary turns.
    Turns ratio = $N_P : N_S$.

    Since the voltage ratio equals the turn ratio:

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

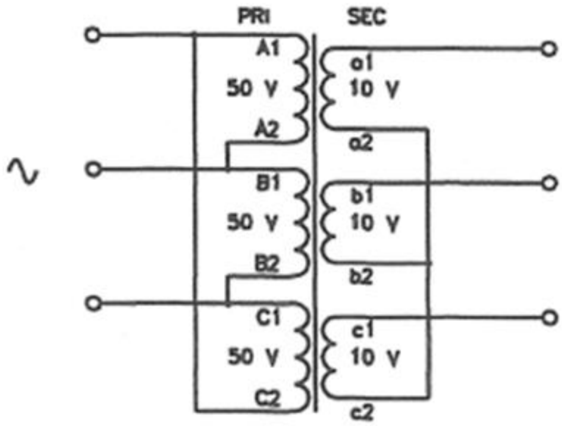
22. For three phase transformers it is the relationship between the primary and secondary COIL voltages (Coil V) that determine the voltage and turns ratios. NOT the input and output line voltages (Line V).

23. For example, the ratio of a three phase transformer is given as 5:1, which, as stated, is the ratio between the primary coil voltage (V1) and the secondary coil voltage (V2).



    When 50 V is applied to each primary coil, a 10 V output will be obtained from each secondary coil.
    V1 : V2 = 5:1 = 50 V : 10 V

24. The transformer's input and output line voltages (line V) will be determined by whichever connection method is used for the primary and secondary windings, STAR or DELTA. If the primary windings were to be connected in DELTA and the secondary windings in STAR, the input and output voltages would be:



Primary	-	DELTA connected:	Line V = Coil V
		Therefore	Line V = 50V
		Primary Voltage	= 50V
Secondary	-	STAR connected:	Line V = Coil V x √3
		Therefore	Line V = 10 x 1.732
		Secondary Voltage	= 17.32 V

25. The four common methods of connecting the primary and secondary windings of three phase transformers are:

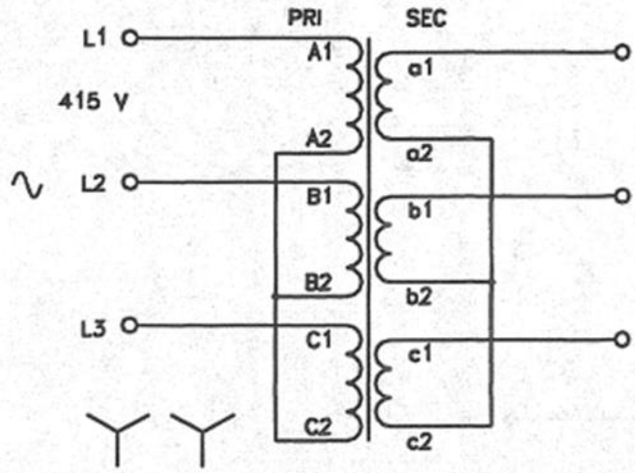
    a. STAR - STAR
    b. DELTA - DELTA
    c. DELTA - STAR
    d. STAR - DELTA

26. Whichever configuration is used the output line voltages can be calculated, given the voltage or turns ratio and the input line voltage.

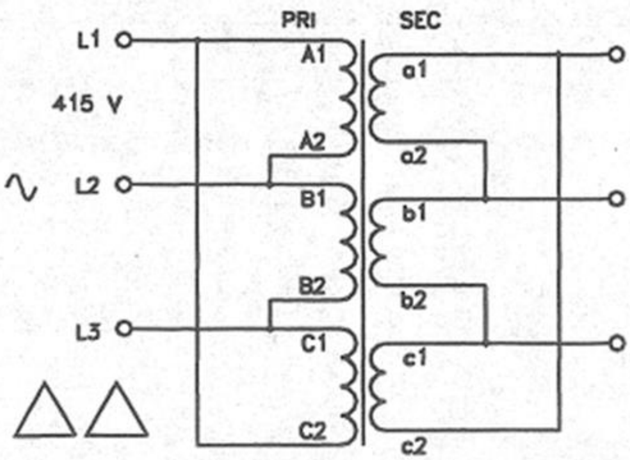
Examples

A 415 V three phase transformer has 200 turns on the primary windings and 40 turns on the secondaries. Find the output voltages for each of the connection methods.

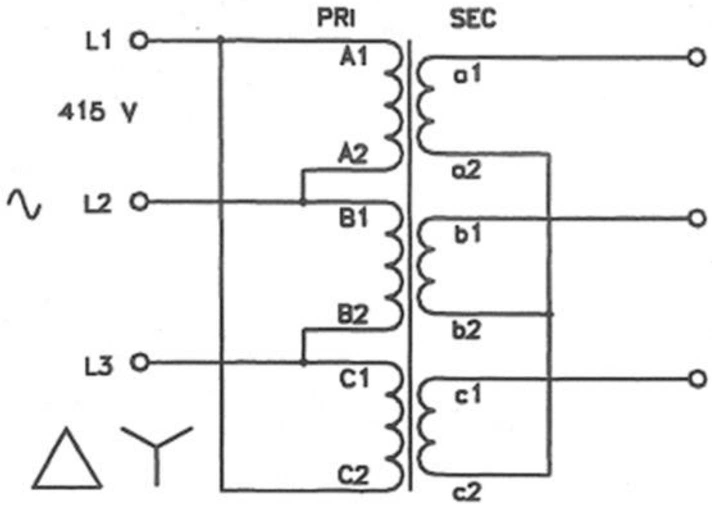
Example 1



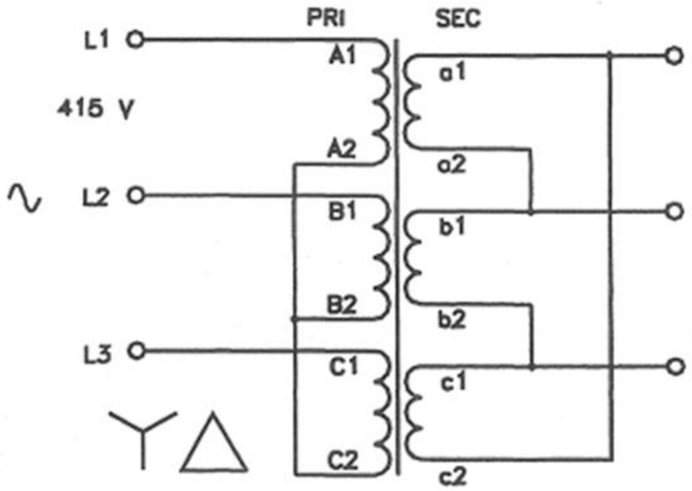
Example 2



Example 3



Example 4



Note:

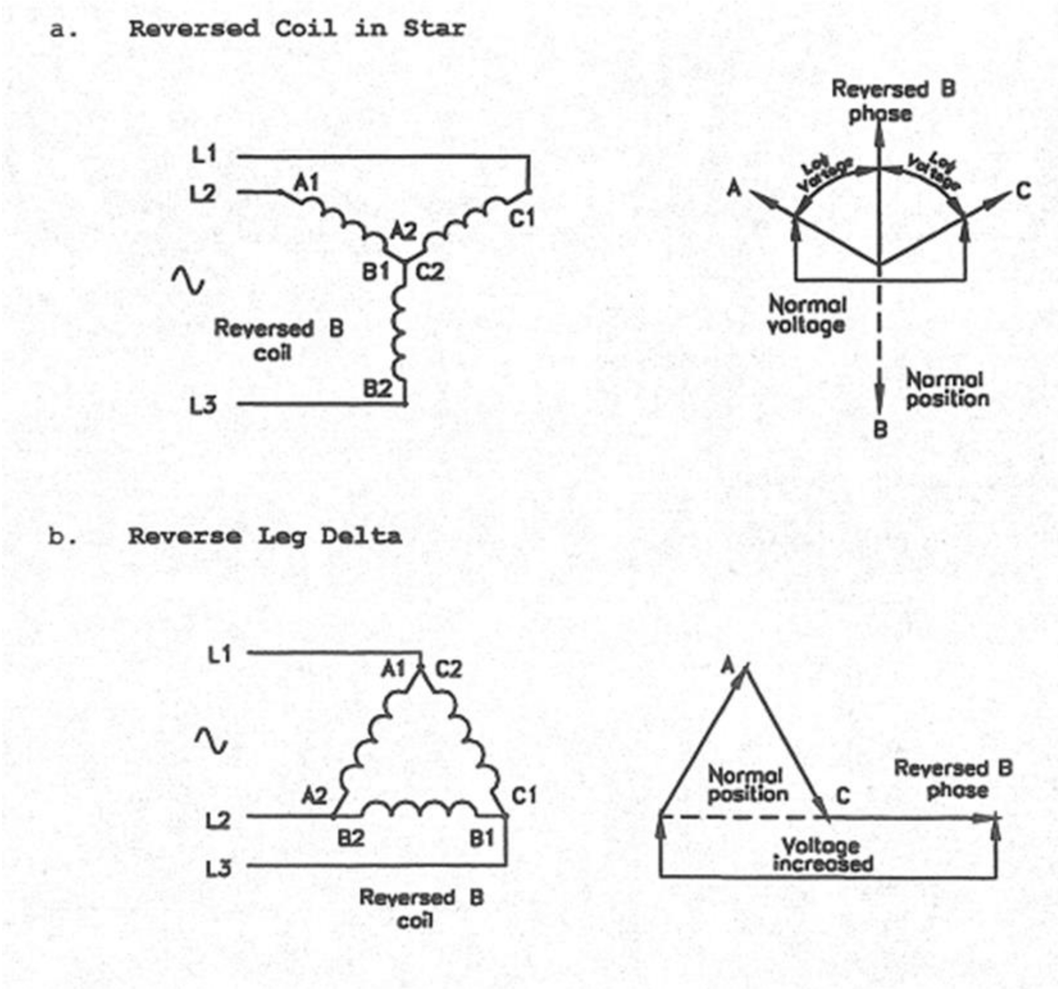
In practice the coil voltage is often referred to as the phase voltage and can be expressed as E_p.

Coil V = Ep

The term Coil V was used in the examples to maintain uniformity throughout this Section.

27. When the windings of a three phase transformer are connected in either star or delta, the voltage and current in each phase winding should be the same. If the voltages are not equal, one of the coils must be reversed.

28. When connecting for delta, always check the 'closing connection' with a voltmeter or a multimeter set on at least twice the Coil voltage.
The reason this safety precaution is if there is reversed coil the transformer will produce a large circulating current. If the transformer delta connection is correct, the voltage across the closing connection should be zero and therefore will not circulate current.
If one coil is reversed, the voltage across the closing connection will be twice the normal coil voltage.



29**. REVERSED COIL CHECKS FOR THREE PHASE TRANSFORMERS**

It is important that a 3-Phase transformer is checked for reversed coils BEFORE it is connected to a load and also that BOTH the primary and the secondary coils are checked.

STAR CONNECTION

a) Primary Coils
   1. Connect the primary coils in STAR and to the supply, but leave the secondary coils unconnected
   2. Switch on and measure the INDIVIDUAL SECONDARY COIL voltages, if one is higher than the other two its associated primary coil REVERSED.

b) Secondary Coils

Having tested (and corrected) the primary side, connect the secondary coils in STAR, switch on and measure the Line to Line voltages. If one is higher than the other two determine which coil gives a LOW reading with respect to the other two – This one is the REVERSED coil.

DELTA CONNECTION

Note: Both the primary and secondary sides are treated in the same way in DELTA, however it is obvious that the primary side must be done first.

1. Connect the coils in DELTA but leave the FINAL CONNECTION POINT OPEN (closing connection).
2. Connect to the supply and switch on, then using a voltmeter set to TWICE the expected line voltage, measure the voltage appearing across this open point.
3. If the reading obtained is approximately zero volts – All is well.
4. If the reading obtained is approximately twice the expected line voltage, one of the coils is REVERSED.
5. To correct a reversed coil, simply reverse any one of the coils and test again. Repeat this until zero volts is found across the connection point, (closing connection) – the open point may now be closed to complete the DELTA connection.

Note: This test is sometimes called the "CLOSING DELTA CONNECTION TEST".

Output Rating

30. The rated output of a transformer (single or three phase) is usually given in volt amps (VA) or kilovolt amps (kVA). The maximum output VA is arrived at by applying the equation:

S (Output VA) **= E x I x √3**

Input VA= Output VA (neglecting losses)

31. The maximum output current can be found by transposing the above equation, i.e.

$$I = \frac{S\ (in\ VA)}{E \times \sqrt{3}}$$

32. Example What is the maximum output current of a 100 kVA star connected transformer if the line voltage is 415 V?

$$I = \frac{S\ (in\ kVA)}{E \times \sqrt{3}}$$

$$I = \frac{100 \times 1000}{415 \times \sqrt{3}}$$

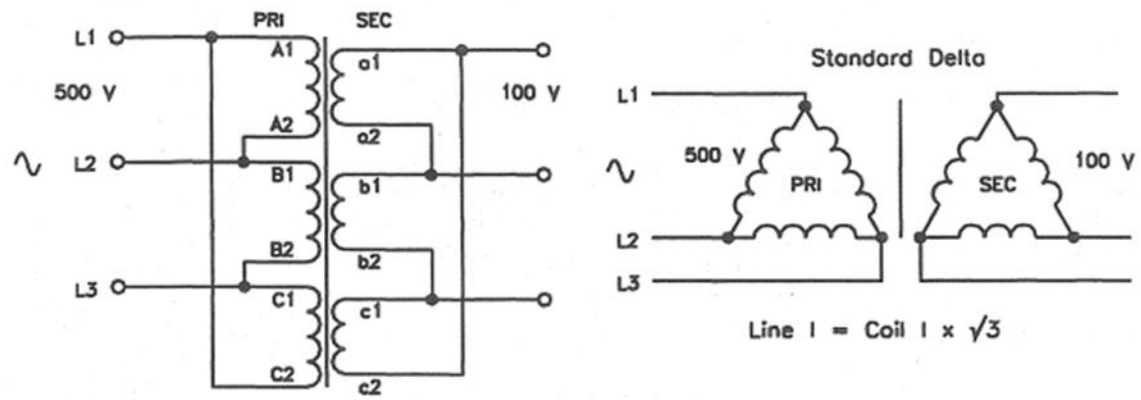
139.12 amps

33. If the power factor of the load was less than unity, the 'useful' current (true current) would be less, but the maximum output current would remain the same.

34. If the transformer was delta connected the maximum line current would still be 139.12 amps, but the coil current would be reduced to 57.7% (1/√3) of 139.12, which is 80.27 amps.

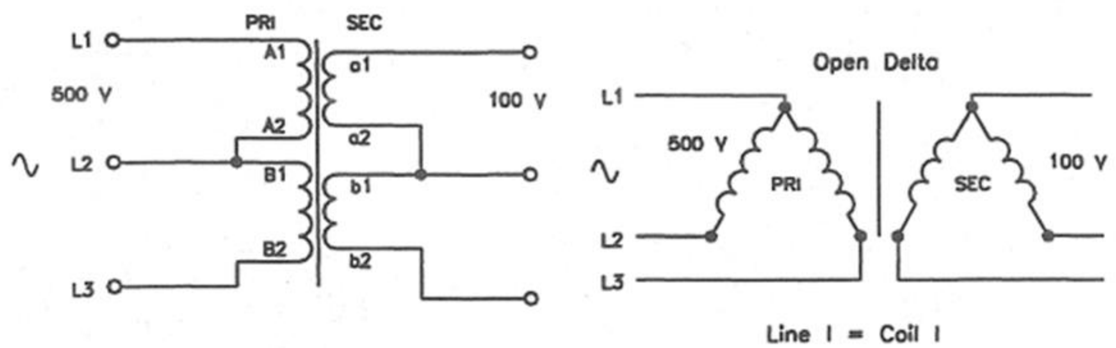
Special Connections

35. Three single phase transformers can be connected in a delta-delta configuration to raise or lower voltages in a three phase system.



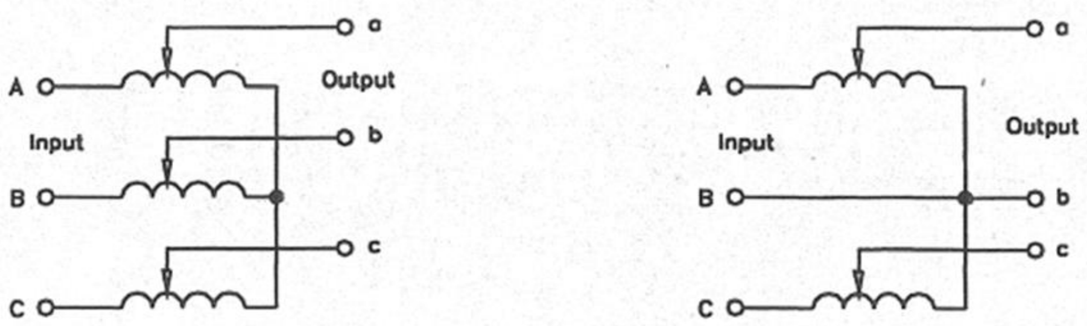
36. Should one of the single phase transformers fail, a three phase supply can still be obtained in an OPEN-DELTA configuration, maintaining the same voltage but with a reduced current rating.

Open Delta Connection



37. In the open-delta connection the normal delta connection is now broken, so the maximum value of line current cannot exceed the coil current without the transformer overheating.

Three Phase Autotransformer



a. STAR Connection b. OPEN DELTA Connection

38. Three phase autotransformers are used extensively for induction motor starting. Both connnection methods are used but the OPEN-DELTA is most popular, where only two windings are used, which gives a lighter and cheaper unit. The unbalanced currents that occur in the open–delta configuration are usually overlooked when the transformer is used for motor starting

purposes, as a balanced state returns when the motor is up to speed and connected directly to the supply. The transformer is only connected into the motor circuit for a very short time.

Harmonics

39. A power supply waveform can include a large number of waveforms, each having a frequency which is an integer multiple of the fundamental frequency. This is known as a Harmonic. Harmonics are a series of subsidiary waveforms that accompany a primary, or fundamental, waveform. A subsidiary waveform which has a frequency of, for example, three times the fundamental frequency is commonly known as a '3rd harmonic'.

40. 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 transformers, electronic lighting equipment, fluorescent ballasts, personal computers, uninterruptable power supply systems, some variable speed motor drives, welders and television sets. See AS/NZS 3000:2018 Clause 3.5.2(b)(i) for information on the size of neutral conductors where harmonic currents are detected.

41. Harmonics can 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.

42. 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. Third harmonic currents in three phase STAR connected transformers can be reduced by connecting an additional delta connected winding (known as a 'tertiary winding').

43. 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.

Paralleling Three Phase Transformers

44. The parallel operation of three phase transformers involves two or more transformers with their primaries connected to a common supply and their secondaries connected to a common load. Three essential requirements must be met before parallel operation can be achieved. They are:

    a. Line voltages are equal.
    b. Phase sequences are the same.
    c. Secondary voltages are in phase with each other.

45. If the transformers have the same voltage rating, the same impedance percent, and the same ratios of reactance to resistance they will divide their loads in proportion to their kVA ratings

a. **Line Voltages are Equal** The principle of paralleling transformers is to share the load. If there is any variation in their line voltage, circulating currents are set up between them with the lower voltage transformer becoming a burden on the other.

b. **Phase Sequence** The phase sequence, of transformers in parallel, must be identical. That is, where the phase sequence of one transformer is Red-White Blue, the sequences of the second transformer's phases must also be Red-White-Blue. Any mismatch will create a short circuit effect causing heavy circulating currents to flow.

c. **Phase Relationships** The primary-secondary relationship of transformers are important due to the phase shift that occurs between them. For example a three phase transformer connected star-delta has a secondary phase shift of 30° compared to a star-star connected transformer with a phase shift of 0°. This difference in phase shift means that the two secondary voltages of the transformers are 30° out of phase and if connected in parallel would result in unwanted high circulating currents between the two transformers. The following table gives the secondary phase shift of the more common configurations, sometimes known as vector groupings:

Winding Connection		Vector Group Symbol	Secondary Phase Shift
Primary	Secondary		
Star	star	Yy 0	0°
Star	star	Yy 6	180°
Star	delta	Yd 1	-30°
Delta	star	Dy 1	-30°
Delta	delta	Dd 0	0°
Delta	delta	Dd 6	180°
Delta	star	Dy 11	30°
Star	delta	Yd 11	30°

Vector Grouping Table: Secondary phase shift of three phase transformers

Winding Identification

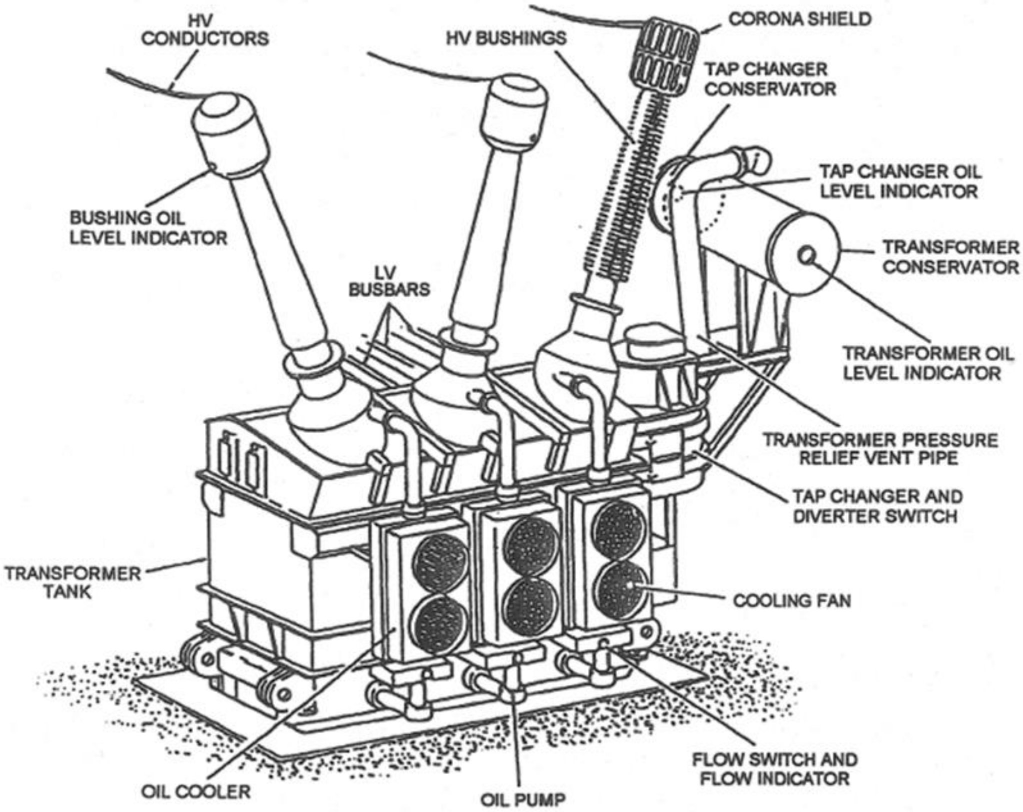
46. It is customary to identify the high voltage winding in upper case letters (D for delta and Y for star) and the low voltage winding in lower case letters (d for delta and y for star). Terminals are also identified with upper and lower case letters: A1, B1, C1, etc., for high voltage windings and a1, b1, c1, etc., for low voltage windings.

Distribution Transformers

47. Large distribution transformers installed by a supply authority or network operator can incorporate a number of components intended to ensure that the transformer can operate reliably for long periods under all predictable conditions, including:

a. bushings - special high voltage insulators.
b. explosion vents - safety valves in case of faults.
c. surge diverters - for control of transient high voltages such as lightning strikes.
d. tap changers - for changing transformer tappings to raise or low secondary voltage on load.
e. conservator tank - reduces the surface area of oil in contact with air.
f. breathers and desiccants - to control oil moisture content;
g. gas relays – buchholz relays - to monitor unwanted gas in oil.
h. temperature indicators - to monitor temperature of oil.

48. A typical large distribution transformer is shown below:



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Three Phase Transformer Principles

1. What are the two most common methods of cooling three phase transformers?

2. Draw a circuit diagram of a three phase transformer connected STAR-DELTA.
   Clearly label the primary and secondary windings and show all terminal markings.

3. A three phase step-down transformer is connected DELTA : STAR.
   If the input line voltage is 415 volts and the turns ratio is 5:1, what is the output line voltage?

4. What precaution must be taken before permanently connecting the primary or secondary coils of a three phase transformer in DELTA?

5. Which winding in a three phase 415:24 volt step down transformer should have the highest resistance?

6. What fault is indicated (if any) if the voltage at the closing connection of the primary of a delta connected three phase transformer is twice the normal input line voltage?
7. What size and type of test instrument should be used to check the insulation resistance to earth and between windings in a 415:110 volt three phase transformer?
   What is the minimum permissible resistance?

8. Which type of core construction is mainly used for three phase transformers?

9. Show, with a simple diagram, how three single phase transformers can be connected into a three phase STAR : STAR configuration.

10. What two functions does the oil perform in oil filled transformers?

11. A three phase transformer with a transformation ratio of 20:1 is connected to an 11 000 V supply.
    What: line voltage would appear across the output terminals when the transformer is connected.
    a. Star - Delta b. Delta - Star

12. What is the maximum output line current, and coil current, of a 50 kVA, DELTA connected three phase transformer if the output LINE voltage is 415 V?

13. Draw a circuit diagram showing how two single phase transformers can be connected to a three phase supply to give a three phase output.

14. What is the purpose of a 'tertiary winding' in a three phase distribution transformer?

15. What is the main undesirable result of harmonic currents in transformers and circuits?

16. List four types of auxiliary equipment which could be found on a typical distribution transformer and state the general purpose of each.

17. List three of the essential properties of transformer oil.

18. List three possible contaminants which should be periodically tested for in transformer oil.

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Three Phase Transformer Ratios

Objective

To identify the primary and secondary windings of a three phase low voltage transformer and calculate the turns ratio.

Equipment

One three phase step down transformer.
Connecting leads.
Multimeter or suitable voltmeter/s and ohmmeter.
Three phase lead.

Procedure

DANGER TAG PROCEDURE REQUIRED

1. Examine the three phase transformer supplied, identify and measure the ohmic values of the primary and secondary windings.

2. Complete Table 1, draw the circuit diagram with the correct terminal markings shown, and the PRIMARY winding connected in STAR.

Table 1

Resistances	A group coils	B group coils	C group coils
Primary			
Secondary			

Circuit Diagram

3. Connect the transformer in accordance with your circuit diagram. Ensure that the transformer frame is EARTHED.

4. Check the circuit for short circuits with an ohmmeter or multimeter.

5. Check with your Lecturer to ensure that:
   a. Your circuit diagram is correct.
   b. All connections are in accordance with the diagram.

6. Energise the circuit, measure and record the primary and secondary Coil voltages.

Table 2

	Coil Voltages	
	Primary	Secondary
A Phase		
B Phase		
C Phase		

7. From the voltage readings obtained calculate and record:

   a. The voltage ratio .... : ....

   b. The turns ratio .... : ....

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

9. Disconnect the circuit and return all of the equipment its proper place.

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Three Phase Transformer Connections

Note: Laboratory Project 4-1 must be completed before attempting this project.

Objective

To connect a three phase step down transformer in four different ways – Star : Star, Star : Delta, Delta : Delta & Delta : Star.
Calculate and measure the coil and output voltages of each connection.

Equipment

One three phase step down transformer.
Connecting leads.
Multimeter.
Three phase lead.

Procedure

DANGER TAG PROCEDURE REQUIRED

1. Examine the transformer supplied, and identify the primary and secondary terminals. Record the terminal markings on a circuit diagram.

Circuit Diagram

2. Connect the primary winding in STAR with a three phase lead connected to its line terminals, Ensure that the transformer frame is earthed.

3. Check the circuit for short circuits and have your connections verified by your Lecturer.

4. Energise the circuit with from the 415 V three phase supply. Measure the COIL voltages and record the ratios.

   Voltage ratio .... : ....

   Turns ratio .... : ....

Part 2

Note: Have your wiring checked by your Lecturer before switching the circuit on **EACH TIME**. Record your complete results in the following table.

5. Calculate the secondary LINE voltage if the transformer was connected STAR-STAR.

   Calculated Secondary Line Voltage: ....

6. Connect the secondary winding in STAR. Measure and record the secondary voltages.

   Measured Secondary LINE voltage: ....

   Measured Secondary COIL voltage: ....

7. Submit your results to your Lecturer for verification.

8. Calculate the secondary LINE voltage if the transformer was to be connected in the STAR - DELTA configuration.

   Calculated Secondary Line Voltage: ....

9. Connect .the secondary in DELTA with the 'closing connecition' open. Have your connections checked by your Lecturer.

10. Plug the circuit into a three phase outlet and measure the voltage across the closing connection. If the voltage across the closing connection is NOT zero, switch the circuit off and remove the plug from the outlet. Make the necessary circuit adjustment, then measure and record the secondary COIL VOLTS and LINE VOLTS. If there is a voltage across the closing connection ask your Lecturer how to correct it.

    Measured Secondary LINE Voltage: ....

    Measured Secondary COIL Voltage: ....

11. Reconnect the transformer DELTA to DELTA and then DELTA to STAR. Measure and record the COIL. VOLTS and the LINE VOLTS on the primary and secondary for each connection, then record in the results table.

12. Have your results checked by your Lecturer;

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

14. Disconnect your wiring and return the equipment to its proper place.

Results

Turns Ratio .... : .... Voltage Ratio .... : ....

Results Table

	Primary				Secondary			
	Line E		Coil E		Line E		Coil E	
	Calc	Meas	Calc	Meas	Calc	Meas	Calc	Meas
STAR: STAR								
STAR: DELTA								
DELTA: DELTA								
DELTA: STAR								

Connections

STAR-STAR STAR-DELTA DELTA-DELTA DELTA-DELTA

Questions

1. What effect does a 'reversed coil' have on the primary or secondary of a three phase transformer when connected in:

a. Star
b. Delta

2. Describe one method of correcting a reversed coil on a small three phase transformer.

3. Why is it necessary to check the 'closing connection' of a delta connected transformer?

4. Briefly describe the procedure for checking the Closing connection on a delta connected three phase transformer

5. Complete the general equations below:

In Star		In Delta	
Coil Volts		Coil Volts	
Line Volts		Line Volts	

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Transformer Characteristics

Task:

To describe operational characteristics of transformers in industry.

Why:

A general knowledge of the operational characteristics of transformers is useful during processes such as maintaining, testing, diagnosing faults and commissioning.

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:

Sample transformers
A.C. ammeters
A.C. voltmeters
Multimeters

References

* Electrical Principles for the Electrical Trades (6th ed.), Jenneson, J., Harper, B & Moore, B.
* Network operators' transformer data sheets.

Safety

You must demonstrate safe working practices at all times.

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Transformer Characteristics

Suggested Self Study Guide

1. Study the following sections in the recommended references:
   Electrical Principles for the Electrical Trades 6th Edition Volume 2
   Chapter 2 Transformers Operating Principles

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

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

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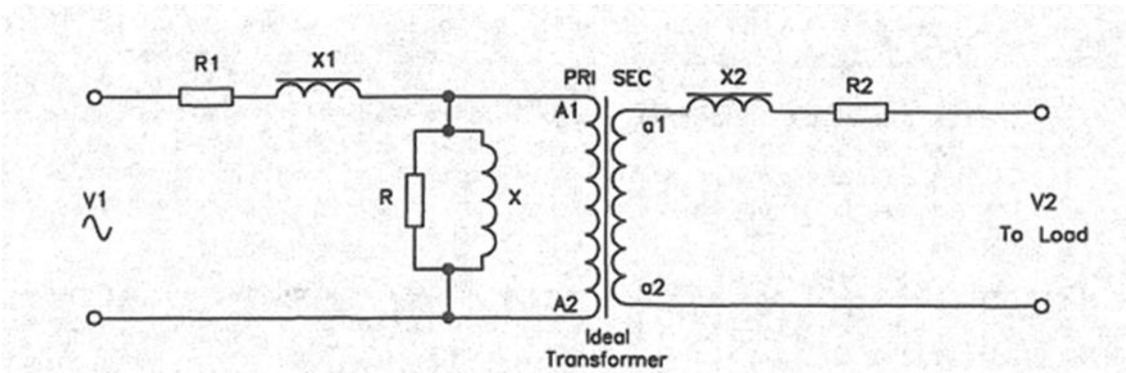
Transformer Characteristics

Equivalent Circuit

1. The behaviour of a transformer is sometimes considered by assuming it to be an ideal transformer (ie with no losses). Under these conditions a typical 'equivalent circuit' of a double wound single phase transformer can be represented by the following circuit

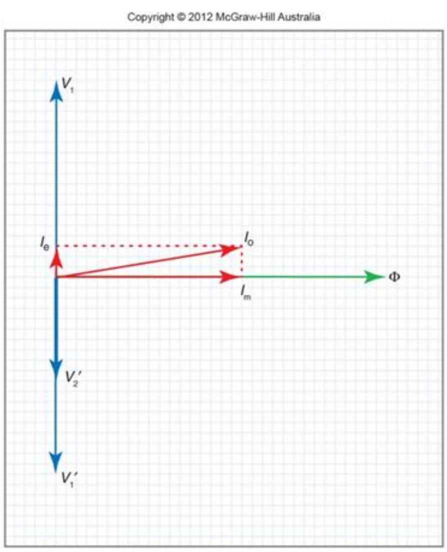


Where:
R1 and R2 are resistors equal to the resistance of the primary and secondary windings.
X1 and X2 represent the reactance of the windings.
X represents the path of the magnetising current (I_m) in the transformer
R represents the path of the core (Iron) loss current (I_e) in the primary circuit.

2. The resultant of I_m and I_e is the current drawn by the transformer on no load.

3. No-Load Conditions. A voltage is applied to the primary winding causes a small current to flow.

The phasor diagram shows the relationships of the magnetising current (I_m) and the Iron loss current (I_e). The phasor I_o is the total current drawn from the supply at no-load. A transformer operating at no-load has a very poor power factor.



Voltage Regulation

4. The voltage regulation of a transformer can be defined as the variation of the secondary voltage between no-load and full-load expressed as a percentage of the no-load voltage:

$$Voltage\ Regulation\ \% \quad = \quad \frac{No\ load\ voltage - Full\ load\ voltage}{Full\ load\ voltage} \quad X\ 100$$

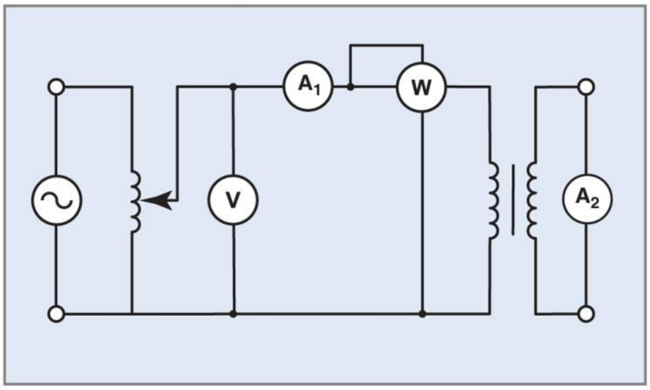
5. The voltage regulation of a typical power distribution transformer is around 4%.

Transformer Losses

6. The power losses which occur in a transformer on load can be divided into two groups - copper losses and iron losses.

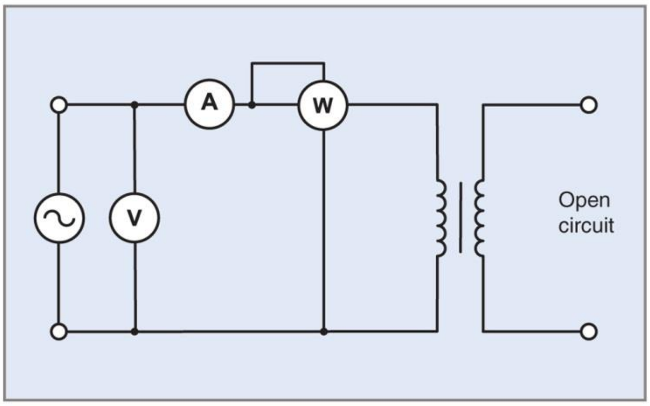
7. **Copper losses** are those which occur in the primary and secondary coils and they change as the current in the windings changes. Copper losses can be calculated using the equation P = I^2 x R where R is the d.c resistance of the winding. Copper losses are also known as I^2.R losses.

   Copper losses are measured with the following circuit. The wattmeter will show the power used (copper losses) by the transformer when the ammeter in the secondary circuit is measuring the full load current of the winding. The voltmeter in the circuit will show the test voltage (V_{PS}) when A_2 is measuring full load current. V_{PS} is used to calculate the transformer impedance percentage. This circuit is sometimes referred to as a 'transformer short circuit test'.



Transformer short circuit test circuit

8. **Iron losses** are eddy current and hysteresis losses in the transformer core and they are considered to be constant at all loads. Eddy current losses can be reduced during manufacture by laminating the iron core and hysteresis losses can be reduced by using a better quality iron in the core.
   Iron losses can be measured with the following circuit. The wattmeter in the primary will show the power absorbed by the iron core. This circuit is often referred to as a 'no-load' or open circuit test.



Transformer open circuit test circuit

9. The efficiency of a transformer is the ratio between the output power and the input power, usually expressed as a percentage. The input power is the output power plus all losses.

$$Efficiency\ \% \quad = \quad \frac{Output\ power\ (in\ watts)}{Input\ power\ (in\ watts)} \quad X\ 100$$

10. The efficiency of a given transformer is at maximum when the variable copper loss is equal to the constant iron loss.

11. The iron losses in a transformer are relatively constant over the full load rating, but the copper losses vary as the square of the load current ($P = I^2.R$). The efficiency of a transformer in which the load is constantly changing over a given period (such as in a typical distribution transformer) can be found by taking the average of the efficiencies over the nominated period.

Transformer Impedance Percent

12. Transformer impedance percent is defined as the percentage of primary voltage necessary to cause the rated full load current to flow in the secondary when the secondary terminals are short circuited. This value can be used to calculate the prospective short circuit current of three phase distribution transformers under fault conditions.
    A typical value of impedance percent for a distribution transformer is around 4-5%.

13. The following equation can be used to calculate the impedance percent from the results of a short circuit test:

$$Z\% \quad = \quad \frac{V_{PS}}{V_P} \quad \times 100$$

Where:
Z% = The transformer impedance percent.
V_{PS} = The test voltage applied to the primary winding with the secondary winding short- circuited and the full load current flowing in the secondary winding.
V_P = The rated primary voltage.

14. The full load current per phase of a typical 415/240 volt 500 kVA distribution transformer can be calculated as follows:

$$I_{FL} = \frac{kVA \times 1000}{\sqrt{3} \times V_P}$$

$$I_{FL} = \frac{500 \times 1000}{\sqrt{3} \times 415}$$

695.6 amps

15. The available short circuit current (I_{SC}) if the 415 volt 500 kVA transformer had a percentage impedance (Z%)of 5% would be:

$$I_{SC} = I_{FL} \times \frac{100}{Z\%}$$

$$I_{SC} = 695.6 \times \frac{100}{5}$$

13 912 amps

NOTE

All electrical workers working near or on distribution transformers, distribution switchboards and mains cables need to be aware of the dangerous level of fault current that power transformers will generate under fault conditions.

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Transformer Characteristics

1. Draw a typical equivalent circuit of a single phase step-down double wound transformer.
2. Calculate the voltage regulation of a single phase 1500 VA transformer if the no-load voltage is 100 volts and the full-load voltage is 96 volts.
3. Name two losses which occur in a typical transformer.
4. Which type of transformer loss varies as the load varies?
5. State the common names of the two tests which can be used to determine the efficiency of a transformer.
6. Name the two types of iron loss which occur in a typical transformer.
7. What is a typical value of efficiency of a single phase 1000 VA double wound step-down transformer.
8. Calculate the full-load efficiency of a 1500 VA single phase transformer if the iron losses are 20 watts and the copper loss is 40 watts.
9. Calculate the impedance percent of a 415 volt transformer if the primary voltage required to produce full load current with the secondary short circuited under test conditions is 20 volts.
10. Calculate the full load current and prospective short circuit current of a 200 kVA 415 volt three phase distribution transformer which as an known impedance percent of 4%.

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Percentage Impedance of a Transformer

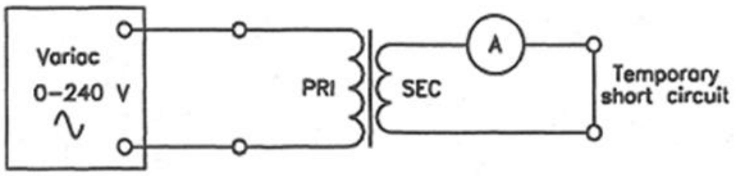
Objective

To determine the percentage impedance of a given single phase transformer.

Equipment

One single phase isolation transformer.
Suitable variable transformer (Variac)
Connecting leads.
Multimeter or suitable voltmeter/s and ohmmeter.
Single phase lead.

Circuit Diagram



Procedure

DANGER TAG PROCEDURE REQUIRED

1. Connect the transformer as shown in the circuit diagram.
   Note the full load current rating on the name-plate of the transformer secondary winding:

   Rated full load secondary current: amps.

2. Short circuit the secondary of the transformer.

4. Check the circuit for short circuits with an ohmmeter or multimeter.

5. Check with your Lecturer to ensure that all connections are in accordance with the diagram.

6. Set the Variac to the lowest voltage position. Energise the circuit and increase the primary voltage until the secondary current is equal to the rated full load current.
   Measure the primary voltage (V_{PS}) and the secondary current. Record the values in Table 1.

Table 1

Rated full load secondary current	
Rated primary voltage (V_P)	
Measured primary voltage at full load secondary current (V_{PS})	
Calculated impedance percentage	

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

8. Calculate the impedance percentage of the transformer and record the result in the Table.

9. Have your results checked by your lecturer.

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

Question

Does your calculation demonstrate that the transformer you tested has an impedance percentage of between 4% and 5%?

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 5 Activity Sheet 2	G006A SGB 02/2010

Transformer Efficiency

Objective

To determine the efficiency of a given single phase transformer.

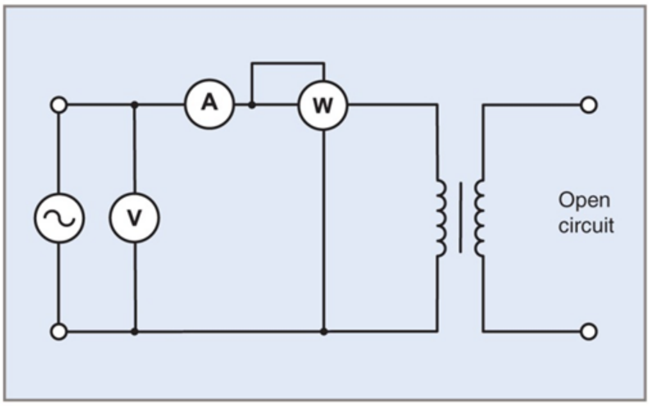
Equipment

One single phase 50 Hz double wound transformer.
Suitable variable transformer (Variac)
Multimeter
Suitable a.c. ammeters
Suitable single phase wattmeter
Single phase lead
Connecting leads.

Procedure

DANGER TAG PROCEDURE REQUIRED

Part A - Open Circuit Test



1. Examine the double wound transformer and record the following details from the nameplate or equivalent in Table 1

Table 1

	Nameplate Data	
1	Primary voltage	
2	Secondary voltage	
3	Transformer VA rating	
4	Secondary full load current	

2. Connect the circuit as shown in the circuit diagram. Note that a multimeter is to be used for all voltage readings.

3. Check your circuit for short circuits with a multimeter.

4. Have your wiring checked by your lecturer.

5. Energise the circuit and record the following readings with the secondary open circuited:

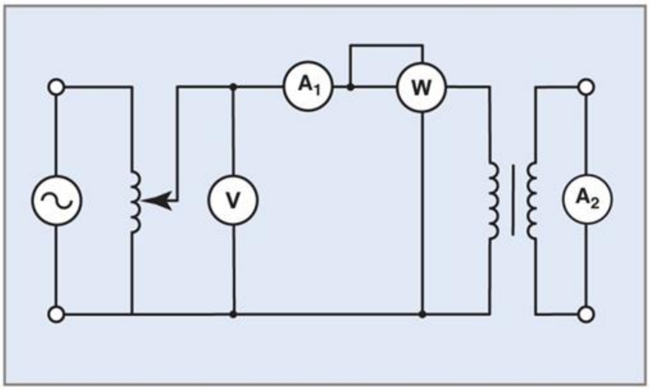
Table 2

	Open Circuit Test Results	
1	Primary Voltage	
2	Primary Current	
3	Input power as indicated on the wattmeter	

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

Part B - Short Circuit Test



1. Re-connect the transformer as shown in the circuit diagram with a short circuit across the secondary winding of the transformer. Note that a multimeter is to be used for all voltage readings.

2. Check the full load current rating of the transformer secondary winding:

Rated full load secondary current: amps.

3. Check your circuit for short circuits with a multimeter.

4. Have your wiring checked by your lecturer.

5. Set the Variac to the lowest voltage position. Energise the circuit and increase the primary voltage gradually until the secondary current is equal to the rated full load .current. Measure the primary voltage and input power and record the values in Table 3.

Table 3

	Short Circuit Test Results	
1	Secondary current (I_S)	
2	Measured primary voltage at full load secondary current (V_{PS})	
3	Input power as indicated on the wattmeter	

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

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

Calculation

Note: For the purposes of this project, the wattmeter reading in the open circuit test can be taken as the transformer iron loss and the wattmeter reading in the short circuit test can be taken as the transformer copper loss.

1. Calculate the approximate efficiency percent of the transformer using the following equation (disregarding power factor):

Efficiency% $= \frac{Power\ out}{Power\ in}$ X 100

Rated input = VA

Rated output = VA – (Copper Losses + Iron Losses)

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 6 Introduction	G006A SGB 12/2013

Three Phase Induction Motors

Task:

To describe the construction and operation of single speed three phase induction motors and connect them to a suitable three phase supply.

Why:

Three phase induction motors are among the most common type of electrical machines used in industry. You need to have knowledge of their construction and general principles of operation so that you can recognise them, safely connect them to a suitable supply, reverse the direction of rotation, and diagnose and correct simple electrical or mechanical faults.

To Pass:

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

Equipment:

Sample three phase squirrel cage induction motors up to about 5 kW.
Sample three phase wound rotor induction motors up to about 3 kW.
Handtools for stripping and assembling three phase induction motors.
Multimeter.
Internal and external growler.
AC clip-on and fixed ammeters.
High voltage insulation tester.

References:

* Electrical Principles for the Electrical Trades (6th ed.)Jenneson, J.R, Harper, B & Moore, B.

Safety:

You must demonstrate safe working practices at all times.

	Solve problems in single phase and three phase low voltage machines	Section 6 Study Guide	G006A SGB 12/2013
Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 6 Study Guide	G006A SGB 12/2013

Three Phase Induction Motors

Suggested Self-Study Guide

1. Study the following sections in the recommended references: Electrical Principles for the Electrical Trades Volume 2
   Chapter 3
   – Section 3.1 Mechanics of Electrical machines

   Chapter 5
   - Section 5.1 Three Phase Induction Motors

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 Activity Sheets 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 single phase and three phase low voltage machines**	Section 6 Summary 6.1	G006A SGB 12/2013

Three Phase Induction Motors

Motor Enclosures

1. Electric motor enclosures are available in many different types of enclosure to suit particular applications. There are three basic types of enclosure with several variations of each type, but the modern trend is to concentrate on protected and totally enclosed types mainly.

The types are:

a **Enclosed**

(i) Those in which there is no restriction to ventilation other that necessary for good mechanical construction (previously known as OPEN machines).

(ii) Those in which the inlet and outlet air ducts are covered with a screen of perforated or expanded mesh, the openings of which have an area of at least 0.645 square centimetres (previously known as SCREEN PROTECTED).

(iii) Those in which ventilation openings are so protected as to exclude vertically falling water or dirt (previously known as DRIP PROOF).

b. **Totally Enclosed** This type includes:

(i) Machines constructed so that the air enclosed has no connection with the external air duct but is not necessarily 'air tight' - cooling is effected by circulating the air within the frame (TOTALLY ENCLOSED).

(ii) Machines that are totally enclosed, but cooling is augmented by a fan, driven by the motor itself, blowing external air over the cooling surfaces and/or through the cooling passages. The fan is covered by a cowl which is often extended to cover the motor completely to give more effective cooling (TOTALLY ENCLOSED FAN COOLED (TEFC).

(iii) A machine in which there is a continuous supply of fresh ventilating air, the frame being so arranged that the ventilating air may be conveyed to and/or from the machine via pipes or ducts (PIPE OR DUCT VENTILATED).

c. **Flameproof**

Machines designed to comply with the relevant Australian Standards for flameproof machines.

Motor Construction

2. An exploded view of a SIEMENS three phase TEFC squirrel cage induction (SCI) motor is shown in Figure 1. Parts A to J are labelled on the diagram.

   a. Drive-end end shield
   b. Rotor and rotor winding (squirrel cage type) on a shaft.
   c. Terminal box
   d. Stator core with 415 volt 50 Hz insulated winding.
   e. Mounting feet.
   f. Bearing.
   g. Non-drive-end end shield.
   h. Main external cooling fan.
   i. Cowl for external cooling fan.
   j. Terminal block.

3. Exercise
   Examine the exploded view in Figure 1. Label the following parts on the diagram if they are shown:

   a. Frame or carcase.
   b. Drive-end keyway.
   c. Lubrication points
   d. Supply cable entry point.
   e. Eyebolt.
   f. Pulley or drive gear (usually keyed to the shaft).
   g. Internal cooling fan.
   h. Earthing terminal.
   i. Nameplate.
   j. Bearing housings.
   k. Bearing cap.
   l. Wave washer.
   m. Circlips.
   n. Flange mounting.

4. Name any other parts can you find on the diagram, or any other parts you would expect to find on a typical three phase squirrel cage induction motor.

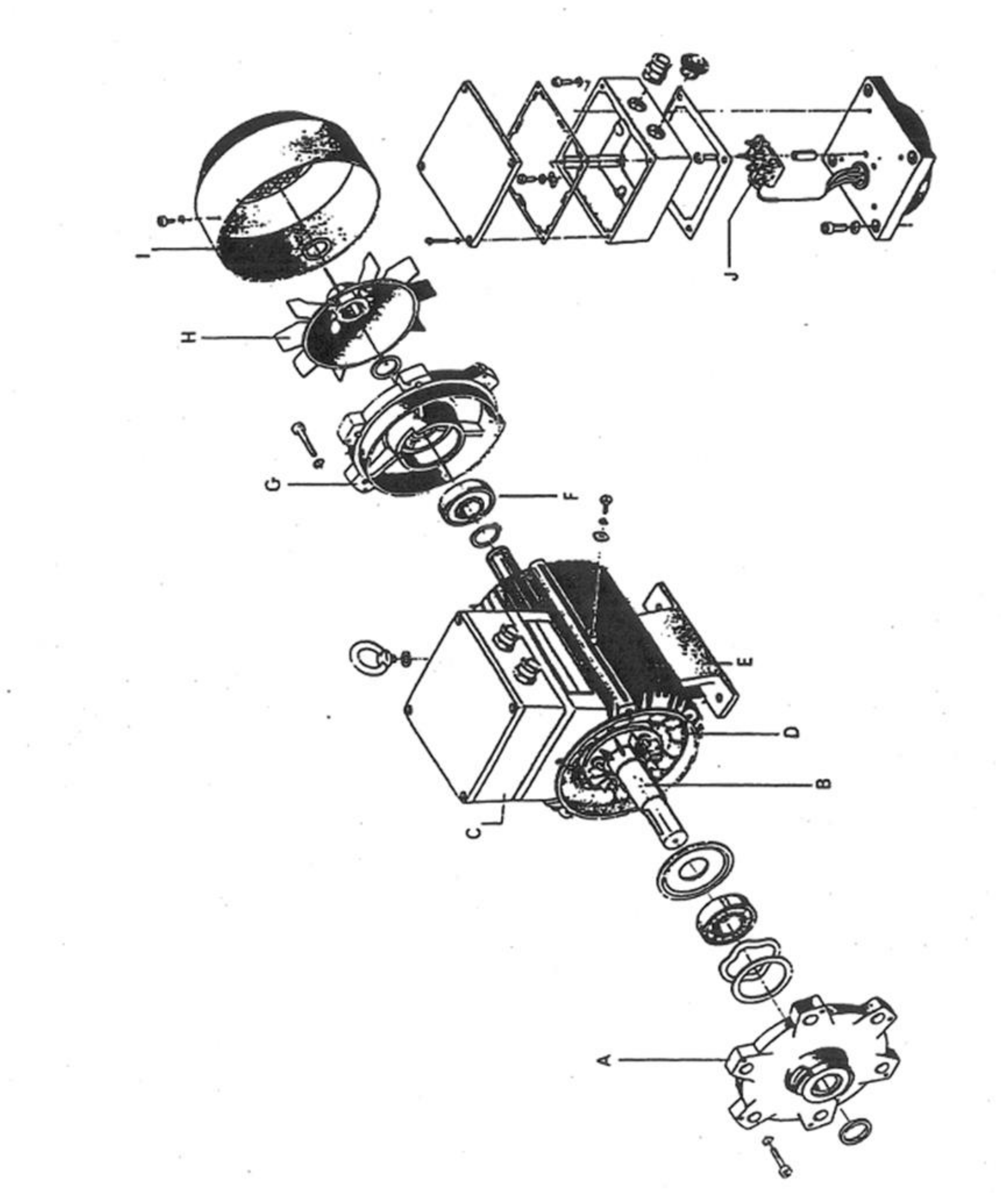


Figure 1 - Exploded view of a SIEMENS three phase TEFC SCI motor.

Three Phase Motor Connections

5. Two basic connections are common in three phase squirrel cage induction motors- the STAR connection and the DELTA connection. Some motors are internally connected in either star or delta, and have THREE input line terminals. Others are designed to be started in star, then switched to delta for full load running - these have SIX line terminals. Most three phase squirrel cage induction motors are single insulated so they must be earthed, but do not require a neutral.

6. The basic star and delta connections are shown in Figure 2.

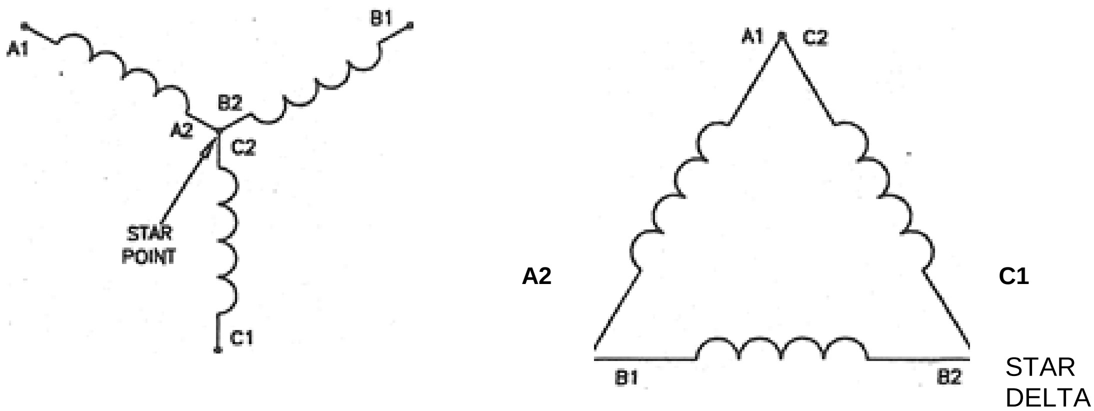


Figure 2 – The basic star and delta motor connection

7. Three Terminal Motors
These have three input line terminals on the terminal block. Typical terminal markings for the three terminals are A, B and C or U, V and W. They also have provision for earthing the frame of the motor. The three incoming line leads (L1, L2 and L3 or RED, WHITE and BLUE) are connected to the three input terminals. The European (DIN) standard markings for the terminals on a three terminal three phase squirrel cage induction motor are U, V and W. Figure 3 shows a typical three terminal motor connected to the three phase supply.

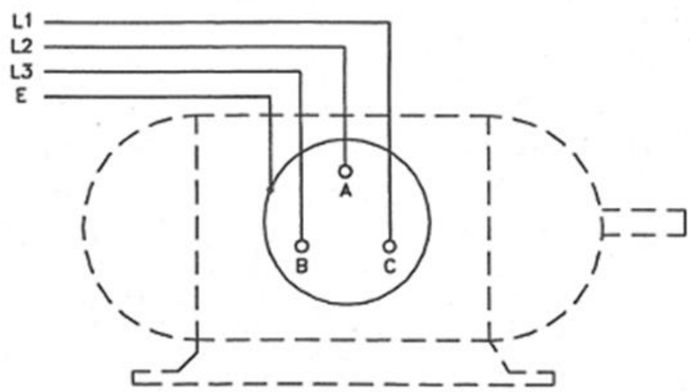
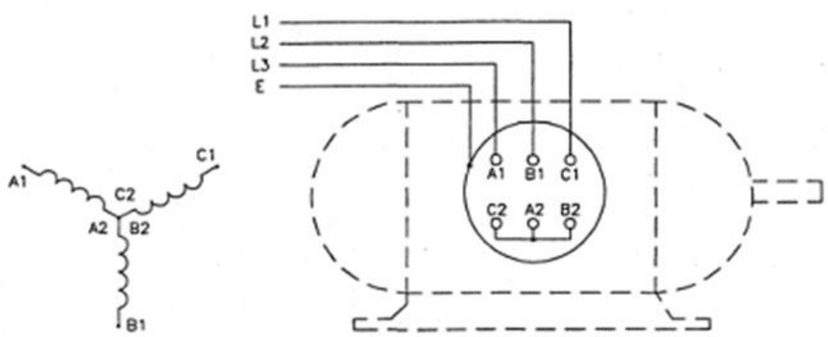


Figure 3 – Typical three terminal motor connections.

8. Six Terminal Motors.
These have six terminals connected to the stator winding. Typical terminal markings are A1, A2, B1, B2, C1, C2 (or U, V, W, X, Y, Z or U1, V1, W1, U2, V2, W2 if they are of European (DIN) origin). They are usually designed to be run in delta for full load operation, but they can be run in star for starting or off load testing purposes.

The type of full load connection for which they have been designed should be shown on the motor nameplate. The basic star and delta connections for a typical six terminal motor are shown in Figure 4.

a. **Star Connection**



b. **Delta Connection**

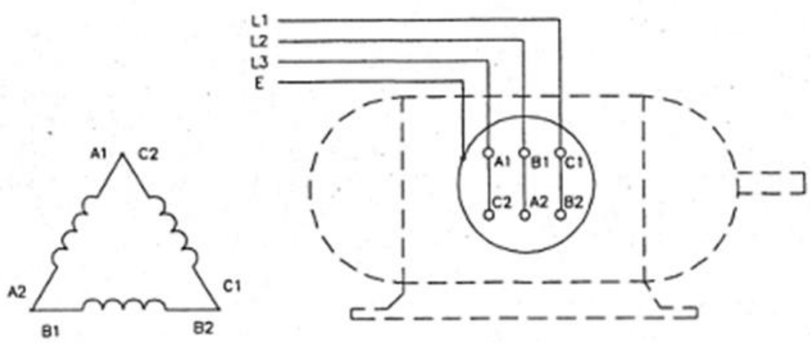


Figure 4 – Basic star and delta motor connections.

9. You should always check the motor nameplate to make sure that the motor is suitable for the supply you are about to connect it to. Most three phase squirrel cage induction motors in common use are designed for 415 volts, 50 Hz, but motors with other voltages may be found in special applications - particularly self-contained machinery of foreign origin.

10. All induction type motors are designed for a.c. operation only - they must not be connected to a d.c. supply unless there is a special reason (such as d.c. injection braking), in which case special additional control equipment is required.

Nameplates

11. The information on a typical electric motor nameplate includes:

   a. The manufacturer's name and the model and serial number of the machine.
   b. The nominal voltage for which the stator winding was designed.
   c. The number of phases and the designed frequency. Three phase motors are usually marked to indicate whether they have been designed for STAR or DELTA operation.
   d. The continuous maximum power rating of the motor in watts or kilowatts. Older motors or motors of foreign origin may have the power rating expressed in the imperial unit horsepower - 1 horsepower is equivalent to 746 watts.
   e. The maximum continuous line current the motor is designed to draw (full load current or FLC) per phase. If this full load current is exceeded the motor is said to be overloaded. If the motor starter has an overload sensing mechanism, the overloads should usually be set to the maximum current rating of .the motor.
   f. The designed speed of the motor on FULL LOAD.
   g. The maximum permissible temperature rise when the motor is operating on full load.
   h. The 'class' of insulation used in the motor winding.

Operating Voltage

12. The main electrical distribution system in W.A. changed from 440/250 volts to 415/240 volts in about 1988, so there a still many motors in service with 440 volts marked ,on the nameplate. Most 440 volt motors will operate satisfactorily on 415 volts and visa versa. The nominal distribution voltages for the Eastern States are 400/230 volts.

Reversal

13. To reverse the direction of rotation of a three phase motor it is necessary to isolate the supply and swap over any two incoming supply conductors.

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 6 Work Sheet 1	G006A SGB 12/2013

Three Phase Motor Construction & Connections

1. List the three basic types of electric motor enclosure.
2. List 10 major parts of a three phase squirrel cage induction motor.
3. What are the two basic types of mounting provided on electric motors?
4. What is the name given to the rotating component in a three phase motor?
5. What is the name of the most common type of general purpose three phase motor?
6. What part of an electric motor enables details such as type, speed, current and connection to be determined?
7. What terms are used to distinguish between the two 'ends' of a typical three phase motor?
8. How are the vee pulleys normally secured to the shaft of a three phase electric motor?
9. What type of three phase motor usually has a cooling fan mounted on the shaft OUTSIDE the end shield?
10. What does the abbreviation 'SCI' stand for when used in relation to electric motors?
11. What are the two basic connections used for connecting the stator winding in a three phase motor?
12. What is the standard line voltage for three phase motors in W.A.?
13. What is the standard line voltage for three phase motors in the eastern states of Australia?
14. If a standard three phase motor is INTERNALLY connected in STAR, how many line terminals will it have at the terminal block?
15. If a standard three phase motor is INTERNALLY connected in DELTA, how many line terminals will it have at the terminal block?
16. To which internal part of a standard three phase motor are the line terminals connected?
17. Does a three phase SCI motor have any electrical connections to the rotor?
18. How can the direction of rotation of a three phase induction motor be reversed?
19. If a standard three phase motor has SIX line terminals, would you expect it to be designed for star or delta operation on full load?
20. What are the Australian standard terminal markings on a three terminal three phase induction motor?
21. What are the Australian standard terminal markings on a SIX terminal three phase induction motor?

22. Would it be safe to connect a 440 volt 50 Hz three phase motor to a 415 volt 50 Hz three phase supply?

23. What are the European (DIN) standard terminal markings on a standard three terminal three phase induction motor?

24. What are the European (DIN) standard terminal markings on a standard SIX terminal three phase induction motor?

25. Is it permissible to terminate an earthing conductor under one of the mounting bolts used to hold an electric motor in position? Provide AS/NZS3000 clause number.

26. Does a STAR connected three phase motor require a neutral?

27. What is the TOTAL number of conductors required to connect a typical three phase SCI motor to the supply?

28. What is the reason that most three phase motors must be earthed?

29. Is it permissible to install a three phase motor with all line conductors of the SAME active colour?

30. List FIVE items of information which would be found on the nameplate of a three phase SCI motor.

31. Draw a wiring diagram showing a SIX terminal three phase motor terminal block connected to the 415 volt mains in STAR. Label all terminals.

32. Draw a wiring diagram showing a SIX terminal three phase motor terminal block connected to the 415 volt mains in DELTA. Label all terminals.

33. Draw TWO simple circuit diagrams - one showing a three phase stator winding connected in STAR, and the other showing the same winding re- connected in DELTA. Label the ends of each coil group on both diagrams.

34. What is another name for a STAR connection?

35. What is another name for a DELTA connection?

36. What four safety precautions must be taken before attempting to work on a typical three phase motor which is installed with fixed wiring?

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 6 Activity Sheet 1	G006A SGB 12/2013

Three Phase Induction Motor Construction

Objective

To identify the.major parts and features of a typical 415 volt three phase squirrel cage induction (SCI) motor.

Equipment

Three phase single speed squirrel cage induction motor up to about 5 kW.
Suitable parts tray.
Hand tools as required.
High voltage insulation tester.
Multimeter.
Suitable bearing pullers.
Felt tip marking pen.

Procedure

Note! Minor variations to this procedure may be necessary for different types of motor.

1. Make sure that the motor is not connected to the supply.

2. Examine the three phase squirrel cage induction motor provided and record all nameplate details. Record the general type of construction of the motor, and the intended mounting position (e.g. foot mounted or flange mounted).

Nameplate Details

Type of Construction Mounting Position

3. Mark the position of both end shields (and the cowling if fitted) in relation to the stator carcase using a felt pen. Use one line for the drive end and two lines for the non-drive end. Note that in industry it is common to mark the position of the end-shields with small centre punch marks.

4. Plan the job - decide on the general sequence in which the motor should be dismantled. If the bearings are of the ball or roller type with bolted bearing caps, the bearing caps should be removed first, otherwise the end shield retaining bolts should be removed first. All parts must be placed in a parts tray.

5. Carefully loosen both end shields and remove the non-drive end end-shield. Leave the drive-end end-shield on the bearing.

6. Withdraw the squirrel cage rotor, taking care not to allow it to touch the stator winding at any time (if you are not careful you. could damage the stator winding with the rotor or the shaft).

7. Remove the bearings from the shaft with a bearing puller.

8. Examine the parts of the motor and answer the following questions:

   a. What metal are the end shields made from?

   ---

   b. What type of fasteners are used to secure the end shields to the stator carcase (e.g. bolts, through bolts, socket-head screws)?

   ---

   c. What type of bearing is used on the drive end of the motor?

   ---

   d. What type of bearing is used on the non-drive end of the motor?

   ---

   e. What is the identification number on the drive-end bearing (if it is a ball or roller type)?

   ---

   f. What is the identification number on the non-drive-end bearing (if any)?

   ---

   g. What type of material is the stator core made from?

   ---

h. What type of material is the rotor core made from?

i. What type of material is the rotor winding made from?

j. How many slots are there in the stator?

k. How many coils are there in the stator winding?

l. What material is the terminal block made from?

m. How many line terminals are there on the terminal block and how are they marked?

n. Is the motor designed for star or delta operation?

o. How many screws (or bolts) are used to retain the drive end bearing cap (if any)?

p. What size is the conduit entry to the terminal box (if any)?

q. Where is the main cooling fan located?

r. Are the bearings the tightest fit on the shaft or in the end-shields?

s. Are the rotor bars parallel to the rotor shaft?

9. Draw a diagram of the motor terminal block, then measure and record the dc resistances between each pair of resistances.

10. Measure and record the, insulation resistance of the stator winding.

11. Re-assemble the motor taking care not to damage any components or force them into position.

12. Have your answers and results checked by your Lecturer.

13. Return all of the equipment to its proper place.

Questions

1. Does a three phase squirrel cage induction motor require a neutral at the terminal block?

2. Refer to your results relating to the resistance between phases at the terminal block. Calculate the expected line current on 415 volts if the opposition to current flow was the value you measured (using Ohm's Law). Was the actual line current anywhere near your calculated value? If not, why not?

3. What is the minimum permissible insulation resistance for a three phase motor which is to be operated on a normal 415 volt three phase supply?

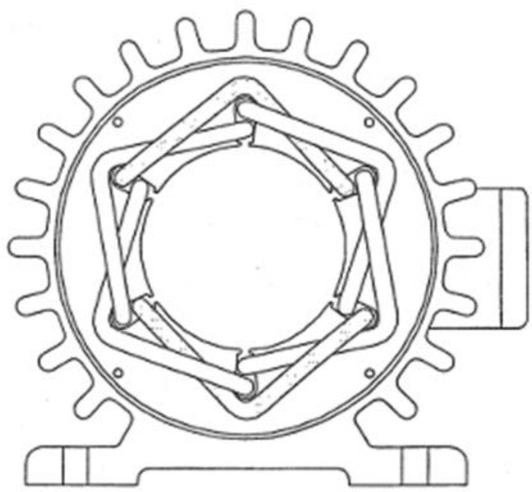
Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 6 Summary 6.2	G006A SGB 12/2013

Three Phase Induction Motor Operation

1. A typical three phase squirrel cage induction motor stator winding consists of a series of coils of insulated copper wire connected in such a way that magnetic poles are formed on the internal surface of the laminated stator core. The winding for each of the three phases is usually identical, but the method used to place them in the stator slots is such that the coils associated with each phase are not readily identifiable (this is known as a 'distributed' stator winding).

2. The coils associated with each phase are usually connected in series so that each phase winding forms an identical even number of magnetic poles on the internal surface of the laminated stator core. The number of poles formed on the stator core (per phase) is a major factor in determining the no-load speed of the motor. The three windings are physically positioned so that they are at 120 electrical degrees to each other, and they are usually referred to as the A phase, the B phase and the C phase.

3. A two pole three phase squirrel cage induction motor stator winding usually has six sets of coils (two for each phase). A simplified diagram of a two pole stator winding is shown in Figure 1. The coils are internally connected so that the two coils associated with each phase form magnetic poles of opposite polarities on opposite sides of the stator core.



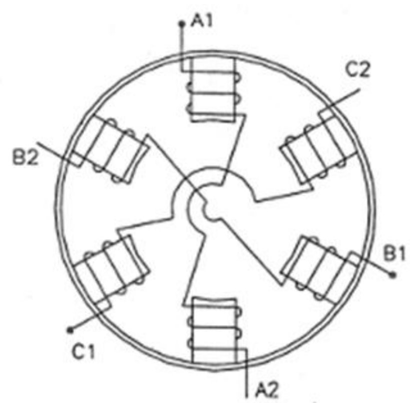


Figure 1 – Simplified two pole stator winding coil arrangement

4. In a six terminal motor the six ends of the coil groups are brought out to the terminal block, in a three terminal motor appropriate coil group ends are connected together internally in star or delta, and three leads are brought out to the terminal block.

5. When a three phase supply is connected to the stator winding the continually changing applied voltage results in groups of magnetic poles being formed in a particular sequence on the internal surface of the stator; the magnetic field of each coil group combines with the two others to form one overall north pole and one overall south pole (for a two pole machine). If the machine is designed for four pole, four overall poles would be formed.

The Rotating Magnetic Field

6. Since the three phase a.c. supply voltage is continually changing in both magnitude and direction the polarity and strength of the resulting magnetism is continually changing. The continually changing magnetic field resulting from the changing current in the coils causes the axis of the two main magnetic poles to move at a constant rate around the inside of the stator core. This changing magnetic field is known as the ROTATING MAGNETIC FIELD (RMF).

7. One method of showing how the rotating magnetic field is produced in a two pole three phase stator winding is shown in Figure 2. A simplified representation of the stator connections is shown beside one complete cycle of the line currents from a three phase supply. The portions of the sine wave above the horizontal axis are assumed to represent currents flowing into the winding, and the portions below represent current flowing out of the winding. The six numbered vertical lines indicate the instant in time depicted by the six diagrams of the stator which have corresponding numbers.

8. For the purposes of this explanation, current flowing INTO a stator coil (as indicated by the small arrows) is assumed to result in a north pole, and current flowing OUT of the coil is assumed to result in a south pole. Notice that at the point in time indicated by each numbered vertical line, current is flowing in one direction in one of the phases, and in the opposite direction in each of the other two phases.

9. At the instant numbered 1, current is flowing IN in the A phase and the C phase, and OUT in the B phase, resulting in magnetic poles as shown. Three adjacent north poles are formed and three adjacent south poles are formed, so the axis of the resulting combined magnetic poles is in the direction indicated.

10. At the instant numbered 2, current is flowing IN in the A phase and OUT in the B phase and the C phase, resulting in magnetic poles as shown. The polarity of the poles in the C phase have reversed, so the axis of the resulting combined magnetic poles has shifted by 30 degrees in a clockwise direction.

11. If you examine the direction of current at each numbered instant, and the corresponding magnetic poles, you will see that in one complete cycle the axis of the combined magnetic poles has rotated one complete revolution.

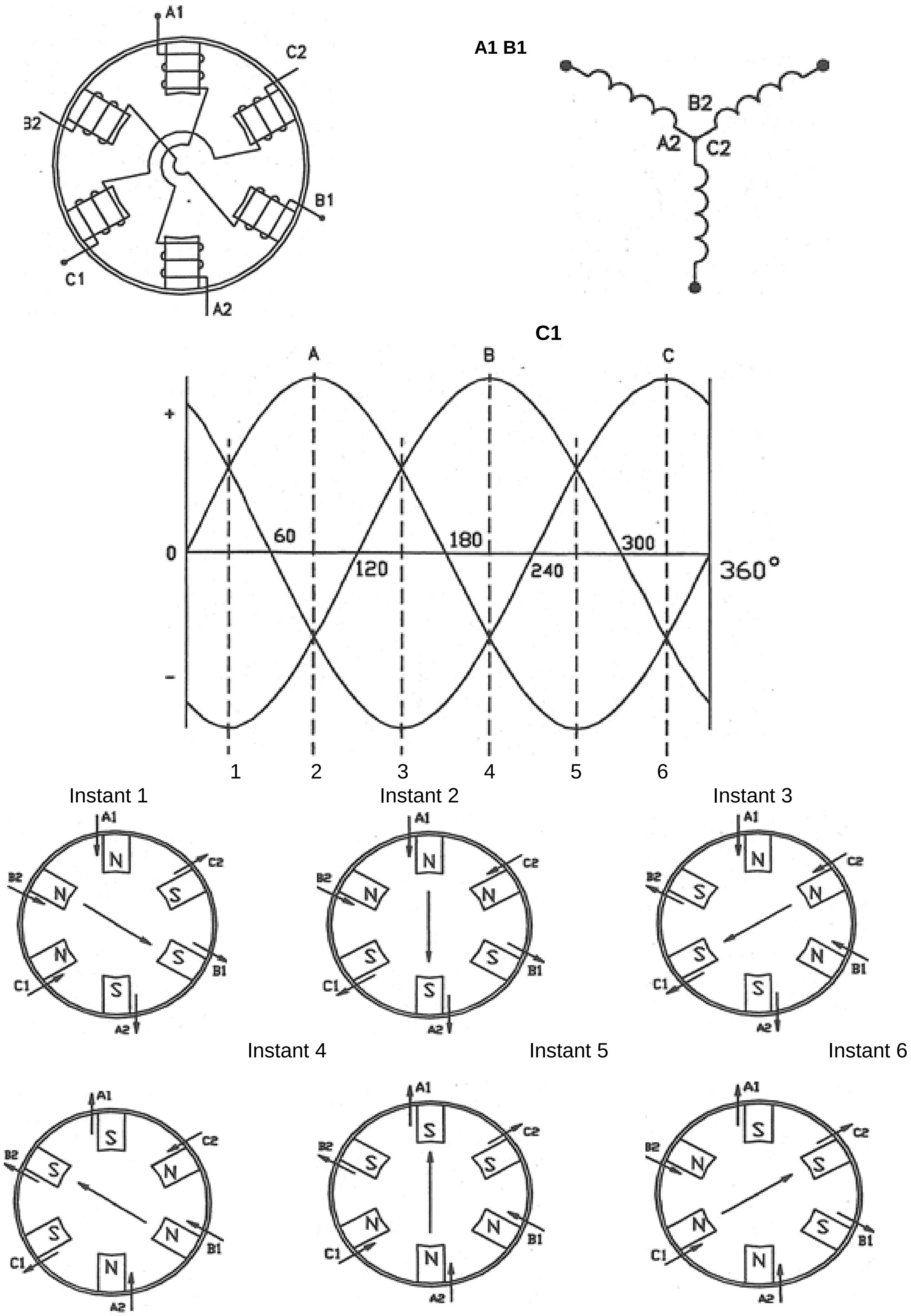


Figure 2 – Three phase rotating magnetic field

12. If the direction of the rotating magnetic field was reversed, the direction of rotation of the rotor would be reversed. The direction of the rotating magnetic field is reversed by reversing .any two of the three incoming supply conductors.

13. In a two pole motor the rotating magnetic field completes one revolution for every full cycle of the three phase supply voltage. Since the supply frequency is 50 Hz (50 cycles per second), the magnetic field rotates 50 x 60 or 3000 times per minute. The speed of the rotating magnetic field is the main factor which determines the speed of a three phase squirrel cage induction motor, and it is known as the 'synchronous speed'.

14. A similar relationship exists in a three phase squirrel cage induction motor which has any even number of poles, so the SYNCHRONOUS speed of a motor can be calculated from the equation:

$$N_{syn} = \frac{f \times 120}{P}$$

Where:

N_{syn} = Synchronous speed (revolutions per minute – rpm)

f = Frequency of supply voltage

120 = Constant (conversion from seconds to minutes and relationship between magnetic poles and windings)

P = The number of poles per phase in the stator

15. Example Calculate the speed of the rotating magnetic field in a three phase 6 pole squirrel cage induction motor on 50 Hz.

$$N_{syn} = \frac{f \times 120}{P}$$

$$N_{syn} = \frac{50 \times 120}{6}$$

= 1000 r/min

16. Exercise Calculate the speed of the rotating magnetic field in a three phase 4 pole squirrel cage induction motor on 50 Hz. What would be the synchronous speed of the same motor if it was connected to a 60 Hz supply?

17. The speed you calculate using the equation above is NOT the speed of the rotor; rotor speed is the synchronous speed less 'slip' - slip is explained a little later.

Squirrel Cage Rotor

18. The typical squirrel cage rotor consists of comparatively large bars of conducting material (usually aluminium) cast into the slots in the rotor and joined at each end of the rotor with conducting 'end rings'. No insulation is necessary between the rotor bars and the laminated steel rotor core because the rotor winding has a much lower resistance than the rotor core. An outline of the construction of a typical squirrel cage rotor is shown in Figure 3, but you should bear in mind that rotor bars and end rings can have other shapes and they can be made from other materials (such as copper).

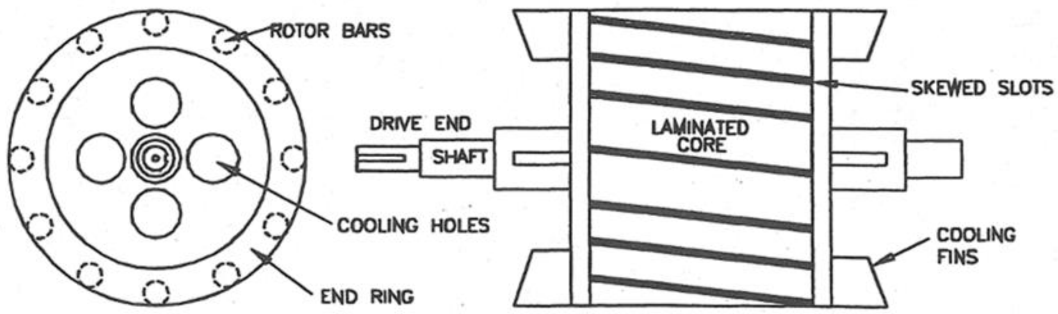


Figure 3 - Typical squirrel cage rotor construction

Operation

19. When the rotor is stationary, the alternating current in the stator winding induces a current in the rotor winding in the same way as current is induced in the secondary of a transformer even though there is no electrical connection. The current in the rotor is high because it has a low number of turns compared to the turns on the stator. A significant difference between the operation of a transformer and the current induced in a rotor is that the frequency of the current in the rotor decreases as the rotor speed increases - it is the same as the supply frequency when the rotor is stationary, and almost zero when the motor is running on no load.

20. The magnetic flux caused by the stator current interacts with the magnetic flux caused by the rotor current in such a way that the rotor moves in the direction of the rotating magnetic field. Some rotors have the rotor bars set at an angle to the axis of the rotor; these rotors are said to have 'skewed' slots. Skewed slots result in a smoother torque from the motor and reduced magnetic noise.

21. As the rotor speeds up the frequency of the current in it decreases; if the rotor reached the same speed as the rotating magnetic field there would be no relative movement between the speed of the rotating magnetic field and the rotor winding, therefore there would be no current induced in the rotor - if there was no current in the rotor there would be no magnetic flux to react with the stator flux, so it is impossible for the rotor of a three phase squirrel cage induction motor to be turning at synchronous speed (unless it is driven by some other means).

22. If the motor is on no load, the rotor speed up until there is just enough magnetic interaction to overcome bearing friction and wind friction on the rotor, and the speed stabilises at a value a few revolutions per minute slower than synchronous speed (at about 2995 rev/min in a two pole machine). At this point the frequency of the current in the rotor is very low, the rotor current is low, and the corresponding stator current is low.

23. As load is applied to the motor, the magnetic interaction between the rotor flux and the stator flux is no longer sufficient to maintain the rotor speed so the rotor slows down. As the rotor slows down the rotor frequency increases, causing a corresponding increase in rotor current and a corresponding increase in stator current. When the load on the motor reaches a value

which results in the stator current reaching its maximum designed value the motor is said to be running on full load.

24. The difference between synchronous speed and full load speed is known as the 'slip' and is usually expressed as a percentage. A typical value of slip for a three phase squirrel cage induction motor is between 4 and 6% of synchronous speed on full load. The slip is 100% at the instant the motor is switched on (before the rotor begins to rotate). The value of slip for a particular motor is set by the designer of the motor.

25. Example
Find the no load and full load speed of a 415 volt 50 Hz two pole three phase squirrel cage induction motor if it has 4% slip on full load.

$$N_{syn} = \frac{f \times 120}{P}$$

$$N_{syn} = \frac{50 \times 120}{2}$$

3000 revolutions per minute (r/min)

Full load speed = Synchronous speed - slip

3000 - (4% of 3000)

3000 - 120

2880 r/min

26. Exercise
Find the no load and full load speed of a 415 volt 50 Hz four pole three phase squirrel cage induction motor if it has 5% slip on full load.

27. Thus the three factors which govern the full load speed of a three phase squirrel cage induction motor are:
a. The number of poles (speed increases as poles decrease).
b. The frequency of the supply (speed increases as frequency increases).
c. The amount of load on the motor (speed decreases as load increases).

Torque

28. The starting torque of a standard three phase squirrel cage induction motor is low compared to some other types of three phase-motor because there is a considerable phase difference between the current in the stator and the current in the rotor (because the rotor circuit is more inductive that the stator circuit).

28. The starting and running characteristics of a particular motor depend on the purpose for which it has been designed, and many variations are possible. The variations are intended to provide the required performance characteristics such as starting torque, full load torque, pull-out torque, starting current, full load running current and overall efficiency. These characteristics are determined by the manufacturer and are rarely adjustable by the electrician, but you need to be aware that one particular three phase squirrel cage induction motor may have the same power rating as another, but its operating characteristics could be completely different.

29. The manufacturer can vary the performance characteristics of a motor by altering the resistance of the rotor winding, by varying its reactance by altering its physical position in the rotor, by varying the shape of the rotor bars, or by providing more than one rotor winding. Some rotors have skewed rotor bars to provide a smoother torque and reduce magnetic noise.

30. The torque produced by an induction motor is proportional to the square of the applied voltage ($\boldsymbol{T} \propto \boldsymbol{V^2}$). This means that if the applied voltage is reduced to 50% of the designed value, the starting torque is reduced to 50% squared or 25% (50% squared is 50% of 50%, which is 25%),

31. There are two major type variations from the standard three phase squirrel cage induction motor; the double-cage squirrel cage motor and the wound rotor motor.

The Double Cage Rotor

32. A three phase double squirrel cage induction motor rotor has two squirrel cage windings instead of one. One winding is embedded deep in the rotor core and the other is closer to the surface of the rotor core; both windings are connected to the same end rings. The second rotor winding is not usually visible so it is not usually possible to distinguish a single cage rotor from a double cage rotor without reference to manufacturer's data. Figure 4 shows how double cage rotor bars can be arranged in a rotor.

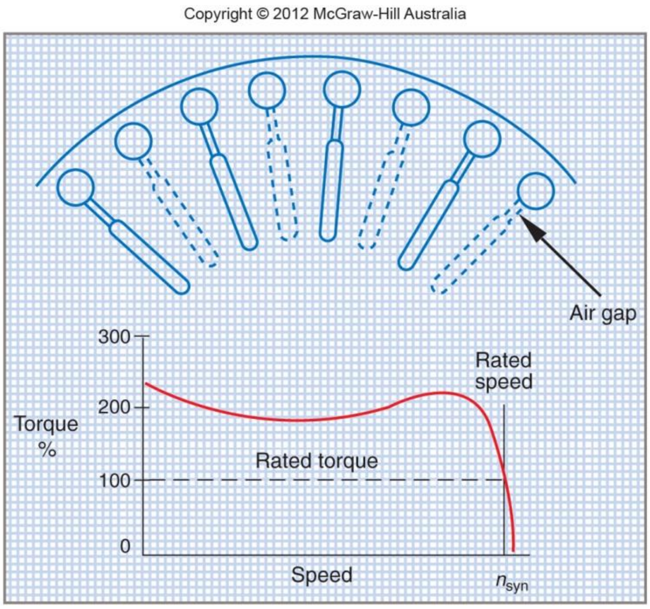


Figure 4 – Double squirrel cage rotor. Used in applications requiring high starting torque

33. The winding which is embedded deeper in the rotor has more inductance than the outer winding, and the outer winding has more resistance. The outer winding provides greater starting torque and the inner winding provides good running torque, but the higher resistance of the outer winding results in a lower overall efficiency for the motor because of the increased copper losses in the rotor.

34. A typical double cage rotor produces about 200-275% of full load torque on starting, with about 5 times full load current.

The Wound Rotor Motor

35. A wound rotor motor (also known as a slip-ring motor) has the same type of stator winding as the three phase squirrel cage induction motor, but it has a star connected rotor winding which is wound with INSULATED copper wire and connected to three slip-rings on the rotor.
Unlike the squirrel cage rotor, the rotor winding is insulated from the laminated steel rotor core and the resistance of the rotor circuit can be varied by connecting external star connected resistance in series with the rotor winding via the slip rings. Figure 5 shows the relationship between the stator winding, the rotor winding and the external rotor resistances.

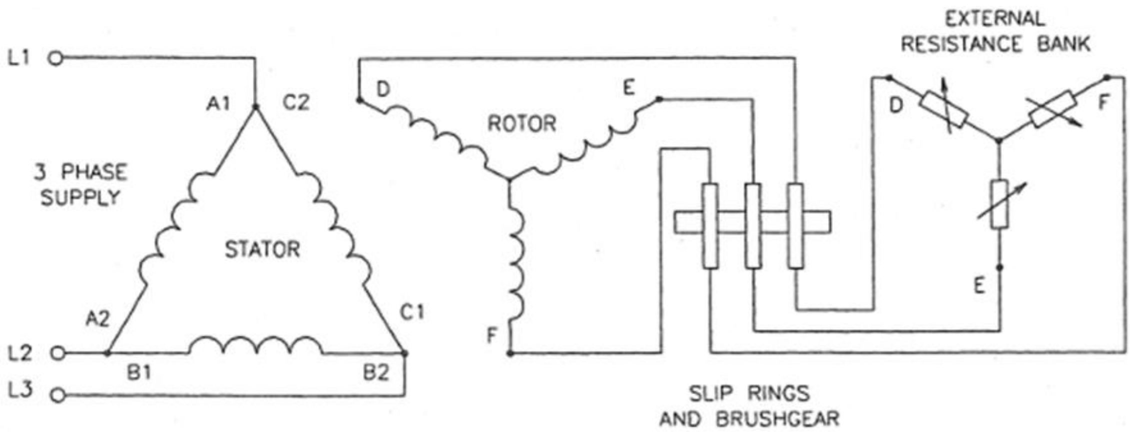


Figure 5 – Stator winding, rotor winding and external rotor resistance bank.

36. Being able to control the rotor circuit resistance means that the motor speed and starting current can be controlled by varying the external resistance. Three phase motor starters or speed controllers which vary the resistance of the rotor circuit are known as secondary resistance starters or drum controllers and they are available in both manual and automatic types.

37. Wound rotor motors usually have a much higher starting torque than standard squirrel cage induction motors but their overall efficiency is lower because of the additional resistance in the rotor circuit.

38. The voltage induced in the rotor of a wound rotor motor is usually much less than the voltage supplied to the stator winding - a typical value of rotor voltage is about 150 volts.

39. Wound rotor motors are usually started with all resistance in the rotor circuit, the resistance is gradually reduced to zero as the motor speeds up. If a wound rotor motor is to be bench tested on no load, the slip rings need to be short circuited, otherwise there would be no circuit for the rotor currents and the motor would not run.

Motor Characteristics

40. The operating characteristics of a particular type induction motor can be shown on a graph known as a characteristic curve or performance curve.
A characteristic curve for a typical general purpose squirrel cage induction motor is shown in Figure 6.

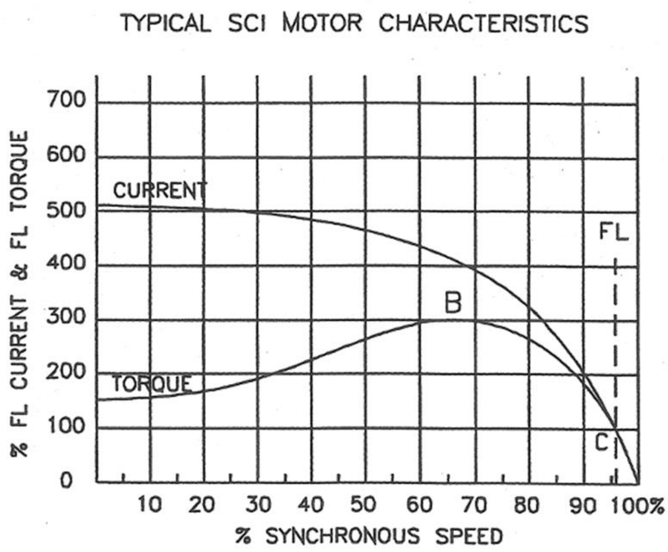


Figure 6 – Typical three phase induction motor characteristics.

41. Figure 6 shows the full load current (FLC) and full load torque (FLT) on the +Y axis, and SYNCHRONOUS speed on the +X axis.

42. You can see from the graph that the initial starting current (A on the current curve) is a little over 500%, and the initial starting torque (A on the torque curve) is about 150% of full load torque.

43. The point marked ‘B’ on the torque curve is usually known as the 'pull-out torque'.If the motor is running on full load and the load increases still further, the rotor speed falls, the torque (and line current) will increase to the point where the motor is unable to turn the load, so the motor stops. If the circuit protection device does not operate the high current will cause the motor to burn out.

44. The point marked ‘C’ is the current and torque when the motor is running at its full designed load and with its designed percentage slip. If the load on the motor is reduced, the line current per phase will be reduced, and the slip will decrease (rotor speed will increase). You should note that it is impossible for an induction motor to operate at 100% of synchronous speed because at that point there is no rotor current so there can be no torque.

45. The shape of the characteristic curves for a particular motor can be varied by the manufacturer, by altering the electrical or mechanical characteristics of the rotor and its winding - as described earlier.

46. Typical characteristics and applications for the most common types of three phase squirrel cage induction motor are:

47. **General Purpose SCI Motor**

Typical characteristics are; about 150% full load torque on starting and about 5 times full load current on starting. See Figure 6 for torque/current characteristics.
Common uses are:

Pedestal grinders
Fans & Air Blowers
Domestic Refrigeration compressors
Motor generator sets
Low inertia machinery

48. **Double-Cage Motors**

Characteristics are; about 200-275% full load torque on starting and about 5 times full load current on starting. Common uses are:

Air compressors
Crushers Conveyors
Commercial Refrigeration Compressors
Reciprocating pumps

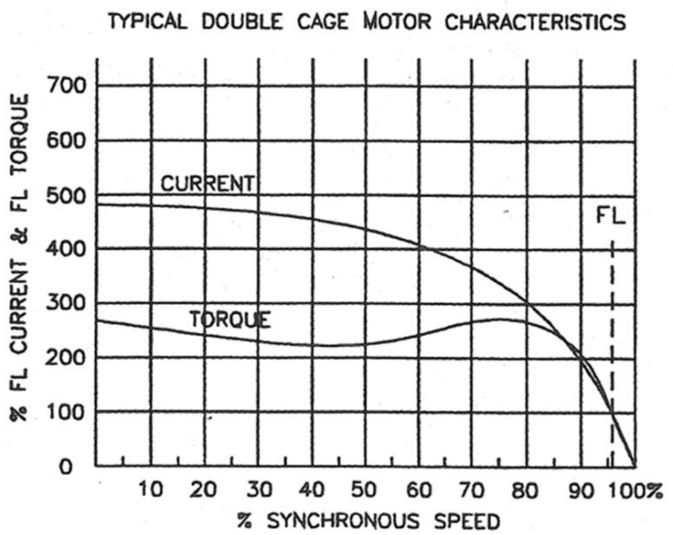
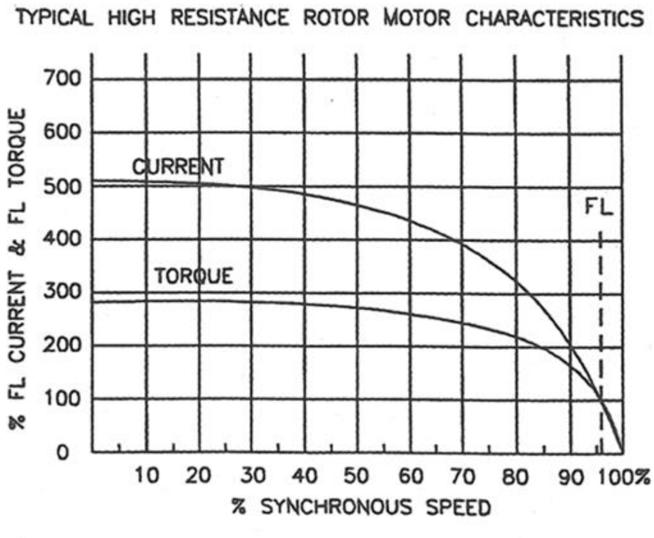


Figure 7.

49. **High Resistance Rotor Motors**

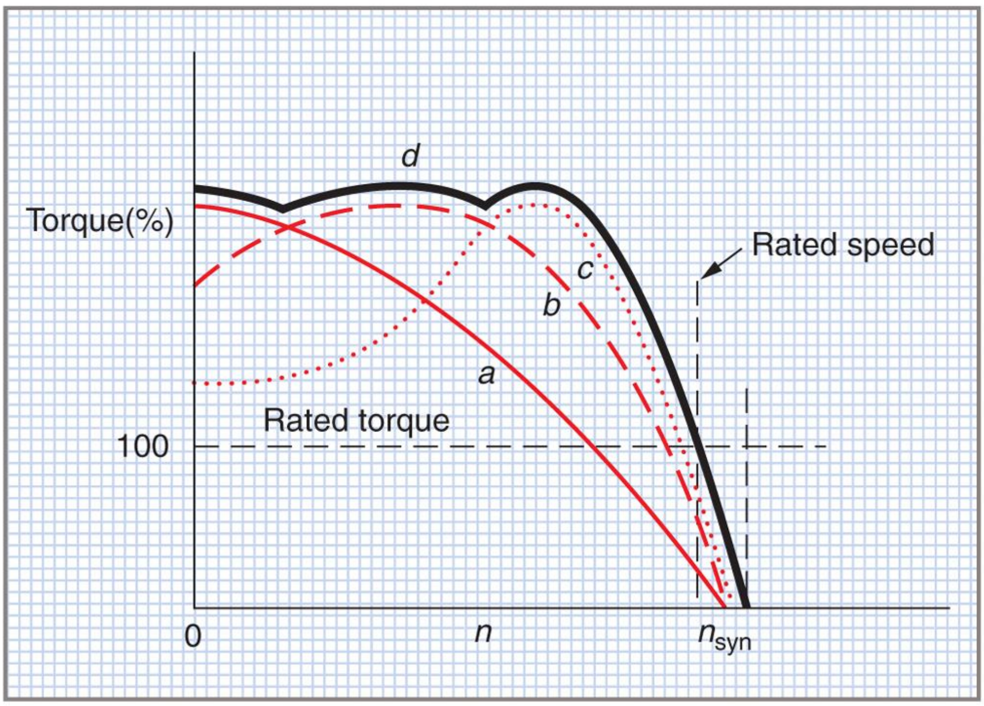
About 250-275% full load torque on starting and about 5 times full load current on starting.
Uses:

High impact loads Flywheel loads Hoists
Presses
Punches
Shears
Cranes and elevators



50. **Wound Rotor Motors**

About 300% full load torque on starting and about 2-3 times full load current on starting when used with external rotor resistance. Typical uses are; Conveyor belts, cranes and lifts.



Wound Rotor Motor- Torque curve of three stage resistors (d curve)

Single Phasing

51. If a three phase motor loses one phase while it is running on NO load it will continue to run as a two phase motor with no harmful effect other than an increased line current. If the load on the motor remains less than or equal to a value which results in full load current the motor will continue to run. If the load increases to a value which results in a line current greater than the designed value, the overload mechanism should operate and stop the motor.

52. However, most three phase motors will not START if there is a loss of supply of one (or two) phases. If the overload mechanism does not operate, the motor will burn out.

Power Factor and Efficiency

53. The power factor of a typical three phase squirrel cage induction motor is best when the machine is operating on full load - a typical value is about 0.8 lagging.

54. The efficiency of a typical three phase squirrel cage induction motor is best when the machine is operating on full load - a typical value is about 80% or greater. Larger motors can have an efficiency of over 90%

55. Figure 8 shows a summary of the operating parameters of a typical three phase squirrel cage induction motor.

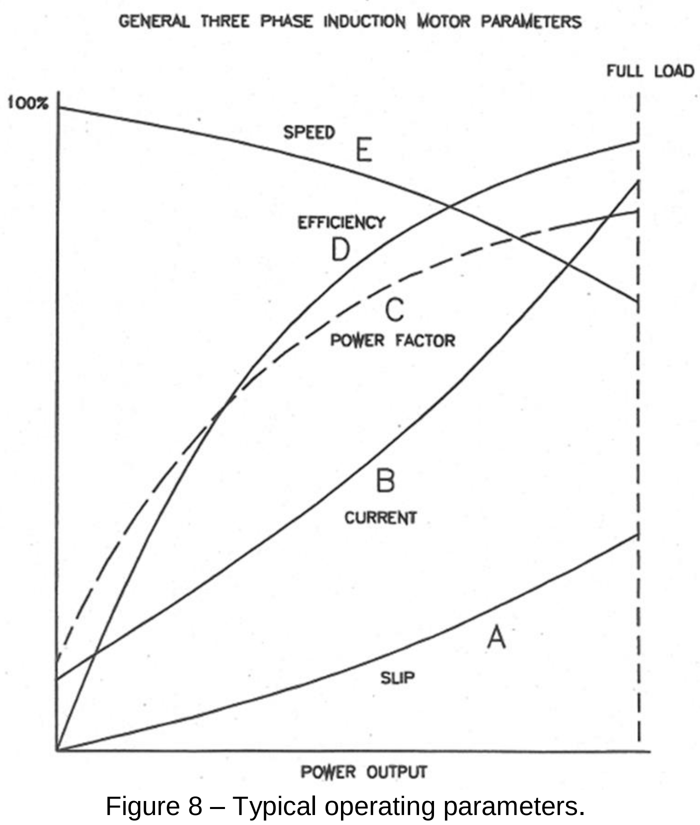


Figure 8 – Typical operating parameters.

Note: In Figure 8, the left hand Y axis is the synchronous speed of the magnetic field of the motor, the right hand Y axis is the full load rotor speed.

Power Calculations

56. The output power and full load current (FLC) are usually contained on the nameplate of the motor. If they are not, the power rating of the motor can be estimated using the following equation:

$$P = \sqrt{3} \times V_L \times I_L \times \lambda \times \eta$$

Where:
P = The output power from the motor in watts
V_L = The line voltage
I_L = The line current per phase on full load
λ = The power factor (Cos θ) usually about 0.8 lagging.
η = The efficiency on full load (usually about 80%)

57. If the full load current per phase is not known it can be estimated by transposing the above equation to give:

$$I_L = \frac{P}{\sqrt{3} \times V_L \times \lambda \times \eta}$$

58. A general rule of thumb which can be used to estimate the full load current rating of a 415 volt three phase squirrel cage induction motor is 'kW X 2'.

59. The output power can also be determined if the motors torque and rotor speed are known by applying the following formula:

$$P = \frac{2 \, x \, \pi \, x \, N \, x \, T}{60}$$

Where:
P = The output power from the motor in watts
N = Rotor speed in revolutions per minute (rpm)
T = Load torque in Newton-metres (Nm)

60. Example
Calculate the output power of a 415 volt three phase induction motor that develops a torque of 110 Nm at 1740 rpm.

$$P = \frac{2 \, x \, \pi \, x \, N \, x \, T}{60}$$

$$P = \frac{2 \, x \, \pi \, x \, 110 \, x \, 1740}{60}$$

P = 20 043.36 W or 20.04 Kw

61. The main Wiring Rules requirements relating to the installation of motors are contained in Clauses 2.8.2, 4.2.2.4, 4.3.1, 4.13, & 7.2.9.

62. The WA Electrical Requirements specify local requirements for electrical equipment with inrush current (such as motors) in Section 3.5.

Minimum Energy Performance Standards

63. Minimum Energy Performance Standards (MEPS) specify the minimum level of energy performance that appliances (including motors) must meet or exceed before they can be offered for sale or used for commercial purposes.
MEPS are an effective way to increase the energy efficiency of products. By specifying a minimum energy performance level they prevent inefficient products from entering the marketplace and help to increase average product efficiency over time. For consumers, this means that products available in the market use less energy and have lower running costs over the life of the product. Using energy efficient products also reduces greenhouse gas emissions and our impact on the environment.

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Three Phase Motor Operation

l. What is the rotor speed of a 50 Hz three phase four pole squirrel cage induction motor if it is running with 4% slip?

2. Will a three phase squirrel cage induction motor start unaided on two phases?

3. Which measuring instrument should be used to measure the insulation resistance to earth in a 415 volt three phase motor?

4. What 'rule of thumb' can be used to ESTIMATE the approximate full load current in a three phase 415 volt induction motor?

5. What is the name given to the electromagnetic principle on which a three phase induction motor operates?

6. How can the direction of rotation of a three phase induction motor be reversed?

7. What is the most common material used to form the conductors in the rotor of a typical 5 kW squirrel cage induction motor?

8. Why are the rotor conductors in some squirrel cage induction motors 'skewed'?

9. What essential electrical safety tests must be carried out on a three phase motor before it is connected to the mains?

10. Under what conditions would it be possible for the speed of a three phase 50 Hz squirrel cage induction motor to exceed 3000 +/min?

11. What is the advantage of a double squirrel cage motor compared to a single cage motor?

12. The nameplate of a three phase induction motor gives the speed as 960 revolutions per minute. What is the 'synchronous speed' of the motor?

13. Why is it physically impossible for the speed of an induction motor to equal its synchronous speed?

14. What is the minimum number of line terminals required on a three phase double squirrel cage motor?

15. A conductor under a SOUTH magnetic pole has current flowing AWAY from the observer. Using Flemings Left hand rule determine the direction the conductor will tend to move?

16. A three phase motor nameplate gives the current rating as 18 amps. When would the line current be 18 amps?

17. What is meant by the term 'synchronous speed' when applied to induction motors?

18. A particular three phase motor has 'f = 60Hz' marked on the nameplate. Would it be safe to operate the motor on full load on 50 Hz?

19. A 4 kW 415 volt squirrel cage induction motor is designed to be connected in star has a full load current rating of 8 amps. Would it be safe to connect the motor to a 415 volt supply in DELTA?

20. Write down the equation which can be used to determine the speed of the rotating magnetic field in a three phase stator?

21. What is the minimum permissible insulation resistance to the frame of a 415 volt three phase motor?

22. The speed shown on the nameplate of a three phase motor is 1420 r/min. When would the speed of the motor be 1420 r/min?

23. What is the frequency of the ROTOR current at the instant a three phase induction motor is switched on?

24. What are the three main factors governing the operating speed of an induction motor?

25. How can a double squirrel cage rotor be distinguished from a single cage rotor if the motor is dismantled?

26. The nameplate of a three phase induction motor gives the speed as 1400 r/min. What would be the approximate speed if the motor was bench tested on NO LOAD at its full rated voltage?

27. A three phase induction motor runs at just under 3000 r/min on no load when connected in STAR. What would be the approximate no-load speed if the same motor was connected in DELTA?

28. A three phase induction motor runs at just under 1500 r/min on no load. What would be the approximate no-load speed if the direction of rotation was reversed?

29. Refer to Figure 1.(on following page) Which of the motor characteristic curves represents a typical standard three phase induction motor?

30. Refer to Figure 1. (on following page) Which of the motor characteristic curves represents a typical three phase double cage induction motor?

31. Refer to Figure 1. (on following page) Which of the motor characteristic curves represents a typical three phase high resistance rotor induction motor?

32. Refer to Figure 1. (on the following page) Which of the motor characteristic curves represents a typical three phase wound rotor induction motor?

33. Figure 2 (on the following page) shows the general operating parameters of a typical standard three phase squirrel cage induction motor. What operating parameter is represented by the letters A, B, C, D and E?

34. What effect does it have on the operation of a standard three phase wound rotor motor if any two of the ROTOR connections are reversed?

35. How many slip rings are required on the shaft of a three phase wound rotor motor?

36. What component do wound rotor induction motors have that squirrel cage induction motors never have?

37. If a wound rotor motor is running at full speed on full load, would the resistance of the rotor circuit be maximum or minimum?

38. How many wound poles would there be on the ROTOR of a 4 pole slip ring motor?

39. How should a 2 kW wound rotor motor be connected to bench test it for operation on no load?

40. What is a typical rated rotor voltage in a wound rotor motor?

41. What are two advantages of a three wound rotor motor compared to a standard squirrel cage motor?

42. When is the rotor frequency greatest in a three phase wound rotor motor which is connected to 415 volts AC?

43. What are the customary Australian terminal markings for the connections from the ROTOR winding of a three phase wound rotor motor?

44. What is the minimum number of terminals required on the terminal block of a wound rotor motor?

45. What is the minimum number of brushes required in a three phase wound rotor motor?

46. To which winding in a three phase wound rotor motor must the three phase supply be connected?

47. Will a three phase wound rotor motor start if the rotor circuit is open circuited?

48. How can the speed of a three phase wound rotor motor be varied?

49. A 415 volt three phase 50 Hz four pole induction motor has a full load speed of 1445 rpm. Calculate the motors output power if it develops a torque of 85 Nm.

50. What is the benefit to the consumer of purchasing a motor that is MEPS compliant?

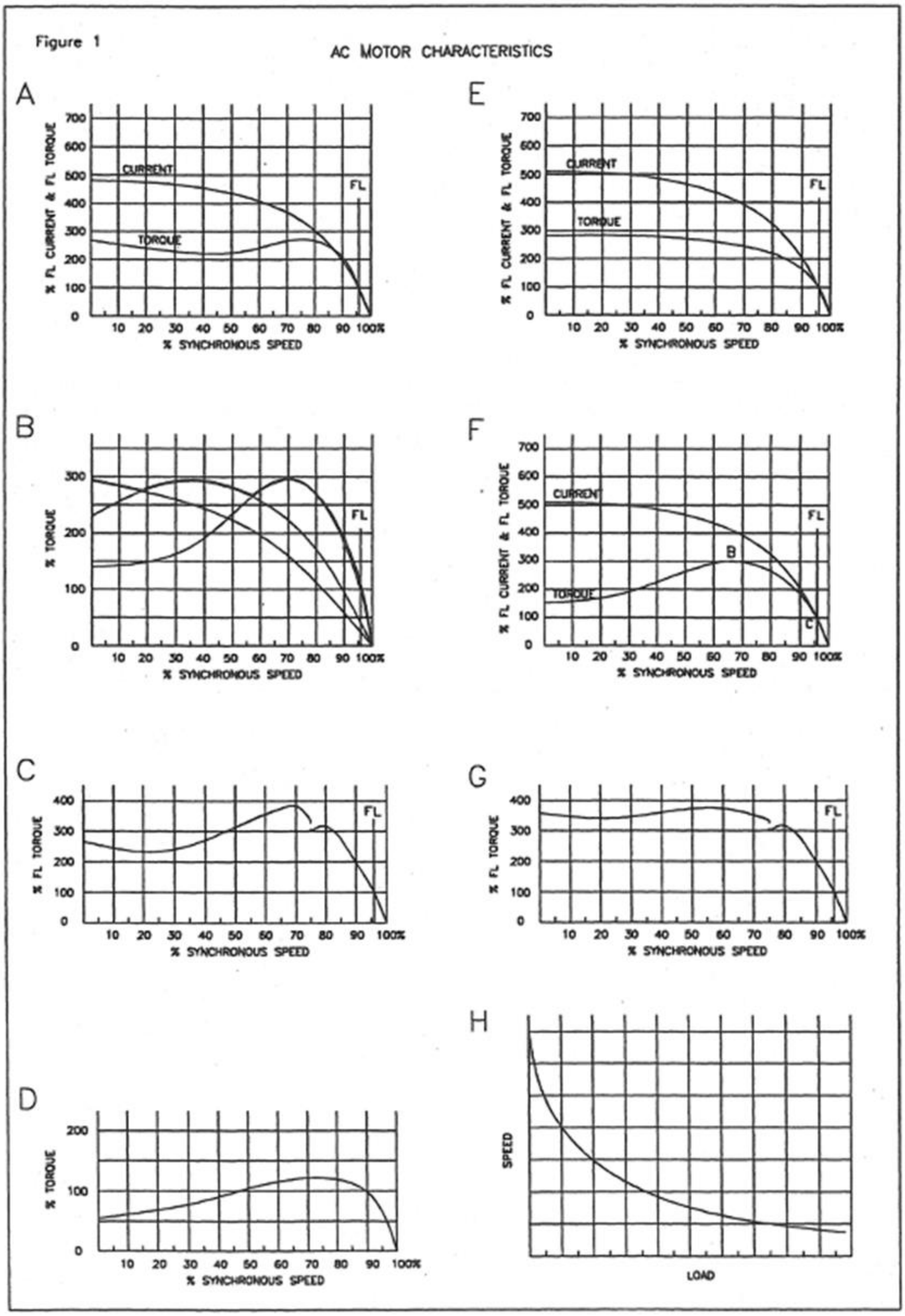

Figure 1 – Motor Characteristics

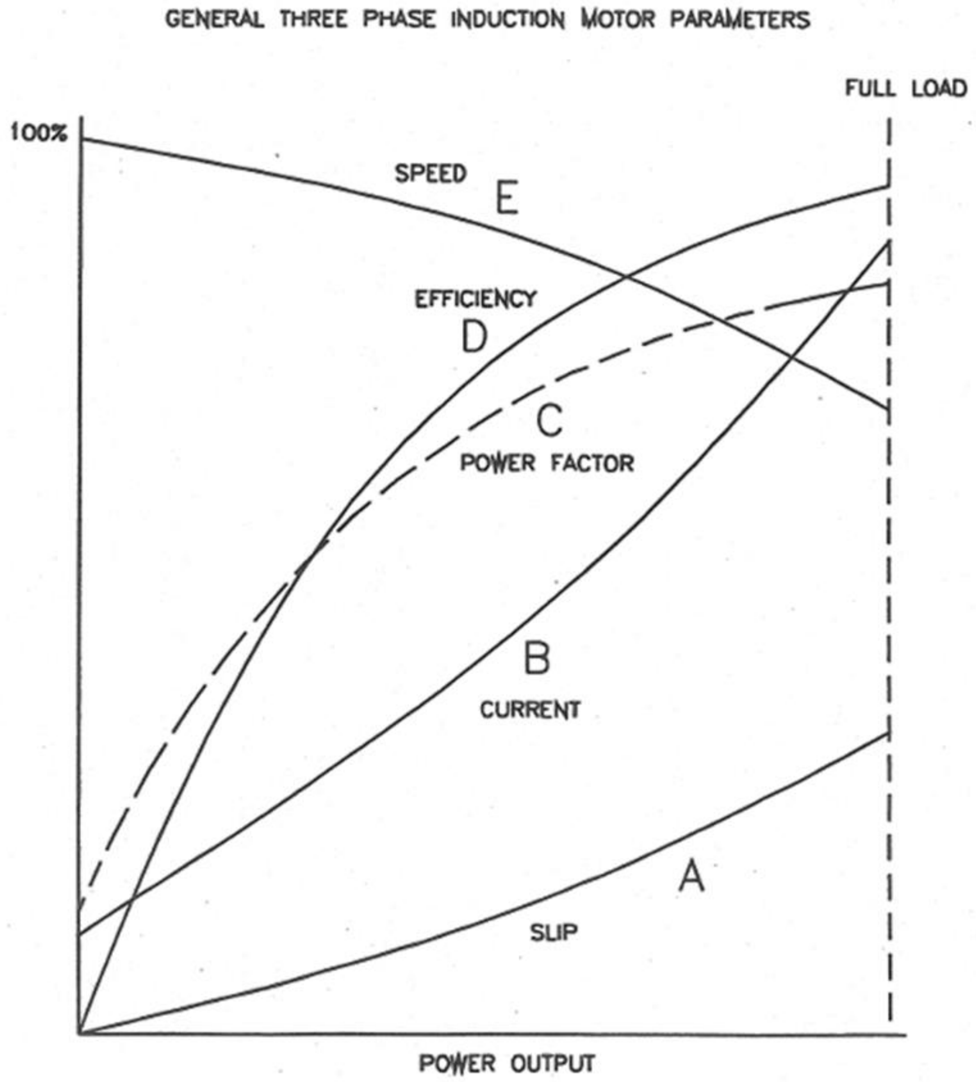

Figure 2. – Information for Q. 33

	Solve problems in single phase and three phase low voltage machines	Section 6 Activity Sheet 2	G006A SGB 12/2013

Government of Western Australia North Metropolitan TAFE

Three Phase SCI Motor Connections

Objective

To connect a three phase squirrel cage induction motor to the supply in STAR and DELTA and test it for correct operation in both directions.

Equipment

Three phase single speed squirrel cage induction motor up to about 3 kW that is able to be connection in both STAR and DELTA.
Multimeter.
Clip-on ammeter.
Connecting leads.
Three phase lead board.
Hand-held tachometer.

Procedure

DANGER TAG PROCEDURE REQUIRED

1. Examine the motor nameplate and record the following details:

Line Voltage		Power Rating	
Full Load Current		Number of Phases	
Full Load Speed		Connection	

2. Draw a circuit diagram of a three phase six terminal squirrel cage induction motor connected in STAR, showing typical terminal markings.
Show the position of the incoming line connections.

3. Connect the motor in STAR at the terminal block and connect the three phase lead to it. Make sure that the earth is securely connected.

4. Check your wiring for short circuits using a multimeter set to the ohms x 1 range.
Check that the earth continuity to the motor is less than 1 ohm.

5. Have your connections checked by your Lecturer.

6. Switch the motor on and test it for correct operation. Record the no- load speed in the Results Table. Measure the current in each phase with a clip-on ammeter. Measure the rotor speed. Record the results.

7. Switch the motor off and remove the plug from the outlet.

8. Change your connections so that the motor will run in the opposite direction.

9. Check your wiring for short circuits using a multimeter set to the ohms x 1 range.
Check that the earth continuity to the motor is less than 1 ohm.

10. Have your connections checked by your Lecturer.

11. Test the motor for correct operation. Measure the current in each phase with a clip-on ammeter. Measure the rotor speed. Record the results.

12. Repeat steps 2 to 11 with the motor connected in DELTA at the terminal block.

13. Switch the motor off and remove the plug from the outlet.

14. Have your results checked by your Lecturer.

15. Return all of the equipment to its proper place.

Results Table

	Speed	Line Current
STAR (forward)		
STAR (reverse)		
DELTA (forward)		
DELTA (reverse)		

Questions

1. Does the measured speed correspond with the speed shown on the motor nameplate? If not, why?

2. Does the measured line current correspond with the current shown on the motor nameplate? If not, why?

3. Was there a significant difference between the speed in star and delta. If not, why?

4. Was there a significant difference between the speed in forward and the speed in reverse?

5. Is it permissible to wire up a three phase induction motor using the SAME active colour for each line conductor?

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Single Phase Motors

Task:

To describe the construction and operation of typical single phase motors and connect them to a 240 volt supply.

Why:

Single phase motors are the common throughout industry. You need to have a knowledge of their construction and general principles of operation so that you can recognise them, safely connect them to a suitable supply, reverse the direction of rotation, and diagnose and correct simple electrical or mechanical faults.

To Pass:

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

Equipment:

Sample single phase induction motors up to about 1 kW.
Sample single phase shaded pole motors.
Sample single phase series universal motors up to about 1 kW.
Sample overload, starting and speed control mechanisms
Hand tools for stripping and assembling motors.
Multimeter.
AC ammeters suitable for measuring motor line current.
High voltage insulation tester.

References:

* Electrical Principles for the Electrical Trades (6th ed.). J.R. Jenneson.

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Singe Phase Motors

Suggested Self-Study Guide

1. Study the following sections in the recommended reference: Electrical Principles for the Electrical Trades Volume 2

   Chapter 6 Single Phase Motors
   - Section 6.1 Single phase induction motors
   - Section 6. 1. 6 Series motors
   - Section 6.3 Abnormal operating conditions

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.

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Single Phase Split Phase Motors

1. There are several different types of single phase motor, the most common of which are:

    a. Split phase motors.
    b. Capacitor start motors.
    c. Capacitor start, capacitor run motors.
    d. Permanent capacitor motors.
    e. Shaded pole motors.
    f. Series universal motors.

2. The first four motors in the list above are induction motors which operate on what is known as the 'split phase principle' and are similar in construction. Shaded pole and series universal motors operate on different principles and will be covered separately.

3. Single phase induction motors typically range in size from about 10 watts to several kilowatts, but motors above about 3 kW are relatively rare, due mainly to the high starting current required.

Split Phase Type Motor Construction

4. An exploded view of a typical single phase split phase induction motor is shown in Figure 1.

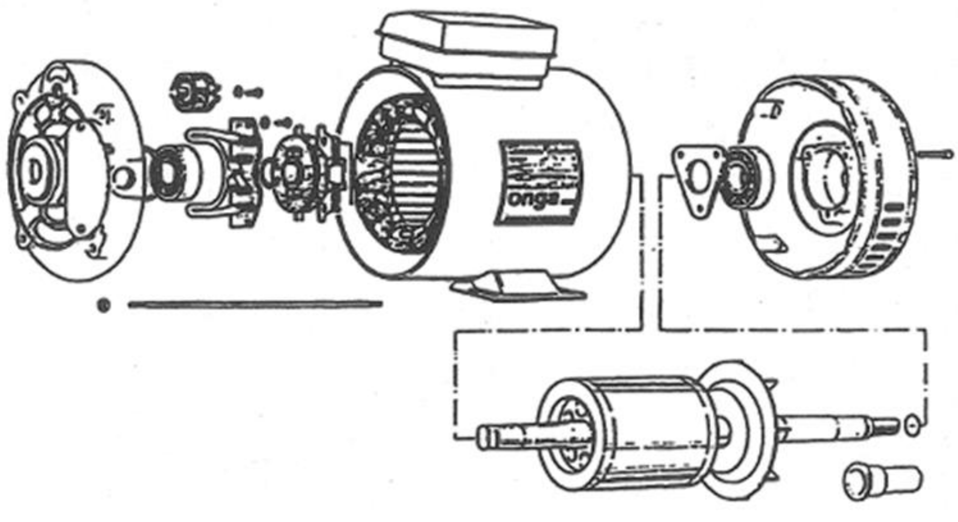

Figure 1 - Typical split phase induction motor

5. The stator core of a typical split phase type motor is made up of a stack of laminations with semi-enclosed slots. The wound poles are made up of three or four series connected coils wound in concentric gangs as shown in Figure 2 - one gang for each magnetic pole.

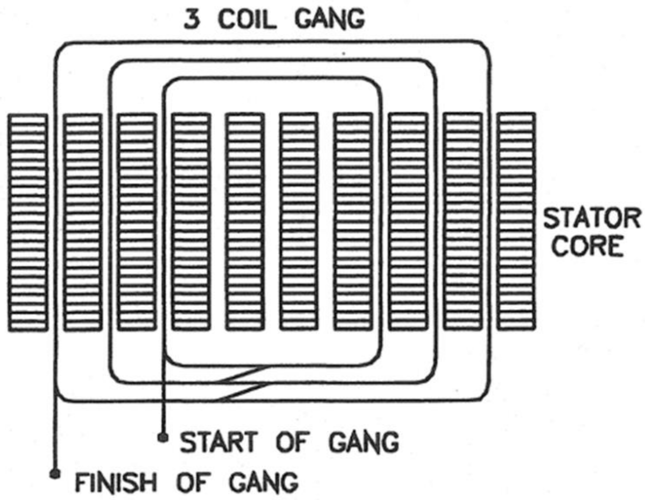

Figure 2 - Concentric coils wound in a gang

6. There are two completely separate groups of coils - one group is known as the RUN winding and the other is known as the START (or auxiliary) winding, and the number of coils in each group must be the same. The number of gangs of coils connected in series for each group determines the number of magnetic poles in the stator. The physical position of the gangs of coils in the start and run windings in a 4 pole split phase motor are shown in Figure 3.

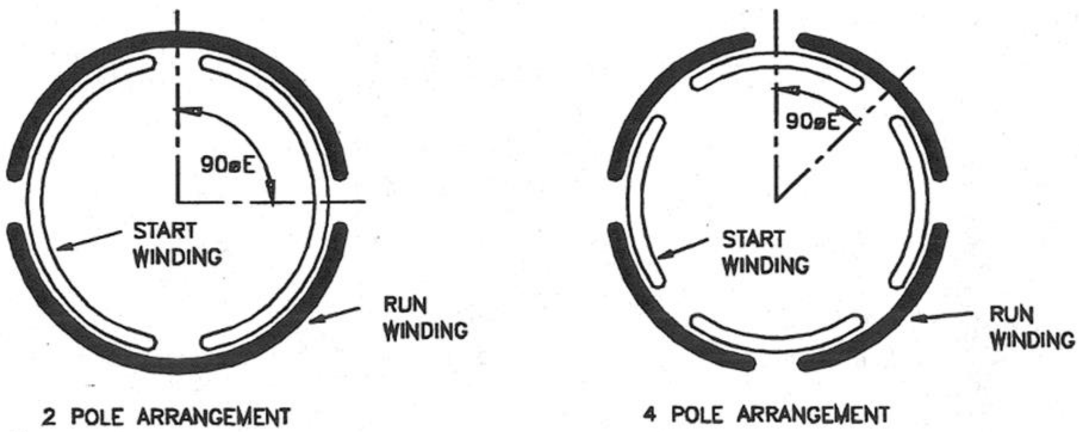

Figure 3 - Position of the start and run windings

7. The start and run windings have different electrical characteristics and they are positioned in the stator so that each adjacent gang of coils is 90 electrical degrees apart. (360 electrical degrees is defined as the number of degrees from the centre of one pole to the centre of the next adjacent pole of the same polarity.)

8. The run winding consists of many turns of a relatively large diameter insulated winding wire and is placed in the slots first. The start winding consists of fewer turns of a relatively small diameter wire and is placed in the slots so that it sits on top of the run winding (with sheet insulation between the windings).

9. Since the run winding is deeper in the slots it has more inductance than the start winding, and since it is wound with a larger diameter wire it usually has a lower resistance than the start winding. Since the start winding is higher in the slots it has less inductance than the run winding, and since it is wound with a smaller diameter wire it usually has a higher resistance than the run winding.

10. Typical values of resistance in a 4 pole 180 watt split phase type motor are about 8-10 ohms for the run winding and about 10-12 ohms for the start winding.

Squirrel Cage Rotor

11. A typical squirrel cage rotor consists of comparatively large bars of conducting material (usually aluminium) cast into the slots in the rotor and joined at each end of the rotor with conducting 'end rings'. No insulation is necessary between the rotor bars and the laminated steel rotor core because the rotor winding has a much lower resistance than the.rotor core. An outline of the construction of a typical squirrel cage rotor is shown in Figure 4, but you should bear in mind that rotor bars and end rings can have other shapes and they can be made from other materials(such as copper).

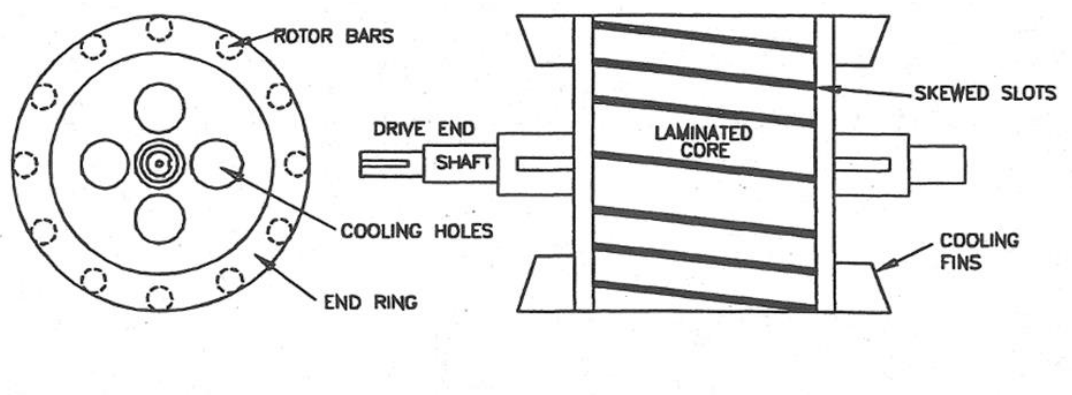

Figure 4 - Basic construction of a squirrel cage rotor

12. Most split phase type motors require a mechanism to disconnect the start winding when the rotor reaches about 75% of full speed. The most common method of disconnecting the start winding is a centrifugal switch mechanism part of which is on the rotor and part attached to the inside of the non-drive-end end shield. The switch mechanism is closed when the motor is stationary.

13. In single phase split phase type motors in which it is undesirable to have a starting switch built into the motor, such as in a sealed unit refrigerator, electromagnetic or thermal starting switches are used.

The Split Phase Motor Principle

14. In a typical split phase motor the start and run windings are connected in parallel across the single phase a.c. supply, and a centrifugal switch is connected in series with the START winding as shown in Figure 5.

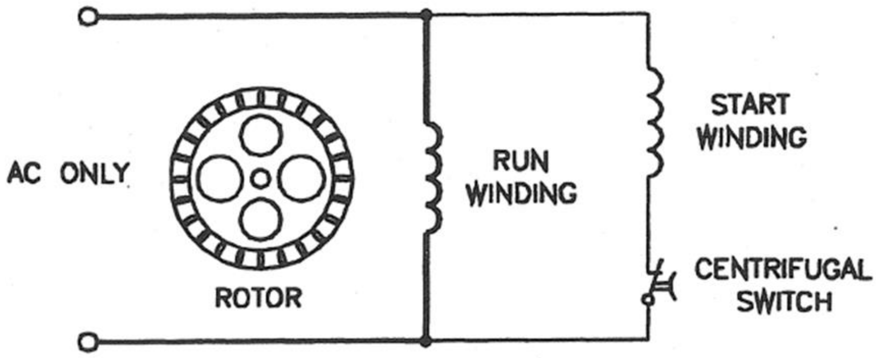

Figure 5 - Typical split phase motor connection.

15. The coil groups in each winding are connected so that magnetic poles will be formed on the stator. The polarity of the poles changes for every half cycle of the input voltage, and the polarity of the run winding poles in relation to the start winding poles will depend on the direction of current at that instant. Figure 6 shows a simplified representation of typical relative polarities of the poles in a 2 pole stator at a given instant.

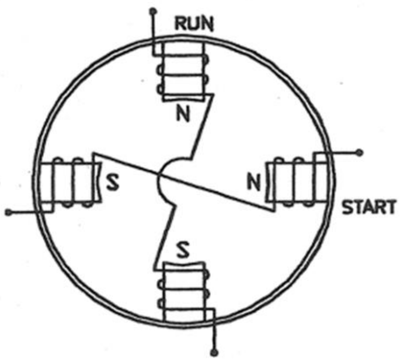

Figure 6 - Magnetic poles on the stator at a given instant.

16. The start and run windings are both inductive so the current in both of them lags the applied voltage. However, the run winding is embedded deep in the stator slots so it is more inductive, so the current in the run winding lags the voltage by more than the current in the start winding. The precise angles of lag depend on the design of a particular motor, but the general relationship between the currents and the applied voltage can be shown on a phasor diagram such as the one shown in Figure 7.

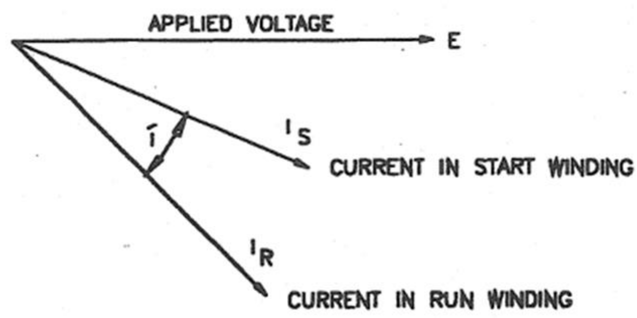

Figure 7 - Phasor diagram of current in the start and run windings.

17. The phase angle between the current in the start and run windings in a split phase motor is typically 20-30 degrees, and it is this 'split' which gives rise to the name 'split phase' motor.

18. The currents in the start and run windings are always out of phase, but since the supply voltage changes polarity every half cycle, the polarity of each of the poles changes every half cycle also. The continuing change of polarity results in the axis of the combined start and run winding fluxes moving around the stator at what is known as 'synchronous speed'. The direction of the single phase 'rotating' field depends on the relative polarity of the start winding flux compared to the run winding flux.

19. As the combined 'rotating' field sweeps past the conductors in the squirrel cage rotor a current is induced in the rotor winding which reacts with the stator flux and the rotor moves in the same direction as the rotating magnetic field. The rotor rotates at a speed which is determined by the number of poles on the stator, the frequency of the supply and the amount of load. The rotor can never rotate at synchronous speed or above (unless it is driven mechanically) because at synchronous speed there would be no relative movement between the rotating magnetic field and the rotor, so no current would be induced in the rotor. The difference between synchronous speed and rotor speed is known as 'slip'.

20. When the rotor reaches a speed of about 75% of synchronous speed the normally closed centrifugal switch opens and disconnects the start winding. The start winding has a very short time rating - if it remains connected in the circuit for more than about 30 seconds it will probably burn out.

21. The full load speed is determined by the amount of slip - a typical value of slip is 4-5%. Full load speed can be calculated as follows.

22. Example Find the full load speed of a 240 volt 50 Hz single phase 4 pole split phase motor if the slip is 4%.

$$N_{syn} = \frac{f \times 120}{P}$$

$$N_{syn} = \frac{50 \times 120}{4}$$

$$= 1500 \text{ r/m}$$

Slip = 4% of 1500

= 60 r/min

Full load speed = 1500 – 60

= 1440 r/min

23. The full load current is governed by the design of the motor. A typical 240 volt 180 watt 50 Hz single phase split phase induction motor has a full load current of around 2.2 amps, and a no load current of around 2 amps. Since an induction motor operates on a.c., Ohm's Law does not apply in the same way as it does in d.c. circuits, therefore the line current cannot be calculated by dividing the power rating by the applied voltage.

24. In order to reverse the direction of rotation of a split phase motor it is necessary to reverse the direction of current in the start or the run winding (but not both); this can be done by reversing the connections to either the start or the run winding (while the motor is isolated from the supply).

25. The starting torque of a split phase motor is relatively low because of the phase difference between the current in the stator winding and the current in the rotor winding. A typical characteristic curve for a split phase motor is shown in Figure 8.

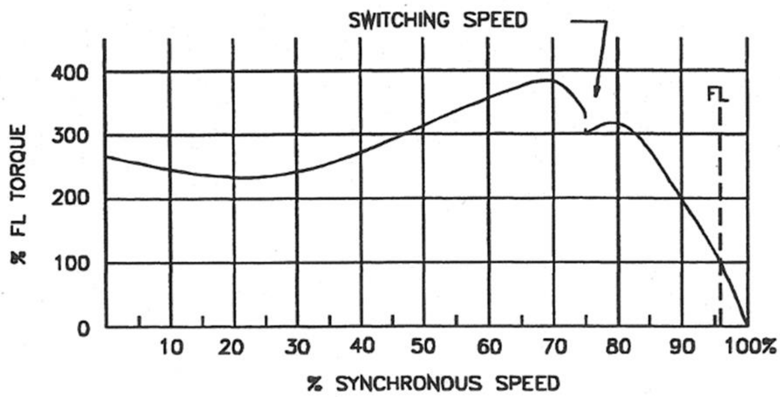

Figure 8 - Typical characteristic curve of a split phase motor

26. Split phase motors do not develop enough starting torque to start heavy loads; they are mainly used in devices which do not require high starting torque such as washing machines, blowers and small bench grinding machines. The efficiency of split phase type motors is lower than three phase induction motors of the same size - typically around 60%.

Capacitor Start Motor

27. The starting torque of a split phase type motor can be improved by increasing the phase angle between the run winding current and the start winding current. This can be achieved by connecting a suitable capacitor in series with the START winding - the motor is them known as a capacitor start motor. A circuit diagram of the connections and a phasor diagram of the relationship between the currents in a typical capacitor start motor is shown in Figure 9.

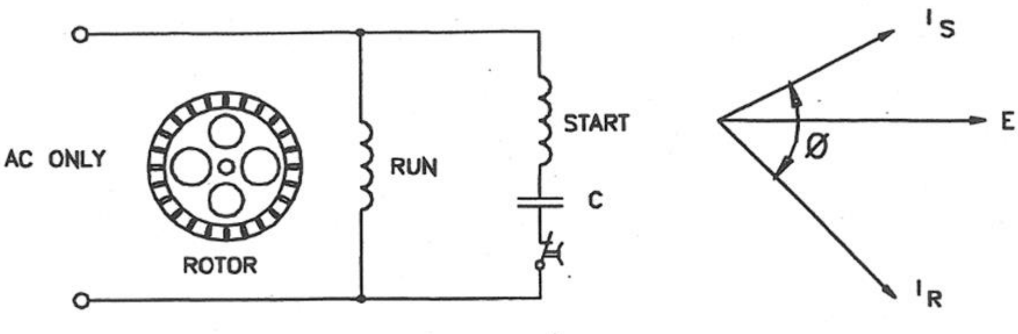

Figure 9 - Phase relationships in a typical capacitor start motor

28. A capacitor start motor has the same size and type of run winding as an equivalent size split phase motor, therefore their running characteristics would be identical, but the start winding is wound with a larger diameter winding wire (so it usually has a lower resistance than the start winding of an equivalent split phase motor).

29. A typical characteristic curve for a split phase motor is shown in Figure 10. The starting torque can be up to about 2.5 times the starting torque of an equivalent split phase motor - depending on the capacitor chosen by the manufacturer.

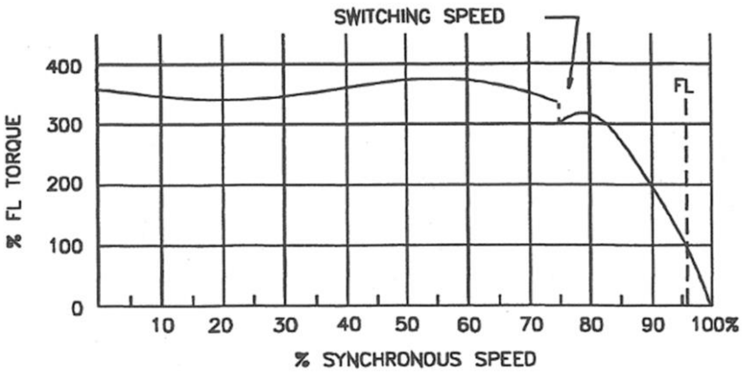

Figure 10 - Typical characteristic curve of a capacitor start motor

30. The capacitor in a 180 watt capacitor start motor is typically a special electrolytic motor starting capacitor of about 150 microfarads and it is usually mounted on the outside of the motor carcase Some manufacturers use two capacitors mounted inside the end- shield. Since the capacitor is in series with the start winding, it is not subjected to the full supply voltage, so some manufacturers use capacitors with a voltage rating below 240 volts rms.

31. The direction of rotation of a capacitor start motor can be reversed in the same was as for a split phase motor - by reversing the connections to either the start or the run winding (while the motor is isolated from the supply).

32. Capacitor start motors are mainly used where a high starting torque is required, such as in refrigeration compressors and air compressors.

33. Some capacitor start motors may have a limited number of starts per hour, for example, 20 three second starts per hour.

34. Although most general purpose split phase type motors have a centrifugal switch, disconnection of the start winding can be achieved using other methods such as:

a. **An electromagnetic** mechanism which opens the start winding circuit when line current falls to a specified value during starting. On starting, heavy current flows in the run winding, pulling a plunger up to connect the start winding. As the motor speeds up the current falls to about 70% of full speed, the plunger is released and the contacts open, disconnecting the start winding. A circuit showing the principle is shown in Figure 11.

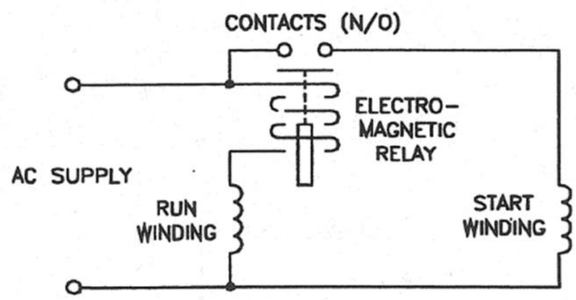

Figure 11. - Electromagnetic starting switch principle.

b. **A thermal mechanism** which opens the start winding circuit when the starting current has heated a bi-metal strip to a pre-set value.

c. **An electronic timing mechanism** is placed in series with the start winding and open-circuits the winding at a pre-set time, usually less than one second after the motor has been connected to the supply.

Capacitor Start Capacitor Run Motor

35. Capacitor start capacitor run motors are similar in operation to the capacitor start motor except that they have another capacitor permanently connected in series with the start winding, in addition to the starting capacitor as shown in Figure 12. Various centrifugal switch connection arrangements are possible.

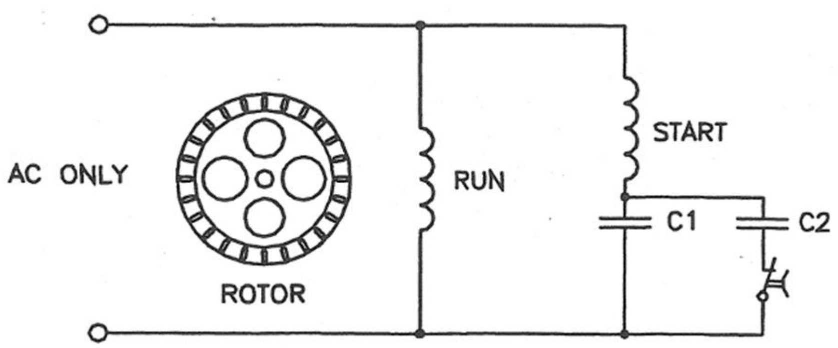

Figure 12 - Capacitor start capacitor run motor connections.

36. The two capacitors in parallel during starting provides good starting torque, while the running capacitor provides good running torque, better overload capacity, better efficiency, better power factor and quieter operation. The capacity of the running capacitor is usually lower than that of the starting capacitor (usually less than 20 μF). It is important that the two capacitors are connected in the circuit correctly as they are designed for different purposes. In Figure 12, the starting capacitor (C2) is a non-polarised Aluminium Electrolyic capacitor (usually greater than 70 μF) and is only designed to be energised for a short time. The Run capacitor (C1) is a polypropylene film capacitor and is designed for continuous duty.
This type of motor is widely used for driving refrigerator compressors.

37. The direction rotation of a capacitor start capacitor run motor can be reversed by reversing the connections to either the start or the run winding, but not both.

Permanent Capacitor (PSC) Motor

38. A permanent capacitor motor has the same type of winding arrangement as a capacitor-start motor, but the 'start' winding is designed to remain permanently connected, as shown in Figure 13, so no centrifugal switch mechanism is required. Both windings are identical, and the 'start' winding is usually referred to as the auxiliary winding.

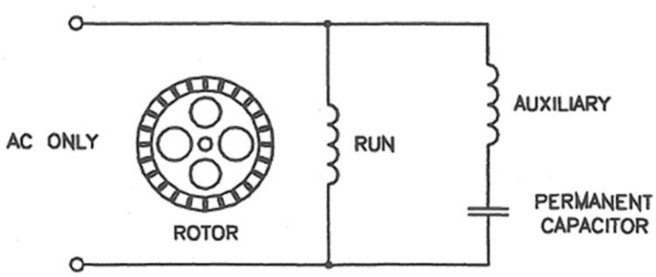

Figure 13 - Permanent capacitor motor connections.

39. The starting torque in a permanent capacitor motor is low compared to capacitor start motors. They are widely used in small fans including ceiling sweep fans (up to about 120 W), and they are well suited to variable speed operation such as in multi-speed air conditioner fans where the speed can be varied by varying the capacitance of the capacitor.

40. The direction rotation of a permanent capacitor motor can be reversed by reversing the connections to either the run or the auxiliary winding, but not both. Another method of reversing a permanent capacitor motor to change the phase angle in one winding relative to the other by connecting a permanent capacitor as shown in Figure 14. This method is commonly used in motors associated with the regulation of air flow in air conditioning systems.

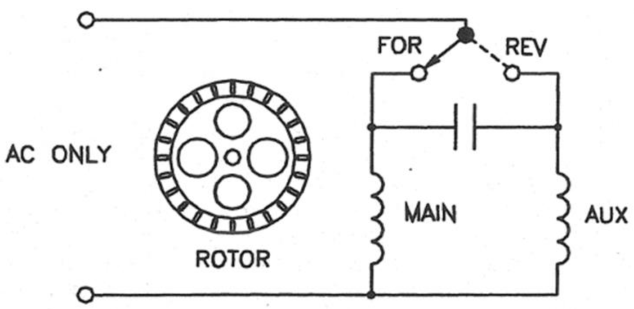

Figure 14 - Arrangement for reversing a permanent capacitor motor.

Ceiling Sweep Fan Speed Control

41. The majority of domestic type ceiling sweep fans are powered by permanent capacitor motors. The installation of ceiling sweep fans normally require speed control to provide the required air circulation in the room.

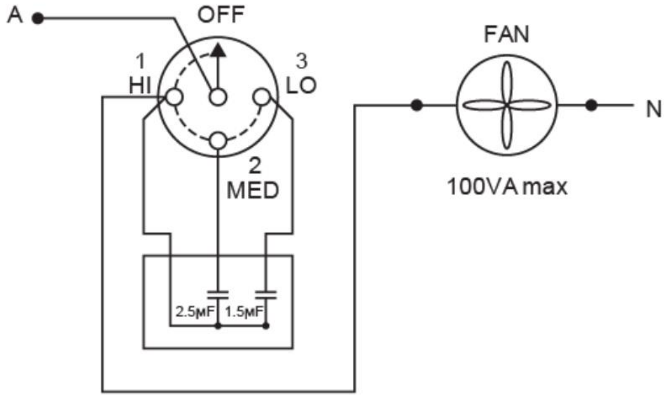

Figure 15 -Ceiling Sweep Fan (Permanent Capacitor motor) capacitor speed control

42. The Fan Controller unit incorporates a three position rotary switch mechanism and a multi-tap capacitor block. This method of control overcomes the motor ‘growl’ (or buzzing noises), often emitted from fans controlled by other electronic (phase control) speed setters, and ensures quiet operation of the fan motor.
The three position capacitor type three speed fan controller may be used to replace a standard controller switch in any existing installation. This includes many older style ‘choke’ controllers.

Single Phase Split Phase Motor Testing

43. The most common faults which occur in electric motors are short circuits, open circuits and insulation resistance faults. In split phase type motors which incorporate a switching mechanism to disconnect the starting winding, the contacts on the switch can weld together causing the start winding to overheat and burn out.

44. Before you connect a motor to the supply you need to accurately identify the ends of the electrical components. The most suitable instrument to use is a multimeter set to the ohms x 1 range. The connections at the terminal block should be disconnected during the test to avoid any unwanted parallel connections.

45. The start or auxiliary winding is usually the one with the highest d.c. resistance - typically 10-12 ohms for a 180 watt split phase motor. The resistance will be less for a larger motor or for a capacitor type motor. If the resistance of a winding is zero ohms it indicates a short circuit. A resistance of infinity indicates an open circuit.

46. The run winding usually has a resistance of about 8-10 ohms for a 180 watt split phase motor, or less for a larger motor.

47. The resistance of the normally closed centrifugal switch should be zero ohms when measured with a multimeter.

48. The capacitor can usually be tested or identified by noting that the multimeter resistance reading goes up-scale on a high ohms range, then slowly moves down scale to the infinity position (as the battery in the multimeter charges the capacitor). If the multimeter indicates around zero ohms it indicates that the capacitor is short circuited. If it indicates infinity ohms without moving, it indicates that the capacitor is open circuited.

49. If a split phase motor is tested for winding resistance with all connections correctly made, the resistance reading should be the equivalent resistance of the run winding and the start winding connected in parallel. If a capacitor type motor is tested the resistance reading would be the resistance of the run winding alone, because the capacitors would be virtually equivalent to an open circuit.

50. In split phase type motors the start winding usually has a higher resistance than the run winding, but this is not always the case, particularly in capacitor start motors. To avoid permanent damage to the motor resulting from incorrectly connecting the run winding in series with the centrifugal switch you should always run a newly connected motor for a few seconds on no load and check the line current. It should be LESS than the value shown on the nameplate. If it is not, you could have the start winding connected direct across the supply.

51. Short circuits between turns in a winding can be detected with an internal growler the motor must be dismantled for this test, and any parallel connections must be disconnected.

52. The insulation resistance between windings and from each winding to earth (or frame) must be measured with a 500 volt high voltage insulation tester (a Megger). The minimum permissible insulation resistance is 1 megohm, but most single phase motors should have an insulation resistance greater than 200 Megohms.

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Single Phase Split Phase Type Motors

1. How can a single phase split phase stator winding be distinguished from a 3 phase winding of about the same power rating?

2. What type of rotor do ALL split phase type motors have?

3. How many windings does a single speed capacitor start motor have and what are they usually called?

4. What component do most single phase split phase induction motors have that three phase squirrel cage induction motors do not have?

5. What is the most common operating voltage for split phase and capacitor start motors in W.A.?

6. What is a typical full load current rating of a 0.18 kW, 240 volt single phase split phase or capacitor-start motor?

7. Can a split phase or capacitor start motor operate satisfactorily on DC?

8. When a single phase split phase type motor is stationary, is the centrifugal switch open or closed?

9. How can the direction of rotation of any split phase type motor be reversed?

10. What is a typical resistance of the RUN winding in a 240 volt split phase or capacitor start motor of about 0.2 kW?

11. What is the only component in a split phase or capacitor start motor which can safely be connected so that it is in PARALLEL with the supply when the motor is running on full load?

12. Is the resistance of the start winding higher or lower than the resistance of the run winding in a typical split phase type motor?

13. What safety precaution should be taken before attempting to test a power capacitor?

14. How many CONDUCTORS are required to connect a typical capacitor start motor to the supply?

15. What are the two most common positions for the capacitor(s) in a capacitor start motor?

16. What component is connected in series with the start winding in a split phase type motor?

17. If the resistance of a start winding in a split phase motor is 12 ohms, and the resistance of the run winding in 6 ohms, what would be the resistance between the line terminals if the motor was stationary?

18. What does the centrifugal switch do when a capacitor start motor reaches about 75% of full speed?

19. What is a typical full load speed for a 4 pole 50 Hz single phase split phase or capacitor start motor?

20. What are the two major differences between a split phase motor and a capacitor start motor?

21. Draw a circuit diagram of a typical 240 volt single phase split phase motor. Label all components and show a typical resistance for each component.

22. Draw a circuit diagram of a typical 240 volt single phase capacitor start motor. Label all components and show a typical resistance for each component.

23. What safety precaution must be taken before attempting to work on a typical single phase motor which is installed with fixed wiring?

24. List four common types of single phase split phase type motor.

25. Which electrical component in a capacitor start motor has the LOWEST resistance?

26. What is the name given to the speed of the 'rotating' magnetic field in an induction motor?

27. What is the advantage of a capacitor start motor compared to a split phase motor of the same power rating?

28. How can the direction of rotation of a single phase capacitor start motor be reversed?

29. What is the function of the centrifugal switch in a single phase capacitor start motor?

30. A start winding is part of the starting circuit of a single phase split phase motor. What other component is connected in the starting circuit of the motor? Is it connected in series or parallel with the start winding?

31. List 10 of the major components in a typical single phase split phase motor?

32. What part of a typical 240 volt capacitor start motor supports the weights for the centrifugal switch.

33. What effect will it have on the operation of a split phase motor if the start winding remains connected when the motor is running at full speed?

34. What is the advantage of a split phase motor over a capacitor start motor of the same power rating?

35. The total measured resistance of a particular **split phase** motor is 4.8 ohms and the Run winding is 8 ohms. Calculate the value of resistance of the Start winding.

36. What type of starting capacitor is usually used in a modern capacitor start motor?

37. What is a typical value of capacitance for the starting capacitor in a typical 180 watt capacitor start motor?

38. What is a typical full load current rating of a 240 volt 180 watt single phase capacitor start motor?

39. What is the major disadvantage of a single phase split phase motor compared to a capacitor start motor of the same power rating?

40. In what unit is the starting torque of an electric motor usually expressed?

41. Where would the capacitor(s) mounted in a typical permanent capacitor motor?

42. What is the minimum permissible insulation resistance to earth between the rotor winding and the rotor core in a 240 volt single phase split phase or capacitor start motor?

43. The run winding of a particular **capacitor start** motor has a resistance of 8 ohms and the start winding is 12 ohms. What value of resistance would be measured between the incoming active and neutral (with the supply disconnected)?

44. What effect will it have on the operation of a split phase motor if the centrifugal switch fails to operate correctly?

45. Describe four faults which can occur in single phase split phase type motors.
How can each of the faults be detected?

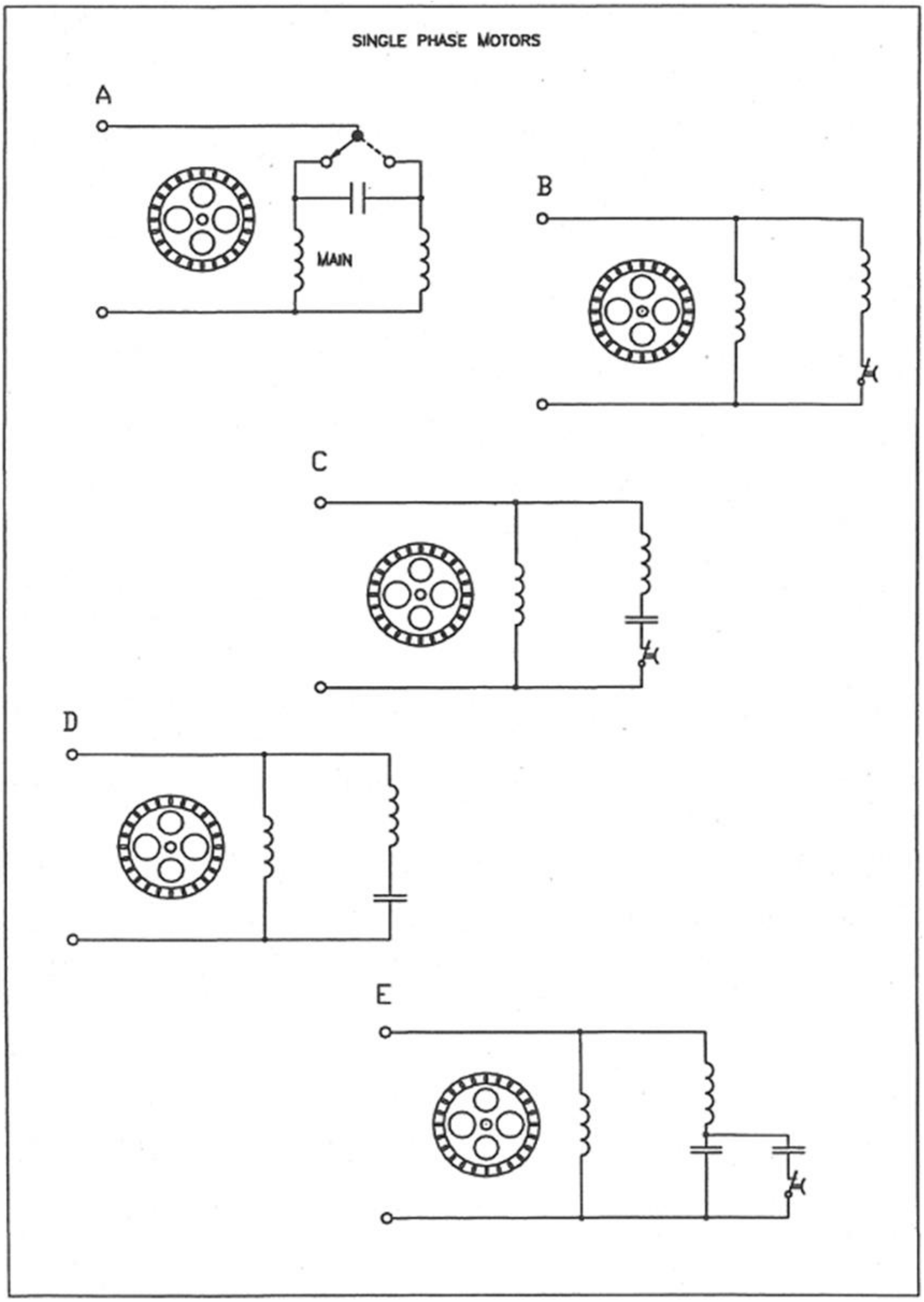
46. Refer to the following page of single phase motor circuits.
What type of motor is shown in Figure A?

47. Refer to the following page of single phase motor circuits.
What type of motor is shown in Figure B?

48. Refer to the following page of single phase motor circuits.
What type of motor is shown in Figure C?

49. Refer to the following page of single phase motor circuits.
What type of motor is shown in Figure D?

50. Refer to the following page of single phase motor circuits.
What type of motor is shown in Figure E?


SINGLE PHASE MOTORS
A
MAIN
B
C
D
E

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Split Phase Motor Identification

Objective

To identify the major parts and features of a typical single speed single phase split phase induction motor.

Equipment

Typical split-phase single phase motor up to about 0.5 kW.
Suitable parts tray.
Hand tools as required.
High voltage insulation tester.
Multimeter.
Felt tip marking pen.

Procedure

Note: Minor variations to this procedure may be necessary for different types of motor.

1. Make sure that the motor is not connected to the supply.

2. Examine the motor provided and record all nameplate details.
Record the general type of construction of the motor, and the intended mounting position (e.g. foot mounted or flange mounted).

Nameplate Details

Type of Construction ---------------   Mounting Position -----------------

3. Mark the position of both end shields in relation to the stator carcase using a felt pen. Use one line for the drive end and two lines for the non-drive end. Note that in industry it is common to mark the position of the end shields with small centre punch marks.

4. Plan the job - decide on the general sequence in which the motor should be dismantled. If the bearings are of the ball or roller type with bolted bearing caps, the earing caps should be removed first, otherwise the end shield retaining bolts should be removed first. All parts must be placed in a parts tray.

5. Carefully loosen both end shields and remove the end shield which does not house the centrifugal switch.

6. Withdraw the squirrel cage rotor, taking care not to allow it to touch the stator winding at any time (if you are not careful you could damage the stator winding with the rotor or the shaft). Support the end shield housing the centrifugal switch so that no strain is placed on the connecting wires.

7. Examine the parts of the motor and answer the following questions:

   a. What metal are the end shields made from?

   b. What type of fasteners are used to secure the end shields to the stator carcase (e.g. bolts, through bolts, socket-head screws)?

   c. What type of bearing is used on the drive end of the motor?

   d. What type of bearing is used on the non-drive end of the motor?

   e. What is the identification number on the drive-end bearing (if it is a ball or roller type)?

   f. What is the identification number on the non-drive-end bearing (if any)?

   g. What type of material is the stator core made from?

   h. What type of material is the rotor core made from?

   i. What type of material is the rotor winding made from?

   j. How many slots are there in the stator?

k. How many separate windings are there in the stator?
What are they called and what is the resistance of each?

l. What material is the terminal block made from?

m. How many terminals are there on the terminal block and how are they marked?

n. How many screws (or bolts) are used to retain the drive end bearing cap (if any)?

o. What size is the conduit entry to the terminal box (if any)?

p. Where is the main cooling fan located?

q. Are the rotor bars parallel to the rotor shaft?

r. Note and record the specifications and ratings of the starting capacitor.

s. Are the centrifugal switch contacts normally open or normally closed?

8. Measure and record the insulation resistance of the stator winding.

9. Re-assemble the motor, taking care not to damage any components or force them into position.

11. Have your answers and results checked by your Lecturer.

12. Return all of the equipment to its proper place.

Questions

1. Use the power and voltage ratings of the motor to calculate the expected line current using Ohm's Law. Explain why the calculated current is much higher than the current shown on the nameplate.

2. What is the d.c. resistance of the following components:

   a. The run winding.

   b. The start winding.

   c. The centrifugal switch.

3. What is the minimum permissible insulation resistance for a split phase start motor which is to be operated on a normal 240 volt single phase 50 Hz supply?

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Capacitor Start Motor - Component Identification

Objective

To identify the major parts and features of a typical single phase capacitor-start induction motor.

Equipment

Typical single phase capacitor-start motor up to about 0.5 kW.
Suitable parts tray.
Hand tools as required.
High voltage insulation tester
Multimeter.
Felt tip marking pen.

Procedure

Note: Minor variations to this procedure may be necessary for different types of motor.

1. Make sure that the motor is not connected to the supply.

2. Examine the capacitor-start motor provided and record all nameplate details. Record the general type of construction of the motor, and the intended mounting position (e.g. foot mounted or flange mounted).

Nameplate Details

____

____

____

____

Type of Construction Mounting Position ----------------

3. Mark the position of both end shields in relation to the stator carcase using a felt pen. Use one line for the drive end and two lines for the non-drive end. Note that in industry it is common to mark the position of the end-shields with small centre punch marks.

4. Plan the job - decide on the general sequence in which the motor should be dismantled. If the bearings are of the ball or roller type with bolted bearing caps, the bearing caps should be removed first, otherwise the end shield retaining bolts should be removed first. All parts must be placed in a parts tray.

5. Carefully loosen both end shields and remove the end shield which does not house the centrifugal switch.

6. Withdraw the squirrel cage rotor, taking care not to allow it to touch the stator winding at any time (if you are not careful you could damage the stator winding with the rotor or the shaft). Support the end shield housing the centrifugal switch so that no strain is placed on the connecting wires.

7. Examine the parts of the motor and answer the following questions:

   a. What metal are the end shields made from?

   b. What type of fasteners are used to secure the end shields to the stator carcase (e.g. bolts, through bolts, socket-head screws)?

   c. What type of bearing is used on the drive end of the motor?

   d. What type of bearing is used on the non-drive end of the motor?

   e. What is the identification number on the drive-end bearing (if it is a ball or roller type)?

   f. What is the identification number on the non-drive-end bearing (if any)?

   g. What type of material is the stator core made from?

   h. What type of material is the rotor core made from?

   i. What type of material is the rotor winding made from?

   j. How many slots are there in the stator?

   k. How many separate windings are there in the stator? What are they called and what is the resistance of each?

   l. What material is the terminal block made from?

   m. How many terminals are there on the terminal block and how are they marked?

n. How many screws (or bolts) are used to retain the drive end bearing cap (if any)?

o. What size is the conduit entry to the terminal box (if any)?

p. Where is the main cooling fan located?

q. Are the rotor bars parallel to the rotor shaft?

r. Note and record the specifications and ratings of the starting capacitor.

s. Are the centrifugal switch contacts normally open or normally closed?

8. Check the serviceability of the starting capacitor.

9. Measure and record the insulation resistance of the stator winding.

10. Re-assemble the motor taking care not to damage any components or force them into position.

11. Have your answers and results checked by your Lecturer.

12. Return all of the equipment to its proper place.

Questions

1. Use the power and voltage ratings of the motor to calculate the expected line current using Ohm's Law. Explain why the calculated current is much higher than the current shown on the nameplate.

2. What is the d.c. resistance of the following components:

   a. The run winding. b. The start winding.
   c. The starting capacitor. d. The centrifugal switch.

3. What is the basic difference between the construction of a split phase motor and a capacitor-start motor of the same kW rating (apart from the presence of a capacitor)?

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 7 Activity Sheet 3	G006A SGB 12/2013

Split Phase Motor Connections

Objective

To connect a typical single speed single phase split phase induction motor to the supply and test it for correct operation.

Equipment

Typical single speed split phase motor project board.
Clip-on ammeter.
Multimeter.
Hand-held tachometer.
Single phase lead board.

Procedure

DANGER TAG PROCEDURE REQUIRED

1. Examine the motor nameplate and record the following details:

Line Voltage		Power Rating	
Full Load Current		Number of Phases	
Full Load Speed		Connection	

2. Draw a circuit diagram of a single phase capacitor start motor connected to a 240 volt supply. Show the position of the incoming line connections. Have your circuit diagram checked by your Lecturer.

Circuit Diagram

3. Identify the terminals for the internal electrical components and record the resistance of each:

   a. The run winding.
   b. The start winding.
   c. The centrifugal-switch.

4. Connect the motor according to your diagram. Make sure that the earth is securely connected.

5. Check your wiring for short circuits using a multimeter set to the ohms x 1 range. Check the earth continuity to the motor is less than 1 ohm.

6. Have your connections checked by your Lecturer.

7. Switch the motor on and test it for correct operation. Record the no-load speed in the Results Table. Measure the line current with a clip-on ammeter. Measure the rotor speed. Record the results.

8. Switch the motor off and remove the plug from the outlet.

9. Change your connections so that the motor will run in the opposite direction.

10. Check your wiring for short circuits using a multimeter set to the ohms x 1 range. Check the earth continuity to the motor is less than 1 ohm.

11. Have your connections checked by your Lecturer.

12. Test the motor for correct operation. Measure the line current with a clip-on ammeter. Measure the rotor speed. Record the results.

13. Switch the motor off and remove the plug from the outlet.

14. Have your results checked by your Lecturer.

15. Return all of the equipment to its proper place.

Results Table

	No Load Speed	Line Current
Forward		
Reverse		

Questions

1. Does the measured speed correspond with the speed shown on the motor nameplate? If not, why?

2. Does the measured line current correspond with the current shown on the motor nameplate? If not, why?

3. Was there a significant difference between the speed in forward and the speed in reverse?

4. What type of mechanism was used to disconnect the start winding in the motor used for this project?

5. Besides the type of starting mechanism in this motor, name another type of device used to disconnect the start windings in split-phase motors.

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 7 Activity Sheet 4	G006A SGB 12/2013

Capacitor Start Motor Connections

Objective

To connect a typical single speed single phase capacitor start induction motor to the supply and test it for correct operation.

Equipment

Typical single speed capacitor-start motor project board.
Clip-on ammeter.
Multimeter.
Hand-held tachometer.
Single phase lead board.

Procedure

DANGER TAG PROCEDURE REQUIRED

1. Examine the motor nameplate and record the following details:

Line Voltage		Power Rating	
Number of Phases		Full Load Current	
Full Load Speed		Connection	

2. Draw a circuit diagram of a single phase capacitor start motor connected to a 240 volt supply. Show the position of the incoming line connections. Have your circuit diagram checked by your Lecturer.

Circuit Diagram

3. Identify the terminals for the internal electrical components and record the resistance of each.

   a. The run winding. b. The start winding.

   c. The starting capacitor. d. The centrifugal switch.

4. Connect the motor according to your diagram. Make sure that the earth is securely connected.

5. Check your wiring for short circuits using a multimeter set to the ohms x 1 range. Check that the earth continuity is less than 1 ohm

6. Have your connections checked by your Lecturer.

7. Switch the motor on and test it for correct operation. Record the no- load speed in the Results Table. Measure the line current with a clip-on ammeter. Measure the rotor speed. Record the results.

8. Switch the motor off and remove the plug from the outlet.

9. Change your connections so that the motor will run in the opposite direction.

10. Check your wiring for short circuits using a multimeter set to the ohms x 1 range. Check that the earth continuity is less than 1 ohm

11. Have your connections checked by your Lecturer.

12. Test the motor for correct operation. Measure the line current with a clip-on ammeter. Measure the rotor speed. Record the results.

13. Switch the motor off and remove the plug from the outlet.

14. Record the capacity and voltage rating of the starting capacitor:

    Capacity: Voltage Rating:

15. Have your results checked by your Lecturer.

16. Return all of the equipment to its proper place.

Results Table

	No Load Speed	Line Current
Forward		
Reverse		

Questions

1. Does the measured speed correspond with the speed shown on the motor nameplate? If not, why?

2. Does the measured line current correspond with the current shown on the motor nameplate? If not, why?

3. Was there a significant difference between the speed in forward and the speed in reverse?

4. Explain the behaviour of the multimeter when testing the discharged capacitor for d.c. resistance.

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 7 Summary 7.2	G006A SGB 12/2013

Shaded Pole Motors

Shaded Pole Motors

1. A shaded pole motor is a single phase a.c. motor which has a squirrel cage rotor and a salient pole field system. It is used in low power applications which require a low starting and running torque, such as small exhaust fans and blowers. Typical sizes range from about 10 watts to about 300 watts.

2. Most shaded pole motors have either two or four magnetic field poles. Each magnetic pole is formed by a wound field coil and is slotted at one end to accommodate a single short-circuited turn of copper or aluminium, known as a 'shading ring'.
A typical arrangement is shown in Figure 1.

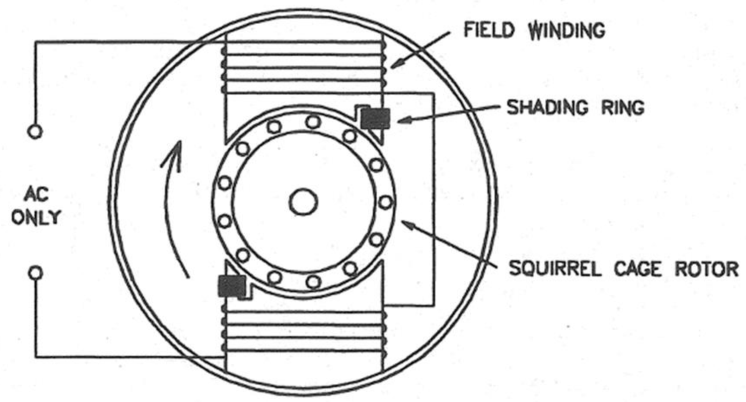


Figure 1 - Typical shaded pole field system with shading rings

Shaded Pole Motor Operation

3. A shaded pole motor develops torque because the arrangement of the field system results in a gradual shift of the magnetic axis across each pole face during each half cycle of the a.c. supply. The shift of the magnetic axis occurs as a result of the interaction between the magnetic flux created by the main field pole(s), and the flux produced by a current induced in the shading ring by electromagnetic induction. The general principle is illustrated in Figure 2.

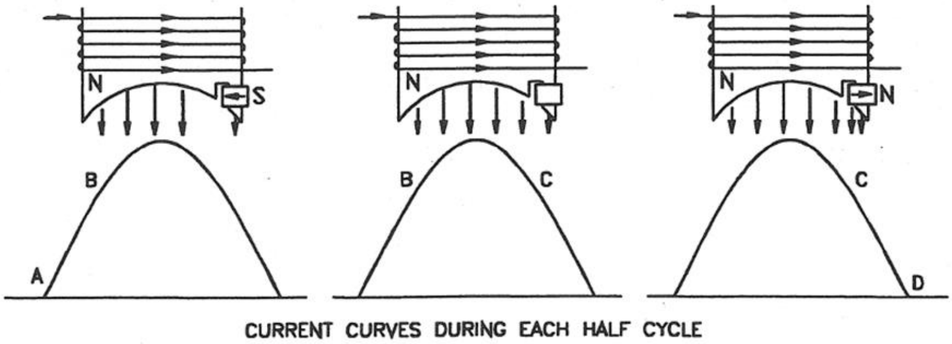


Figure 2 - Shift of magnetic flux during each half cycle.

4. When the current in the main field coil is increasing at the start of the half cycle (from A to B in Figure 2), a current is induced in the shading ring which opposes the force which is creating it (Lenz's Law). The direction of the current in the shading ring is such that it produces a magnetic flux which opposes the main flux, thereby reducing the total flux on the right hand side of the field pole.

5. When the main field coil current is changing from B to C, the rate of change is lower than it is from A to B, so very little current is induced in the shading ring. Under these conditions little flux is produced by the shading ring so there is no significant opposition to the flux produced by the main field coil.

6. When the main field coil current is falling from C to D the rate of change is comparitively large, so current is induced in the shading ring, but the direction of current is such that it results in a flux which tends to prevent the main flux from falling, thus the total flux is stronger than it would otherwise be.

7. The slight change in total flux across each pole face during each half cycle is sufficient to induce a current in the squirrel cage rotor, which, in turn, produces a magnetic flux in the rotor core. The reaction between the flux from the field poles and the flux produced by the current in the rotor is sufficient to cause the rotor to develop torque in the same direction as the flux sweeping across the pole faces - i.e. from the un-shaded side to the shaded side.

Characteristic Curve

8. The characteristic curve for a typical shaded pole motor is shown in Figure 3.

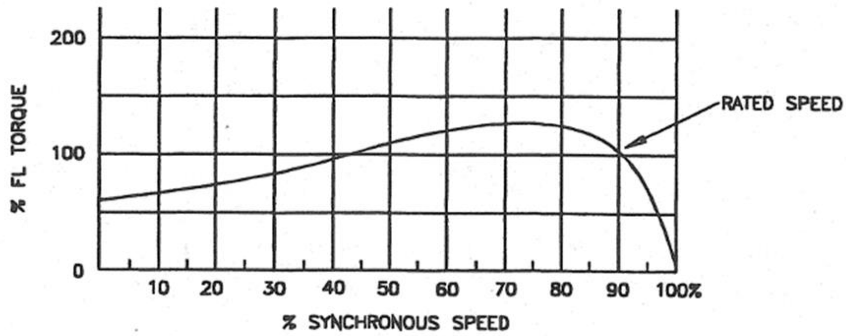


Figure 3 - Characteristic curve of a typical shaded pole motor.

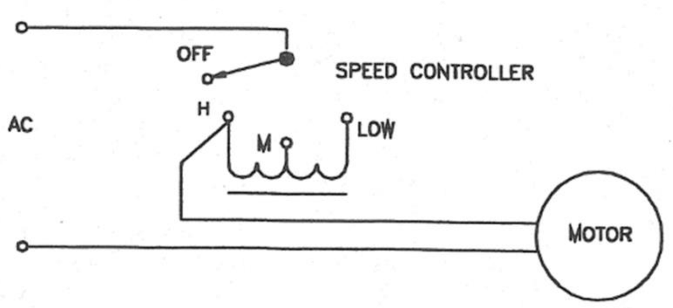
Reversal.

9. Since the direction of rotation of the rotor is governed by the physical position of the shading ring on the field pole, typical shaded pole motors cannot be reversed electrically. It is possible to fit a shading ring at each end of each field pole and switch one or the other to provide for reversal of direction, but this arrangement is very rare. It may be possible to physically end-for-end the stator in its housing to provide for reversal of direction, but in most cases this is not practical.

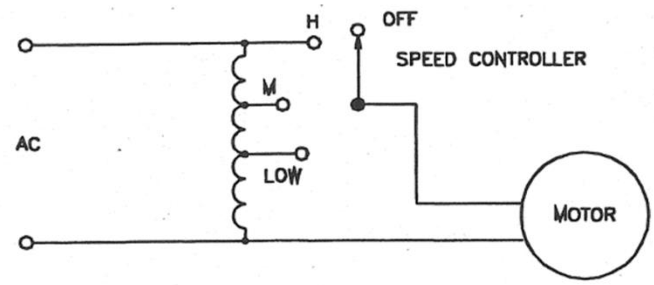
Speed Control.

10. The speed of a shaded pole motor at its full rated voltage depends on the load. If the load is constant (such as in an exhaust fan) the speed can be controlled using one of the following methods:

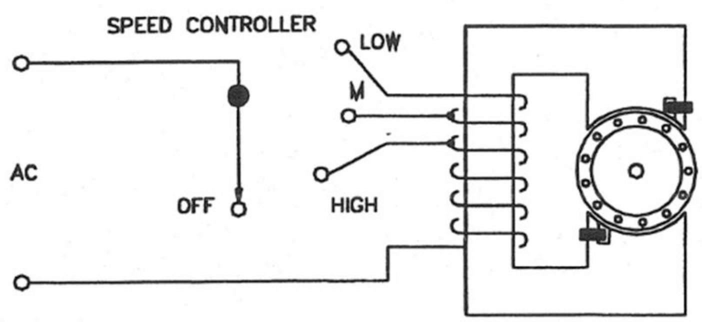
   a. Choke control.



   b. Autotransformer control.



   c. Tapped winding control.



11. Since shaded pole motor develop very little torque it is customary for speed control devices to switch directly from OFF to the high speed - then to the lower speeds if required.

12. If a shaded pole motor is being bench tested, the speed control mechanism will not usually cause a significant change in rotor speed unless the motor is loaded because the slip depends on the load.

Common Fault

13. A common fault which develops in small shaded pole motors is poling - the rotor touches the stator poles and the rotor cannot turn. This can be caused by bearing wear, bearing misalignment, or the accumulation of foreign matter in the air gap. The bearings of small shaded poles are usually plain metal bearings made from either brass or bronze. These bearings may dry out over time causing the rotor to lock. The stator winding may not burn out, because although the rotor is stationary, the current in the stator winding is not sufficient to cause it to burn out. By applying a small amount of light machine oil will free up the bearings and the motor can be put back into service.

14. If the stator winding is not burnt out the motor can often be repaired by cleaning it out and lubricating the bearings, then re-aligning the end-shields so that the rotor is not touching the stator core.

Testing

15. A shaded pole motor must be tested for short circuits, open circuits and insulation resistance, using the same test instruments as for split phase type motors.

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Shaded Pole Motors

1. How can the direction of rotation of a standard shaded pole motor be reversed electrically?

2. Why are some shaded pole motors fitted with a tapped field coil?

3. What type of rotor is used in a shaded pole motor?

4. What type of rotor bearings are usually used in shaded pole motors?

5. How can the direction of rotation of a shaded pole motor be determined by examining the stator of the motor?

6. A 3 speed shaded pole motor is being tested for correct operation on no load, but no significant speed variation is found between each speed setting.
   What is the most likely fault?

7. What is the lowest possible number of WOUND coils in the field system of a shaded pole motor?

8. What are the three most common methods of controlling the speed of a shaded pole motor?

9. What type of field .pole construction is most commonly used in shaded pole motors?

10. How many line terminals would usually be found on a single speed shaded pole motor?

11. What is a common fault that can occur in small shaded pole motors and how can it be corrected?

12. Can shaded pole motors be operated on d.c.?

13. Describe three electrical faults which can occur in shaded pole motors, and state how they can be detected.

14. Draw a circuit diagram of a typical shaded pole motor connected to a 240 V a.c. supply (without speed control).

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 7 Activity Sheet 5	G006A SGB 12/2013

Shaded Pole Motor Construction

Objective

To identify the major parts and features of a typical single phase shaded pole motor.

Equipment

Typical shaded pole motor up to about 0.5 kW.
Suitable parts tray.
Hand tools as required.
High voltage insulation tester.
Multimeter.
Felt tip marking pen.

Procedure

Note: Minor variations to this procedure may be necessary for different applications of motor.

1. Make sure that the motor is not connected to the supply.

2. Examine the shaded pole motor provided and record all nameplate details. Record the general type of construction of the motor, and the intended mounting position (e.g. foot mounted or flange mounted).

Nameplate Details

____

____

____

Mounting Position

____

3. Mark the position of both end shields in relation to the stator carcase using a felt pen. Use one line for the drive end and two lines for the non-drive end. Note that in industry it is common to mark the position of the end-shields with small centre punch marks.

4. Plan the job - decide on the general sequence in which the motor should be dismantled. If the bearings are of the ball or roller type with bolted bearing caps, the bearing caps should be removed first, otherwise the end shield retaining bolts should be removed first. All parts must be placed in a parts tray.

5. Carefully loosen both end shields and remove the end shields.

6. Withdraw the squirrel cage rotor, taking care not to allow it to touch the stator winding at any time (if you are not careful you could damage the stator winding with the rotor or the shaft).

7. Examine the parts of the motor and answer the following questions:

   a. What metal are the end shields made from?

   ---

   b. What type of fasteners are used to secure the end shields to the stator carcase (e.g. bolts, through bolts, socket-head screws)?

   ---

   c. What type of bearing is used on the drive end of the motor?

   ---

   d. What type of bearing is used on the non-drive end of the motor?

   ---

   e. What is the identification number on the drive-end bearing (if it is a ball or roller type)?

   ---

   f. What is the identification number on the non-drive-end bearing (if any)?

   ---

   g. What type of material is the stator core made from?

   ---

h. What type of material is the rotor core made from?

i. What type of material is the rotor winding made from?

j. How many salient poles are there on the stator?

k. How many shading rings are in the motor?

l. What material is the terminal block made from?

m. Where is the main cooling fan located (if any)?

n. Are the rotor bars parallel to the rotor shaft?

o. How many line terminals or supply cables are there on the motor?

8. Measure and record the insulation resistance of the stator winding.

9. Re-assemble the motor taking care not to damage any components or force them into position. Make sure that the rotor rotates freely when the motor is assembled.

10. Have your answers and results checked by your Lecturer.

11. Return all of the equipment to its proper place.

Questions

1. What is the d.c. resistance of the entire stator winding?

2. What is the minimum permissible insulation resistance for a shaded pole motor which is to be operated on a normal 240 volt single phase 50 Hz supply?

3. List three typical applications for shaded pole motors.

4. How many line terminals would you expect to find in a typical shaded - pole motor?

	Solve problems in single phase and three phase low voltage machines	Section 7 Activity Sheet 6	G006A SGB 12/2013

Government of Western Australia North Metropolitan TAFE

Shaded Pole Motor Connections

Objective

To connect a shaded pole motor to the supply and test it for correct operation.

Equipment

Shaded pole motor project board (with speed controller).
High voltage insulation tester.
Hand-held tachometer.
240 volt power board.
Multimeter.

Procedure

DANGER TAG PROCEDURE REQUIRED

1. Examine the shaded pole motor and locate the terminals for the incoming supply.

2. Measure the d.c. resistance of the motor and record the reading.

   Resistance:

3. Note whether the motor is single insulated or double insulated.

   ____

4. Draw a diagram showing the motor connected to the supply, with an ammeter to measure the line current.

5. Connect the motor according to your diagram.

6. Check your circuit for short circuits with a multimeter set to the ohms times 1 range. Have your connections checked by your Lecturer.

7. Energise the circuit and measure the line current and speed for each position of the speed controller. Record the readings in the Results Table.

Results Table

	Line Current	Speed
Off Position		
Low Position		
Med Position		
High Position		

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

9. Have your results checked by your Lecturer.

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

Questions

1. What type of speed controller was fitted to the motor?

2. Is it practical to reverse the direction of rotation of a typical shaded pole motor?

3. Would a shaded pole motor be able to operate on d.c.?

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 7 Summary 7.3	G006A SGB 12/2013

Series Universal Motors

Series Universal Motor

1. A series universal motor is a motor which has the same basic construction as a d.c. series motor. It is known as a universal motor because it can operate on either d.c. or a.c. up to about 50 Hz (if it is run on d.c. the operating switch must be suitable for d.c. operation).

2. The series universal motor is the type of motor used in many portable appliances such as electric drills, saws, angle grinders, sewing machines, domestic vacuum cleaners, floor polishers and food mixers. Small battery operated portable appliances usually have series universal motors operating at extra-low voltage d.c. - typically less than 36 volts.

3. A typical series universal motor consists of two field coils wound on laminated iron poles, and a rotating armature. The electrical connection to the armature is through two spring-loaded carbon brushes. A typical general arrangement for small appliances is shown in Figure 1.

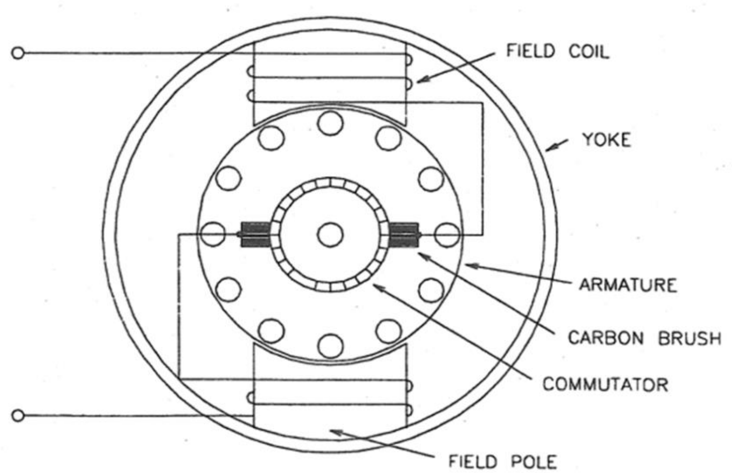

Figure 1 - Series universal motor arrangement.

4. The armature consists of coils of insulated winding wire wound in semi-enclosed slots in the armature. The two ends of each coil are connected to two adjacent segments on the commutator so that the complete armature winding forms a closed series loop as shown in Figure 2. Many variations in winding design are possible, and consideration of the types is beyond the scope of this course, but you should be aware that the position of the carbon brushes is not the same in all series motors.

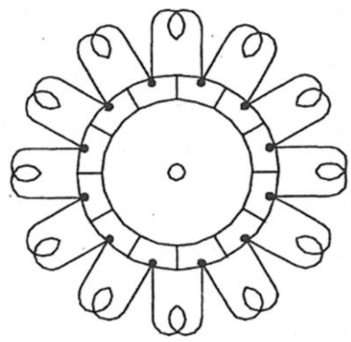

Figure 2 - Armature winding forming a closed loop.

5. The field coils and the armature are connected in series. When current passes through the motor, magnetic poles are formed by the field system and a corresponding magnetic field is formed on the armature. Interaction between the magnetic fields of the field poles and the armature cause the armature to rotate.
The characteristic curve of a typical series universal motor is shown in Figure 3.

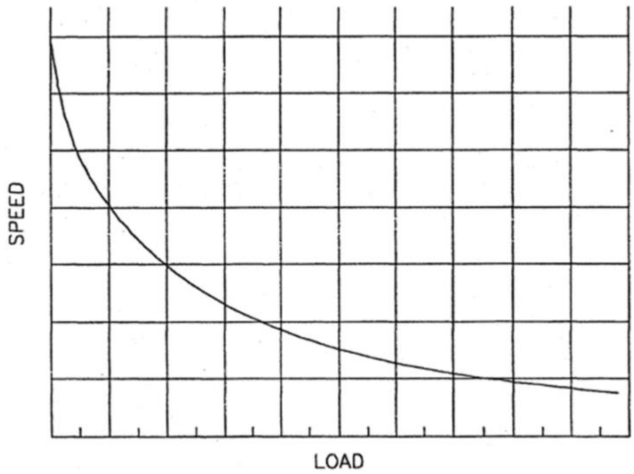

Figure 3 - Characteristic curve of a typical series universal motor.

Reversal.

6. The direction of rotation can be reversed by reversing the current in either the field coils or the armature - but not both. In most cases it is easier to alter the connections to the armature.

Brush Position

7. The position of the carbon brushes on the commutator is critical - if it not within the designed limits excessive sparking at the brushes will occur. The optimum brush position for minimum brush sparking in a particular motor varies as the speed and load varies. Machines which run at a constant speed have the brushes set for that speed, but motors which can be operated at different speeds will usually spark more at one speed than another. Most single direction electrical drills, for example, have the brush position set so that minimum sparking occurs at full load. Drills which can be reversed have the brush position set so that minimum sparking occurs on no load, so some brush sparking should be expected on full load in either direction.

8. The operating characteristics of a series motor are such that there is no electrical means of limiting the maximum speed on no load. If a series motor is allowed to run on no load the armature can reach dangerous speeds (many thousands of revolutions per minute), so they should not be run on no-load. Portable electric hand tools usually have a reduction gear mechanism which provides enough load when they are running unloaded to prevent excessive armature speed.

Advantages

9. The main advantage of the series universal motor over other types of single phase motor is its high starting and running torque. Another advantage is that the speed can be controlled using relatively inexpensive electronic speed controllers. However, care should be taken when operating series motors at low speeds because the speed of the internal fan may not be enough to provide adequate cooling for the windings.

Interference

10. The continual making and breaking of the electrical contact at the commutator, of a series motor results in a significant amount of electrical interference to sensitive electronic equipment such as radios and television sets, so many motors are fitted with interference suppression equipment.

Testing

11. Field Coils The field coils should be tested for resistance and insulation resistance during any routine service. The resistance of both field coils should be the same, and the insulation resistance should be sufficiently high for the combined insulation resistance of the fields and armature to be above the minimum permissible value of 1 megohm.

12. Armature The armature should be tested for short circuits, open circuits and earth faults.

13. Short circuits can be detected by placing the armature on an external growler and placing an old hacksaw blade over each slot in turn as shown in Figure 4. If the blade vibrates it indicates that there is a short circuit in the coil in that slot. If a short circuit is indicated you should clean out the small slots between the commutator segments - in case any conducting material has lodged between them.

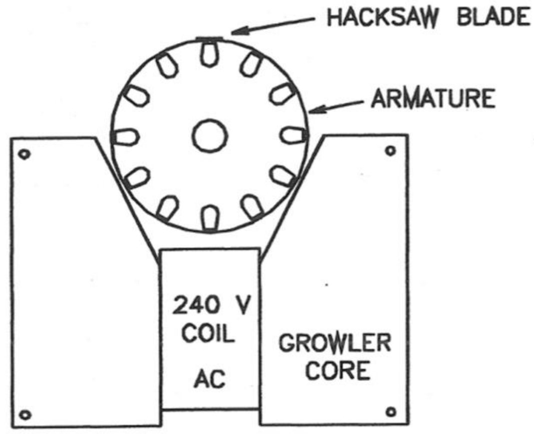

Figure 4 - Testing an armature for short circuits on a growler.

14. Open circuits can be detected by wrapping several turns of fuse wire around the commutator, then testing for short circuits on an external growler. With the commutator short-circuited the hacksaw blade should vibrate over every slot. If there is no vibration it indicates an open circuit. It is also possible to test for open circuits by placing the armature on a growler and gently drawing an old hacksaw blade across the ends of the commutator so that it provides a circuit between adjacent commutator segments. There should be a small spark, if there is no spark it indicates that there could be an open circuit. The armature should be turned so that the commutator segments being tested are always in the same relative position on the growler.

15. Earth Faults The insulation resistance of a typical armature winding can be tested by connecting a high voltage insulation tester between any segment and the laminated armature core. It is not necessary to test all segments because they are all connected together by the armature winding.

16. The armature in a double insulated portable appliance often has an insulating sleeve in the shaft to insulate the laminated armature core from the associated driving gear.

17. If an armature test indicates the presence of any one of the faults listed above the armature needs to be replaced or rewound.

Speed Control

18. Speed control of universal motor-driven appliances is usually achieved using electronic speed controllers. The operation of electronic speed controllers is beyond the scope of this unit.

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 7 Work Sheet 3	G006A SGB 12/2013

Series Universal Motors

1. What material are the BRUSHES made from in series universal motors?
2. What undesirable situation can arise if electronically-controlled series universal appliance motors are operated at low speed, for long periods.
3. Under what conditions (if any) would a single speed 240 volt a.c. series universal motor operate safely on 240 volts d.c.?
4. How is torque produced in a series universal motor?
5. What dangerous situation can arise if a series universal motor is operated with no load?
6. What type of speed control is most commonly used for series universal motors?
7. What type of field pole construction is most commonly used in series universal motors?
8. How many line terminals would usually be found on a typical series universal motor?
9. How can the direction of rotation of a single phase series universal motor be reversed?
10. Why does a uni-directional series universal motor often spark more on no load than it does on full load?
11. How many field poles does a typical series universal motor have?
12. What three common electrical faults can occur in universal motors?
13. What common electrical device is used to bench-test a universal motor armature for short circuits?
14. What common types of universal motor-driven appliances have insulation between the main armature shaft and the associated metallic driving gear?

	Solve problems in single phase and three phase low voltage machines	Section 7 Activity Sheet 7	G006A SGB 12/2013

Government of Western Australia North Metropolitan TAFE

Series Universal Motor Construction

Objective

To identify the major parts and features of a typical single phase series universal motor.

Equipment

Series motor project board.
High voltage insulation tester.
Multimeter.
Felt tip marking pen.

Procedure

1. Examine the series universal motor provided and draw a neat freehand pencil sketch of the following components:

   a. The armature (Label each part)

b. The brush assembly (Label each part)

c. The field system (Label each part)

2. Measure and record the resistance of each field coil.

3. Examine the parts of the motor and answer the following questions:

   a. What metal are the end shields made from?

   b. What type of bearing is used on the drive end of the motor?

   c. What type of bearing is used on the non-drive end of the motor?

   d. What type of material is the core of the field made from?

e. What type of material is the armature core made from?

---

f. What type of material is the commutator segments made from?

---

g. How many salient poles are there on the field system?

---

h. How many brushes are there in the motor?

---

i. What material is the terminal block made from?

---

j. Where is the main cooling fan located?

---

k. Are the armature slots parallel to the shaft?

---

l. How many line terminals or supply cables are there on the motor?

---

4. Measure and record the insulation resistance of the armature and the field coils.

   Armature: Field Coils:

5. Have your answers and results checked by your Lecturer.

6. Return all of the equipment to its proper place.

Questions

1. Why is it dangerous to operate a series motor on no load?

2. List three applications for a.c. series universal motors.

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Series Universal Motor Connections

Objective

To connect a typical series universal motor to the supply and test it for correct operation.

Equipment

Universal motor project board.
Clip-on ammeter.
Multimeter.
Hand-held tachometer.
Single phase lead board.
Single phase variable transformer (Variac)

Procedure

DANGER TAG PROCEDURE REQUIRED

1. Examine the motor nameplate and record the following details:

Line Voltage		Power Rating	
Full Load Current		Frequency	
Full Load Speed		Manufacturer	

2. Draw a circuit diagram of the universal motor connected to a 240 volt supply. Show the position of the incoming line connections. Have your circuit diagram checked by your Lecturer.

Circuit Diagram

3. Identify the line terminals. Measure and record the d.c. resistance of the motor.

4. Connect the motor according to your diagram. Make sure that the earth is securely connected. Make sure that the load is connected.

5. Check your wiring for short circuits using a multimeter set to the ohms x 1 range. Check that the earth continuity to the motor is less than 1 ohm.

6. Have your connections checked by your Lecturer.

7. Switch the motor on and test it for correct operation. Record the loaded speed in the Results Table. Measure the line current with a clip-on ammeter. Measure the rotor speed. Record the results.

8. Switch the motor off and remove the plug from the outlet.

9. Change your connections so that the motor will run in the opposite direction.

10. Check your wiring for short circuits using a multimeter set to the ohms x 1 range.

11. Have your connections checked by your Lecturer.

12. Test the motor for correct operation. Measure the line current with a clip-on ammeter. Measure the rotor speed. Record the results.

13. Switch the motor off and remove the plug from the outlet.

14. Have your results checked by your Lecturer.

15. Return all of the equipment to its proper place.

Results Table

	On Load Speed	Line Current
Forward		
Reverse		

Questions

1. Why is it dangerous to run a series motor on full voltage on no load?

2. Does the measured line current correspond with the currents shown on the motor nameplate? If not, why?

3. Was there a significant difference between the speed in forward and the speed in reverse?

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Motor Protection

Task:

To describe the construction and operation of electric motor protection equipment used in motor circuits.

Why:

You need to have knowledge of the construction, the operation and general principles of electric motor protection so you can recognise them, safely connect them into motor circuits, and diagnose and correct simple electrical or mechanical faults.

To Pass:

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

Equipment:

Sample HRC motor rated fuses
Sample motor overload devices including:
    Three phase motor thermal overloads, microtherms and thermistors.
Multimeter.
AC clip-on and fixed ammeters.
High voltage insulation tester.

References:

* Electrical Principles for the Electrical Trades (6th ed.)Jenneson, J.R, Harper, B & Moore, B.

Safety:

You must demonstrate safe working practices at all times.

	Solve problems in single phase and three phase low voltage machines	Section 8 Study Guide	G006A SGB 12/2013

Motor Protection

Suggested Self-Study Guide

1. Study the following sections in the recommended references: Electrical Principles for the Electrical Trades Volume 2
   Chapter 9 Electric Motor Protection

   – Section 9.1 Motor Protection

   - Section 9.2 Protection Devices

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 Activity Sheets in this Workbook.

5. Submit your answers to the Work Sheets and your completed project reports to your Lecturer for discussion and assessment.

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Motor Protection

1. Most motor starters need to provide protection against the following conditions (see Wiring Rules Clause 4.13.2 for protection against overload):

a. Short circuits in the wiring or the motor.
b. Failure of the supply voltage.
c. Sustained excessive current in the motor winding.

Short Circuit Protection

2. Short circuit protection can be provided by using HRC fuses or circuit breakers. Semi-enclosed rewirable fuses may be found in existing circuits.

3. Fuses and circuit breakers are designed to operate indefinitely at their rated current- they will not 'blow' until the line current reaches between about 120% and 180% of their rated value, depending on the type of fuse and the severity of the fault. Therefore they will NOT protect a motor winding against over-heating in the case of moderate overload.

4. Clause 2.5.4 of the Wiring Rules specifies the requirements for protection against short circuit current. In general, protective devices must interrupt any short circuit current before the current can cause danger due to thermal and mechanical effects.

5. Suitable adjustments may be necessary in special cases such as:

   a. Prolonged starting on heavy load.
   b. A large number of starts in rapid succession.
   c. High enclosure temperature.

No-Volt Protection

6. If the supply to a motor circuit fails it is usually desirable to have the motor stop automatically and remain stopped until action is taken by an operator. This type of protection is known as no-volt protection or under-voltage protection and is automatically provided by magnetic contactors because they drop outs soon as the operating coil is de-energised. If three-wire control is being used the retain contacts will be opened so the motor cannot re-start until the start button is pressed.

7. If the circuit is operating from a two-wire control system protection against a voltage failure may be less critical because the circuit would be designed to operated on an intermittent basis.

8. The control voltage required to operate a contactor satisfactorily is known as the 'pick-up' voltage and the voltage at which it will drop out is known as the 'drop-out' voltage. Pick-up voltages are typically about 85% of the rated voltage and drop-out voltages are typically less than 50% of the rated voltage. This means that a contactor will remain energised even if the supply voltage is reduced to, say, 80% for a prolonged period. Under these conditions the motor would continue to run but the reduction in voltage would result in a corresponding increase in the line current if the motor was on full load. Motor protection under these conditions would be provided by the overloads - not the 'no-volt' protection.

9. If the supply voltage falls to below the contactor coil drop-out value for more than a few milliseconds (the precise time depends on the design of the contactor), it can cause the coil to drop out. Extra-low voltage control circuits (e.g. 24 volts) are much more prone to nuisance tripping as a result of transient voltage fluctuations than 240 or 415 volt coils.

Over-Voltage Protection

10. Over-voltage protection is not normally provided.in electromagnetic motor starter circuits because the motor and the starter can withstand the typical transient voltage spikes in a major supply system.

11. Sustained over-voltage conditions are very rare in major supply systems, but they can occur when power is supplied from a local alternator. If over-voltage is likely to cause a problem, suitable voltage dependent resistors (VDR's) can be connected across he supply.

12. Protection against transient over-voltage as a result of lightning strike can be provided by fitting lightning arresters (surge diverters) as close as possible to the equipment being protected - this is usually at the supply terminals of the installation.

Overload Protection

13. If a motor is operating under conditions which result in the line current exceeding the designed value it is said to be 'overloaded'. Protection against this condition is known as overload protection, over- current protection or over-temperature protection. Motors having a rating exceeding 0.37 kW must be provided with overload protection - see Clause 4.13.2.

14. There are two general overload conditions - short duration overload and sustained overload. Most motors can withstand moderate overload for short durations (up to several minutes, 'depending on the severity of the overload). However, the heat resulting from an increase in load current increases in proportion to the SQUARE of the current ($P = I^2.R$), so doubling the line current would quadruple the amount of heat produced. The overload protection devices discussed here provide protection against severe short duration overload and most sustained overloads.

15. Overload protection is typically provided by connecting a series current-sensing component in the power circuit so that if the line current in one or more phases exceeds a pre-set value a normally closed contact in the control circuit opens and cuts off the supply to the contactor operating coil. The unit which comprises the current sensing components and the control circuit contacts is known as an 'overload relay'.

16. The insulation used in typical electric motors does not have an indefinite life. Overheating of windings over long periods causes a gradual deterioration in the insulation, so overheating should be avoided wherever possible.

17. Electronic overload devices are available to provide against a range of conditions such as phase loss, over-temperature in the motor winding, locked rotor, earth faults and short circuits. They use resistor/capacitor networks to simulate the internal conditions in the motor. Although they are relatively expensive they provide comprehensive protection, and since they usually have indicators to show the fault, the time taken to locate a fault can be significantly reduced.

18. There are two common types of overload relay:

    a. The thermal type.
    b. The electromagnetic type.

Thermal Overload Relays

19. A thermal overload relay makes use of the fact that a bi-metallic strip bends in a particular direction when heated, and returns to its original condition when it has cooled. Figure 2 shows an outline of the general construction of a typical overload relay, and the equivalent circuit in symbol form.

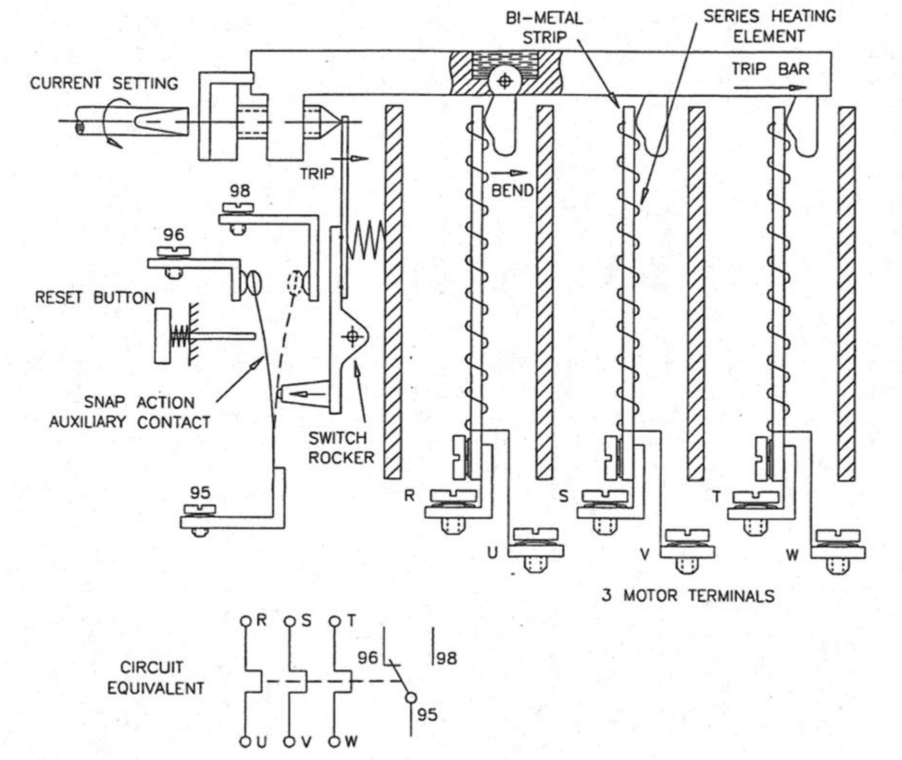

Figure 2 - General construction of a typical overload relay.

20. In Figure 2, all the line current to the motor passes through the series heating element in each phase, causing the bi-metal strips to heat up and bend in a clockwise direction - moving the insulated trip bar to the right. When one or more of the bi-metal strips reaches a pre-set position the movement causes the switch rocker to pivot, opening the snap action auxiliary contact between terminals 95 and 96 and closing the contacts between 95 and 98. Manually pressing the reset button after an overload has occurred resets the overload to its original condition. The current at which the overload trips can be adjusted to any value within the limits of the particular heaters installed in the overload relay.

21. The correct setting for an overload relay is the full load current rating of the associated motor - obtained from the motor nameplate.

22. In larger motors, the overload heaters are not connected directly in the power circuit. Current transformers are connected in series with the motor and the output provides the supply to the overload heaters. This reduces the size of the overload relay required.

23. Since the overload heaters are much smaller than the associated motor they cool down quicker than the motor after an overload. If the motor is restarted repeatedly before it has cooled down, the cumulative heating effect can result in the motor burning out despite the overload protection. Under these conditions thermal overloads would not adequately protect the motor - another type of overload mechanism such as a thermistor overload unit should be installed.

24. Any overload condition which develops in a three phase motor will always result in an increase in line current in at least two phases, so it is only necessary to fit overload heaters to any TWO of the three phases, although many overload relays provide heaters in all three phases.

Single Phasing

25. Special consideration needs to be given to overload protection for delta connected three phase motors because of an effect known as 'single phasing'.

26. Under normal operating conditions a three phase delta connected motor with a full load current rating of 10 amps would draw a full load line current of 10 amps and the correct setting for the overloads would be 10 amps. However, since the coil current in the motor is only 57% of the line current (Phase I= Line I/√3 in delta), the maximum permissible current in each phase would be 5.7 amps. This relationship is shown in Figure 3.

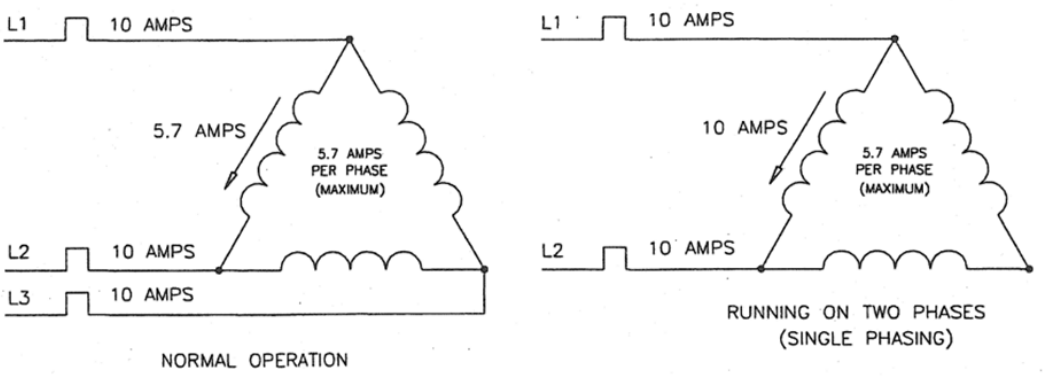

Figure 3 - Phase and line currents in a delta connected motor.

27. If a fault developed which resulted in one line fuse open circuiting while the motor was running, the motor would continue to run as a two phase motor and the line current in the two remaining phases would increase. If the motor was running at less than 57% of full load the line current (in two phases) would be less than 10 amps so the motor would continue to run without suffering any damage. However, if the load on the motor was above 57% of full load the current in ONE of the phases would increase to a value in excess of the maximum allowable phase current of 5.7 amps and that phase could burn out. This effect is known as 'single phasing' of a delta connected motor - it is not as significant in a star connected motor because in star the line current and the phase current are equal.

28. Some overload relays provide protection against single phasing of delta connected motors by using a special mechanism which requires that the current in each phase be approximately the same. In this case the failure of one phase would cause an imbalance in the line currents and the overload mechanism would operate.

29. Overload relays which provide single phasing protection are usually marked accordingly- so if you install a relay without such a marking it is quite likely that single phasing protection is not provided.

Electromagnetic Overload Relays

30. The magnetic overload relay consist of a coil of a few turns of large diameter wire which carries the line current and produces a magnetic field the strength of which is proportional to the line current. The field produced c uses a plunger or central core of the coil to move at a predetermined level .this movement of the plunger operates a trip which opens the contactor circuit.

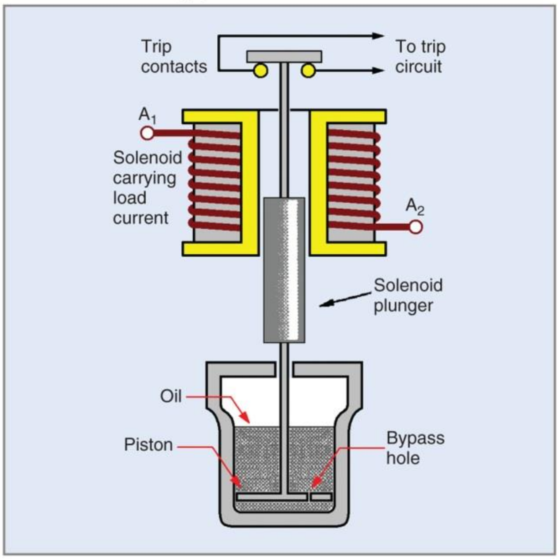

Figure 4 – Electromagnetic overload relay

Oil Dashpot

31. In order to prevent the trip operating when the motor is starting as the motor will draw approx. 6 times its running current from the supply, the relay must be fitted with a delay device. The movement of the plunger is often dampened by having to move through an amount of oil which has to pass through an orifice in the core or via a by-pass hole.

32. This is called a dashpot and can be set at various levels (by means of screwing the dashpot up or down within its support) to suit the conditions under which the motor operates.

Magnetic Overload Tripping Current

33. The trip time and trip current of magnetic overload relays can be independently adjustable which makes the relay ideal for special applications such as slow accelerating, high in rush current motors or any application where normal time/current curves of thermal overload relays do not provide satisfactory operation, or nuisance tripping occurs,

34. The minimum operating current is virtually independent of ambient temperature variations and cumulative heating as might be encountered with frequent starting of motors. Reset time is virtually negligible.

Locked Rotor Protection

35. The 'locked rotor' condition is when a motor is energised, but the rotor is prevented from moving for some mechanical reason - such as a jammed gearbox or fan. Under locked rotor conditions the motor draws the same current as it would at the instant of switching on (say 6 times full load current), but the high current is sustained at that high level.

36. Thermal overload relays can provide Protection against the locked rotor condition because their tripping characteristic is proportional to the product of the square of the current and time, so the overload should trip before the motor burns out.

Temperature Sensing Devices

37. One of the main disadvantages of the thermal and electromagnetic overload devices discussed so far is that they operate by using the line current to indirectly monitor motor temperature. While this is satisfactory in many cases it is not satisfactory when the motor is subjected to abnormal operating conditions such as repeated tripping on overload or excessive ambient temperatures.

38. Standard thermal overload relays are also unsuitable for motors which are started or reversed frequently because of the cumulative heating effect in the motor.

39. Another approach to overload protection is to place a temperature sensing device inside the motor enclosure or inside the motor winding so that it responds to the actual temperature of the motor rather than the current in the winding.

Thermistors

40. A thermistor is a small resistive device which has a high positive or negative temperature coefficient of resistance - a positive temperature coefficient device (PTC) has a large increase in resistance as the temperature increases and a negative temperature coefficient device (NTC) has a large decrease in resistance as the temperature increases.

41. Thermistors can be embedded a motor winding. They are usually used in conjunction with a specially designed electronic circuit which causes the contactor coil circuit to be interrupted when the motor winding temperature reaches a pre-set limit. Thus the motor cannot be operated if the temperature of the winding is above the set limit - regardless of the current in the motor.

Microtherms

42. A microtherm is a small thermostat in which a bi-metal mechanism opens a contact when a particular temperature is reached. The microtherm is small enough to be able to be located inside the motor and the contacts are large enough to be able to be connected in series with the contactor coil.

43. Several variations of this general principle are available, including a self-contained snap action device which can be installed in the end-shield of a single phase motor to disconnect the motor if it overheats for any reason. The trade name of these devices is 'klixon'.

Protection in Motor Starter Circuits

44. Most motor circuits are required to have overload and/or under-voltage protection and isolation in accordance with the requirements of the Wiring Rules. Given that virtually all starters other than electronic types are operated electromagnetically, any of the overload devices discussed in this section could be used in conjunction with any type of electromagnetic starter. As mentioned earlier a standard contactor coil will provide under-voltage when it is connnected to the same supply as the motor.

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Motor Protection

1. Which two common types of motor protection provide protection against a locked rotor condition?

2. Approximately how much current would a typical 20 amp three phase squirrel cage induction motor draw if it was started DOL?

3. Approximately how much current would a typical 10 amp three phase squirrel cage induction motor draw if an attempt was made to start it using a DOL starter with the rotor locked so that it could not move?

4. In general, would it be permissible to install a 10 kW three phase induction motor without over-temperature protection if it was driving an essential fire pump in a large building?

5. What type of protection is provided by all magnetically operated motor starters?

6. What is the largest three phase conveyor motor which may be installed without overload protection according to the Wiring Rules? Give the Clause number.

7. What type of protection is provided by 'surge diverters'?

8. A 20 amp three phase squirrel cage induction motor is to be installed with 20 amp copper cable and protected by HRC fuse. What is the largest HRC fuse which could be installed according to the Wiring Rules?
   Give the Clause number.

9. What is meant by the term 'single phasing' when applied to a three phase motor?

10. Which type of contactor coils are most likely to be affected by transient fluctuations in the supply voltage?

11. What type of motor protection is most likely to provide protection for a three phase induction motor in which the supply voltage is reduced to 90% of its designed value while the motor was running on full load?

12. What type of motor protection is most likely to provide protection for a three phase induction motor if it is subjected to a 50% overload for about 5 seconds?

13. What is the minimum number of overload heaters required in the overload relay for a three phase induction motor?

14. What are the two distinct parts of a thermal 'overload relay'?

15. In which part of a 4 kW three phase motor starter circuit are the overload heaters connected?

16. What are two other names for the type of protection provided by a typical 'overload relay'?

17. Would a thermal overload relay provide protection for a motor in which the ventilating openings were blocked with foreign matter?

18. What additional control component is required in a magnetic motor starter circuit if the full load current rating of the motor is over the maximum available overload relay current range?

19. Why is a typical thermal overload relay unsuitable for protecting a motor which is subjected to repeated overload tripping over a short period of time?

20. What is the advantage of a 'thermistor' type overload protection compared to a thermal overload relay?

21. List five types of overload protection device.

22. Draw a neat WIRING DIAGRAM of a complete thermal over-load relay.

23. To what value should the starter overloads be set if the full load current of the associated motor is 20 amps?

24. What method is normally used to alter the current setting in a magnetic overload relay.

25. A magnetic overload relay has been reported to trip each time the motor is turned on but there does not appear to be a fault in the circuit and the motor is not overloaded. What would be the most likely fault?

26. What type of overload relay can only be operated in a vertical position? Why?

27. What type of overload relay is likely to have an oil dashpot mechanism?

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Synchronous Machines

Task:

To describe the general construction and operation of typical single and three phase alternators and synchronous motors and describe the general effect of varying the d.c. field excitation on synchronous machines.

Why:

Single and three phase alternators are widely used for generating alternating current for use in domestic, industrial and commercial installations. Three phase synchronous motors are not common, but their construction is very similar to three phase alternators. You need to have a knowledge of their construction and general principles of operation so that you can recognise them and make operational adjustments when required.

To Pass:

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

Equipment:

Three phase alternator laboratory test bench.
Sample alternator components and control equipment.
Alternator manufacturers' data.
Sample synchronous motor components and control equipment.
Synchronous motor test bench.
Wound rotor motor/synchronous motor laboratory test bench.

References

* Electrical Principles for the Electrical Trades,(6th ed.). J.R.. Jenneson.

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Synchronous Machines

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades (6th ed.) – Volume Two

Chapter 7 Synchronous machines

1. Read the Summaries and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.
2. Answer the questions given on the Work Sheets. Use a separate answer sheet or sheets for each worksheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.
3. Complete the projects in this workbook.
4. Submit your answers to the Work Sheets and your completed project reports to your Lecturer for discussion and assessment.

Synchronous Machines

1. Synchronous machines are generally electrical machines in which the rotors are designed to run at EXACTLY the same speed as the rotating magnetic field (i.e. synchronous speed).

2. There are three major groups of common synchronous machines, with several variations of each; the groups are:

   a. Single and three phase alternators.
   b. Three phase synchronous motors.
   c. Single phase synchronous motors.

3 The simplest way to explain the differences between alternators and synchronous motors is to use the following power transfer diagrams. In figure 1 – an alternator is converting mechanical energy in to electrical energy and a motor is converting electrical energy in to mechanical energy.

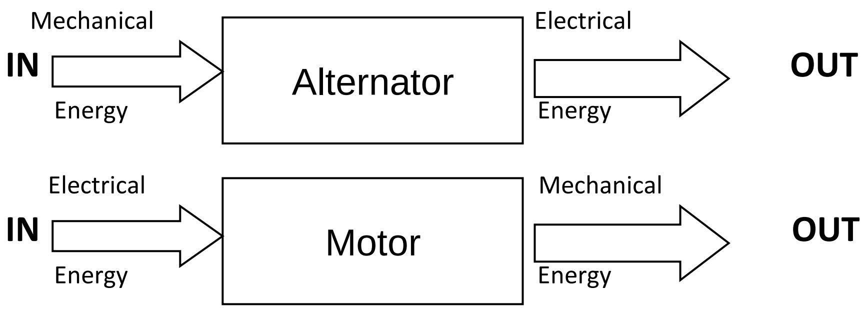


Figure 1- Power transfer of electrical machines

Alternators

4. If a single coil is rotated through a stationary magnetic field at a uniform speed a sinusoidal voltage is induced in the coil. An identical a.c. output can be obtained by reversing the position of the two major components - i.e. by revolving a d.c. magnetic field inside a stationary stator winding called an armature. This arrangement allows for simpler insulation of high voltage output windings, and solid connections between the output winding and the load.

5. A machine which is designed to produce a sinusoidal a.c. output is known as an alternator or a.c. generator - a simplified arrangement for a single phase alternator is shown in Figure 2. The output from the alternator is supplied directly to the load. In large alternators the d.c. for the rotating field is supplied from a d.c. generator (known as an 'exciter') mounted on the same shaft.

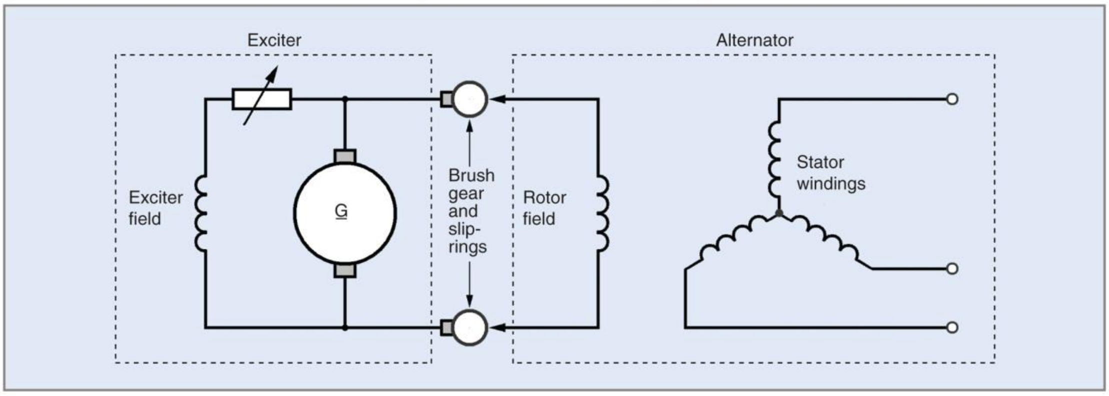


Figure 2 - Simplified representation of a three phase alternator.

6. The voltage produced by a single 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).

7. The frequency of the output voltage from a specific machine depends on the number of magnetic poles and the speed.at which the rotor is rotated, and can be calculated using the equation:

$$Frequency\ (Hz) = \frac{N\ (rpm) \times Poles}{120}$$

8. In order to produce an output frequency of exactly 50 cycles per second (50 Hz) from a two pole alternator, the coil must be rotated at exactly 3000 r/min (synchronous speed).

$$50\ Hz = \frac{3000 \times 2}{120}$$

9. If a d.c. field is rotated within a three phase stator winding similar to the one in a typical induction motor, each revolution of the rotor will produce three separate sinusoidal voltages 120 degrees out of phase with each other, and the machine would be a three phase alternator or three phase a.c. generator. A simplified diagram of a 2 pole three phase alternator is shown in Figure 3.

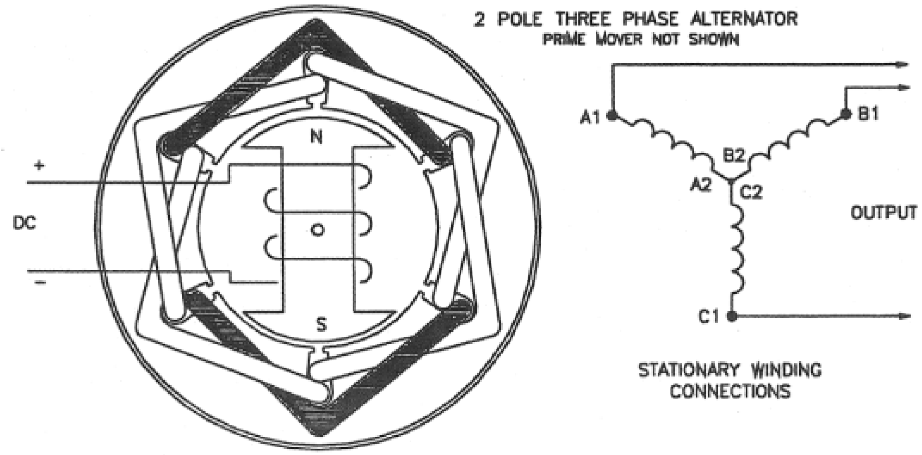


Figure 3 - Simplified three phase two pole alternator.

10. A sine curve of the output from the 2 pole three phase alternator for one revolution of the field is shown in Figure 4- this arrangement would give an output frequency of 50 Hz if the field was rotated at 3000 r/min. If the stationary armature winding was designed for 4 poles, each phase of the alternator would produce 2 cycles for one revolution, so 50 Hz would be obtained at 1500 r/min.

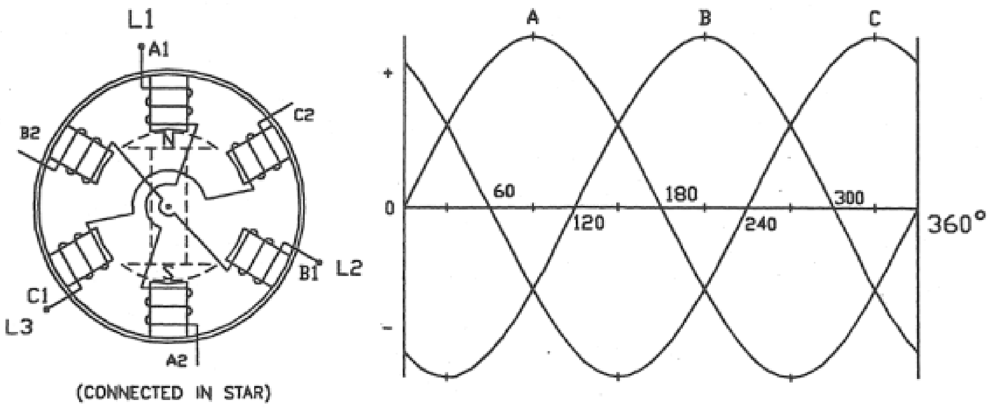


Figure 4 - Two pole three phase alternator output.

11. There are two common types of large three phase alternator- low speed and high speed.

12. **Low Speed Alternators.** A typical low speed alternator (about 100 to 500 r/min) has a rotating field which has many salient poles bolted to a 'spider'. The d.c. is fed to the rotor via slip rings. An outline of the arrangement of the rotating field is shown in Figure 5. A typical prime mover is a diesel engine or a vertically mounted low speed water turbine.

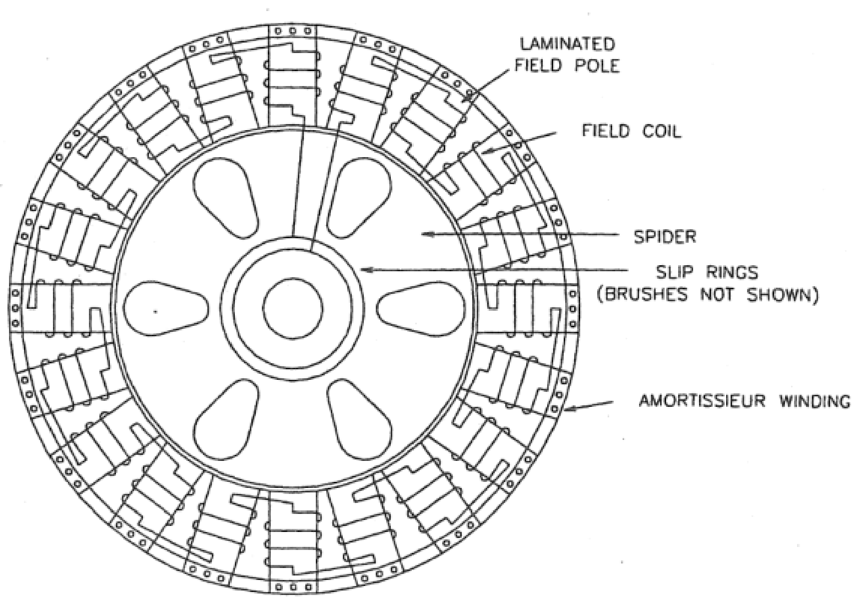


Figure 5 - Outline of a low speed alternator field.

13. Exercise: At what speed would the alternator field shown in Figure 5 need to be rotated to produce an output of 50 Hz?

14. Low speed alternators usually have an amortissuer (similar to a squirrel cage) winding to provide a damping mechanism to lessen the effects of load fluctuation.

15. **High Speed Alternators**. High speed alternators (1500 or 3000 r/min for 50 Hz) have a revolving field which is much smaller in diameter, but much longer - this reduces the effects of centrifugal force on the periphery of the rotor. Most supply authority power generating stations use high speed steam turbines or gas turbines to drive high speed alternators which have a typical output of around 200 megawatts at a voltage of around 22 000 volts.
An outline of the mechanical arrangement of a high speed alternator is shown in Figure 6.

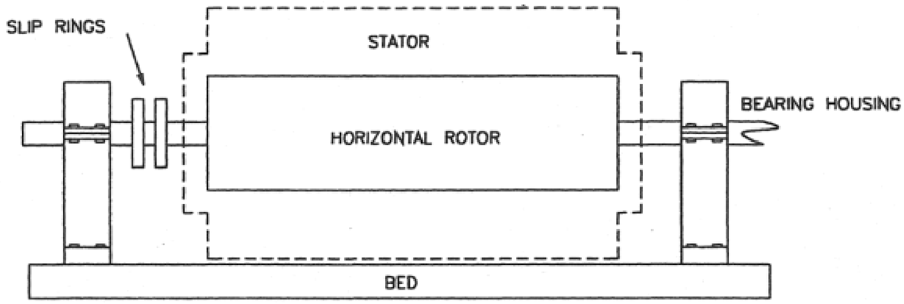


Figure 6 - High speed alternator - mechanical arrangement

Parallel Operation of Alternators

16. A Generating network is designed to run a number of alternators in parallel. These alternators are grouped together in Power Stations such as Muja – near Collie, and Kwinana. The reasons to run alternators in parallel are to share the electrical load and maintain supply if a single alternator is disconnected from the supply network because of a fault or the machine requires maintenance.

Brushless Alternators

17. Portable single and three phase alternators are commonly used where electricity is not readily available from the normal supply. A typical arrangement is for a small petrol engine to supply a 'brushless alternator' of about 1 to 6 kW.

18. Unlike larger alternators which require slip rings and brushes to supply power to the revolving field, brushless alternators have an internal arrangement for providing d.c. for the field from within the alternator, rather than from an external source. In one type a small a.c. exciter alternator is built into the main alternator. A bridge rectifier mounted on the shaft inside the machine converts the a.c. from the internal three phase exciter to d.c. to supply the revolving field.A sectional view of one type of brushless alternator is shown in Figure 7.

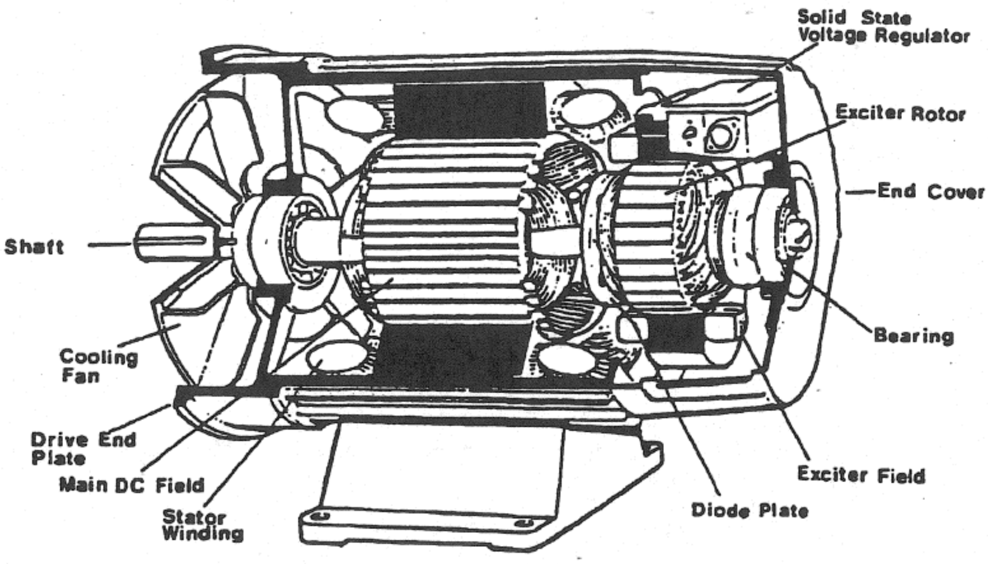


Figure 7 - Sectional view of a brushless alternator.

Alternator Control

19. Control of the output frequency of an alternator is achieved by controlling the speed of the prime mover - usually by some form of automatic engine speed governor. Control of the output voltage from a SINGLE alternator is usually controlled by automatically adjusting the d.c. excitation to the revolving field. Figure 8 shows the control loop of an automatic voltage regulator (AVR) monitoring the output voltage controls the d.c. excitation current that supplies the field windings of the alternator.

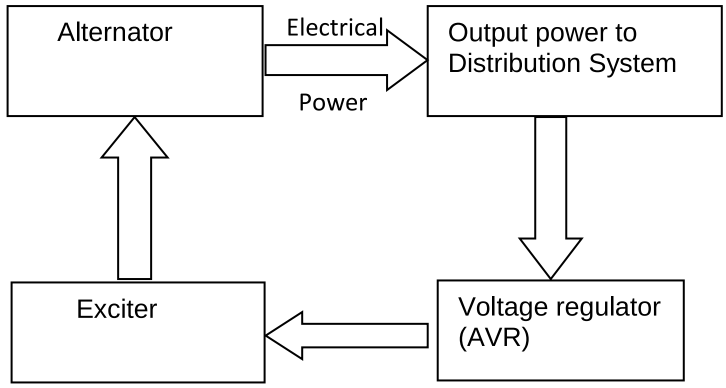


Figure 8-Digram of voltage control loop

20. **Voltage Regulation**. Voltage regulation is the difference between the output voltage on no load and the output voltage on full load - usually expressed as a percentage. Regulation can be calculated using the following equation:

$$Regulation\ \% \quad = \frac{No\ load\ voltage - Full\ load\ voltage}{Full\ load\ voltage} \times \quad 100$$

21. Example: The no load voltage of a given three phase alternator is 415 volts. If the voltage falls to 410 volts on full load, what is the regulation (assuming a resistive load)?

$$Regulation\ \% \quad = \frac{415 - 410}{410} \times \quad 100$$

= 1.2 %

Power Factor

22. The maximum output current rating of an alternator should be given in volt-amps (VA) rather than watts, because of the effects of power factor.

23. The maximum output current from a three phase alternator can be calculated using a derivation of the standard three phase power equation:

$$Three\ phase\ power\ (P) = \sqrt{3} \times V_L \times I_L \times \lambda$$

Therefore

$$I_L = \frac{P}{\sqrt{3} \times V_L \times \lambda}$$

24. If a 415 volt 10 kVA alternator was supplying a resistive load (at unity power factor) P = S, the full load current would be:

$$I_L = \frac{10kW}{\sqrt{3} \times 415 \times 1}$$

= 13.9 amps.

25. If the same alternator was to supply a load which had a power factor (λ) of 0.5, the maximum allowable current would still be 13.9 amps, but the power output would be reduced to approximately 5 kW - as shown in the following calculation:

$$Three\ phase\ power\ (P) = \sqrt{3} \times V_L \times I_L \times \lambda$$

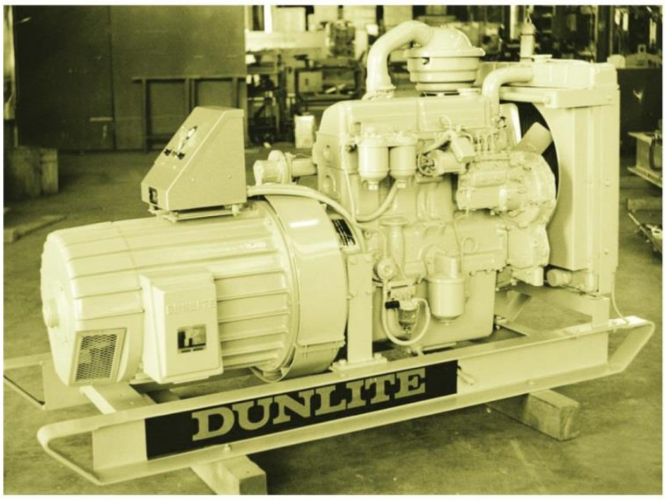
$$P = \sqrt{3} \times 415 \times 13.9 \times 0.5$$

= 4996 watts (approximately 5 kW)

26. If the maximum current rating is exceeded (at any power factor), the windings in the alternator would overheat, therefore the power factor of the load must be considered when determining the maximum load which can be supplied by any given alternator.

Portable and Standby Alternators

27. Applications of Portable and Standby Systems can be as varied as power supplies to a remote camp site to large standby generator systems for major hospitals and international airports. Small petrol driven single phase alternators with an output of up to 2.5 kW are sufficient for camping applications where the load is restricted to lighting and small refrigeration units. Capital city hospitals have diesel powered generator set of up to 2 Megawatts installed to provide power to essential services when there are major power disruptions.



Diesel powered 15 kVA standby alternator

Induction (Asynchronous) generators

28. Most wind turbines in the world use a so-called three phase asynchronous (cage wound) generator, also called an induction generator to generate alternating current. This type of generator is not widely used outside the wind turbine and small hydropower applications. The curious thing about this type of generator is that it was really originally designed as an electric motor. In fact, one third of the world's electricity consumption is used for running induction motors driving machinery in factories, pumps, fans, compressors, elevators and other applications where you need to convert electrical energy to mechanical energy.
One reason for choosing this type of generator is that it is very reliable and tends to be comparatively inexpensive. The generator also has some mechanical properties which are useful for wind turbines, like the generator slip and a certain overload capability.

The cage rotor

29. The key component of the asynchronous generator is the cage rotor (sometimes called a squirrel cage rotor).It is the rotor that makes the asynchronous generator different from the synchronous generator. The rotor consists of a number of copper or aluminium bars which are connected electrically by aluminium end rings. The rotor is provided with an "iron" core, using a stack of thin insulated steel laminations, with holes punched for the conducting aluminium bars. The rotor is placed in the middle of the stator, which in this case, once again, is a 4-pole stator which is directly connected to the three phases of the electrical grid.

Motor operation

30. When the electrical supply is connected, the machine will start turning like a motor at a speed which is just slightly below the synchronous speed of the rotating magnetic field from the stator. The rotating magnetic field moves relative to the rotor, induces a very strong current in the rotor bars which offer very little resistance to the current, since they are short circuited by the end rings. The rotor then develops its own magnetic poles, which in turn become dragged along by the electromagnetic force from the rotating magnetic field in the stator.

Generator operation – Wind Turbines

31. If the wind turbine turns this rotor at exactly the synchronous speed of the generator, e.g. 1500 rpm, nothing will happen, because the magnetic field rotates at exactly the same speed as the rotor, there will be no induction phenomena in the rotor and it will not interact with the stator.
When the turbine speed is increased above 1500 rpm then the rotor moves faster than the rotating magnetic field from the stator, which means that once again the stator induces a strong current in the rotor. The harder the rotor is cranked (the stronger the wind), the more power will be transferred as an electromagnetic force to the stator, and in turn converted to electricity which is fed into the electrical grid.

Generator slip

32. The speed of the asynchronous generator will vary with the turning force (torque) applied to it. In practice, the difference between the rotational speed at peak power and at idle is very small, about 1%. This difference in per cent of the synchronous speed, is called the generator's slip. Thus a 4-pole generator will run idle at 1500 rpm if it is attached to a grid with a 50 Hz current. If the generator is producing at its maximum power, it will be running at 1515 rpm.
It is a very useful mechanical property that the generator will increase or decrease its speed slightly if the torque varies. This means that there will be less wear and tear on the gearbox, because of lower peak torque. This is one of the most important reasons for using an asynchronous generator rather than a synchronous generator on a wind turbine which is directly connected to the electrical grid.

Grid connection required.

33. An asynchronous generator requires the stator to be magnetised from the grid before it works. However, an asynchronous generator in a stand-alone system can be used if it is provided with capacitors which supply the necessary magnetisation current. It also requires that there be some residual magnetism in the rotor iron, to start the turbine. Otherwise a battery and power electronics will be needed, or a small diesel generator to start the system.

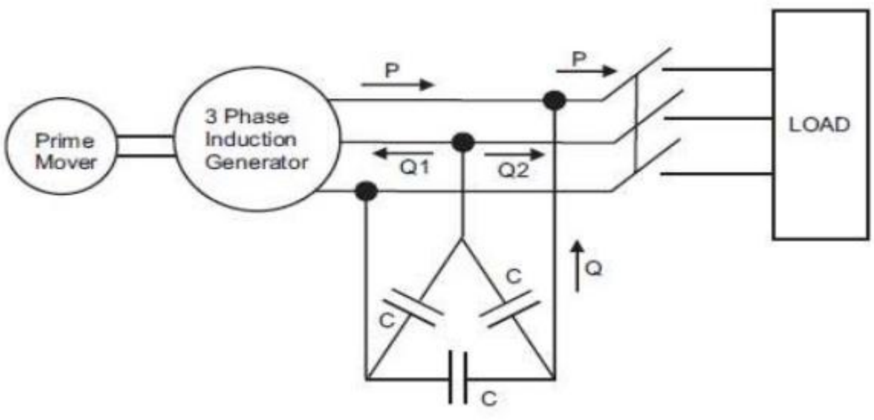


Figure 12 – 3 phase Induction (asynchronous) generator

The difference between asynchronous and synchronous generators

34. A synchronous generator is called “synchronous” because the waveform of the generated voltage is synchronized with the rotation of the generator. Each peak of the sinusoidal waveform corresponds to a physical position of the rotor. The frequency is exactly determined by the formula f = RPM x p / 120 where f is the frequency (Hz), RPM is the rotor speed (revolutions per minute) and p is the number of poles formed by the stator windings. A synchronous generator is essentially the same machine as a synchronous motor. The magnetic field of the rotor is supplied by direct current or permanent magnets.

The output frequency of an asynchronous generator is slightly (usually about 2 or 3%) lower than the frequency calculated from f = RPM x p / 120. If the RPM is held constant, the frequency varies depending on the power level. The peaks of the waveform have no fixed relationship with the rotor position. An asynchronous generator is essentially the same machine as an asynchronous or induction motor. The magnetic field of the rotor is supplied by the stator through electromagnetic induction.

The output frequency of a synchronous generator can be more easily regulated to remain at a constant value. Synchronous generators (large ones at least) are more efficient than asynchronous generators. Synchronous generators can more easily accommodate load power factor variations. Synchronous generators can be started by supplying the rotor field excitation from a battery. Permanent magnet synchronous generators require no rotor field excitation.

The construction of asynchronous generators is less complicated than the construction of synchronous generators. Asynchronous generators require no brushes and thus no brush maintenance. Asynchronous generators require relatively complicated electronic controllers. They are usually not started without an energized connection to an electric power grid, unless they are designed to work with a battery bank energy storage system. With an asynchronous generator and an electronic controller, the speed of the generator can be allowed to vary with the speed of the wind. The cost and performance of such a system is generally more attractive than the alternative systems using a synchronous generator.

Three Phase Synchronous Motors

35. A three phase synchronous motor is a motor which is designed to run at exactly the same speed as the rotating magnetic field in the stator.

36. The construction of a three phase synchronous motor can be the same as that of a low speed alternator, but instead of rotating the d.c. field and taking the output from the stationary armature winding, d.c. is applied to the revolving d.c. field and a three phase supply is connected to the stator winding- as shown in Figure 9.

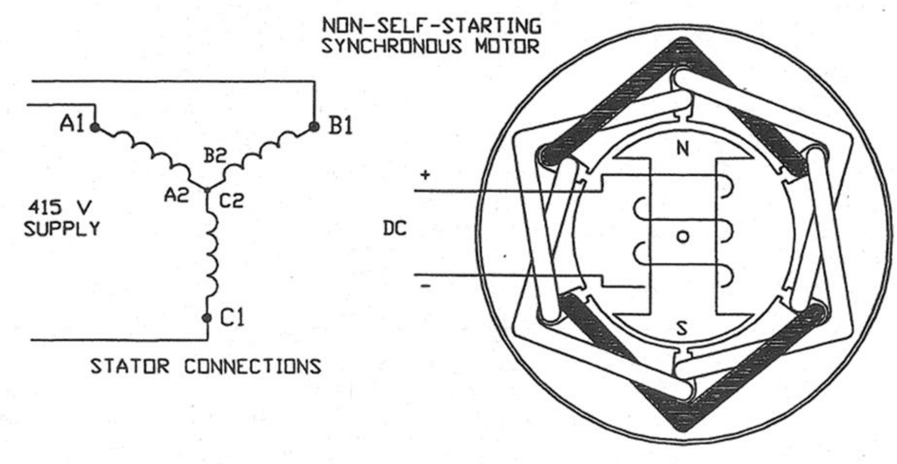


Figure 9 - Three phase synchronous motor.

377. In the type of synchronous motor shown in Figure 9 the rotor is run up to almost synchronous speed by some mechanical means, then d.c. is applied to the rotor. The fixed magnetic poles on the rotor are attracted to the opposite matching poles on the stator, so the rotor 'locks in' to the exact speed of the rotating magnetic stator field.

38. If load is applied to the motor, the rotor attempts to slow down but it cannot because it is locked in synchronism with the rotating magnetic field of the stator, so it lags a few degrees behind it - as shown in Figure 10. If the load is increased to a critical point the attraction between the stator field and the rotor field reaches a value where it can no longer remain in synchronism and the rotor simply stops.

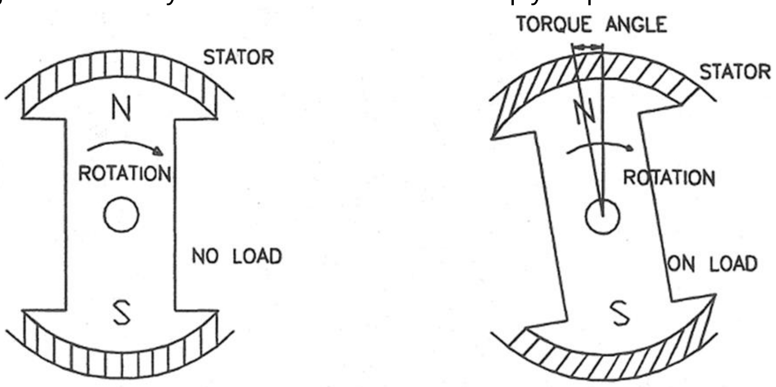


Figure 10 - Stator and rotor fields on no load and full load.

39. If a synchronous motor is run on no load or a very light load, increasing the d.c. excitation to the rotor causes the power factor of the current in the stator to become leading. Synchronous motors can be used in a large installation as a means of providing a leading power factor to compensate for a lagging power factor in other parts of the installation - when used in this way they are known as rotary capacitors or synchronous condensers.

40. Three phase synchronous motors are usually relatively large motors - usually over 50 kW. They are well suited to driving constant speed loads such as ball mills, pumps, blowers, d.c. generators, compressors and the like. If they are run at a value less than full load, they can serve the dual purpose of correcting the power factor of the installation if the d.c. to the rotor is increased to a value above that required to drive the load.

41. A major disadvantage of a pure synchronous motor is that it is not self-starting - it has to be run up to speed by some other means. This disadvantage can be overcome by providing a squirrel cage type (or amortissuer) winding on the rotor - the motor is then known as a synchronous induction motor or auto synchronous motor.

42. The squirrel cage type of winding provides enough starting torque on a light load to allow the rotor to reach a speed at which it can be pulled into synchronism when d.c. is applied to the rotor, but it has no effect when the motor is running in synchronism because there is no relative movement between the rotor and the rotating magnetic field (they are both moving at exactly the same speed). The squirrel cage winding also serves to reduce 'hunting' if the motor is driving a fluctuating load.

43. A normal three phase wound rotor motor can be run as a synchronous induction motor by running it up to speed in the normal way, then using a change-over switch to provide d.c. to the rotor winding via the rotor slip rings. The d.c. to the rotor is fed in on two slip rings and out on the other as shown in Figure 11.

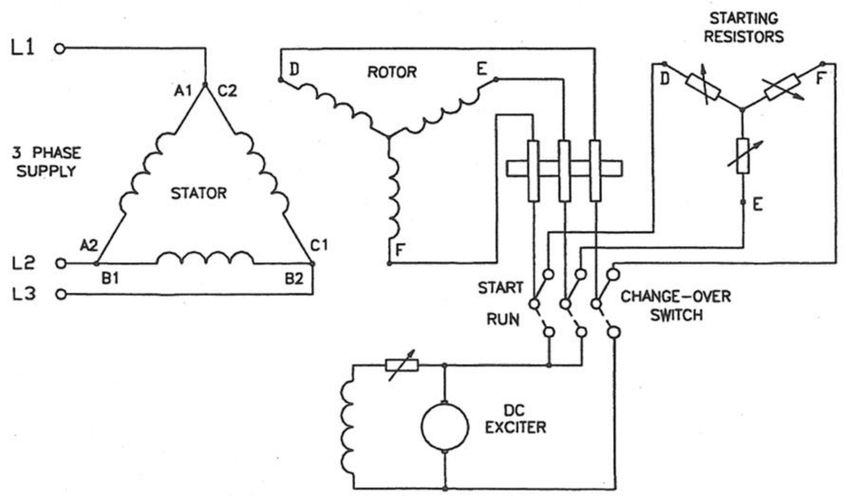


Figure 11 - Wound rotor motor as a synchronous motor.

Single Phase Synchronous Motors

44. Single phase synchronous motors are usually restricted to very small sizes - around 5-50 watts.

45. A typical type is known as the hysteresis motor. The name is derived from the electromagnetic property which results in some materials being able to retain magnetism after the magnetising force is removed. In most a.c. inductive devices hysteresis is a loss which results in a reduced overall efficiency, but in a hysteresis motor it is used to produce a small single phase motor which runs at synchronous speed with relatively high torque.

46. A typical hysteresis motor rotor consists of several flat discs of cobalt steel mounted on a shaft. The stator consists of two laminated magnetic poles, each of which as a shading ring, and a main a.c. stator coil - as shown in Figure 12.

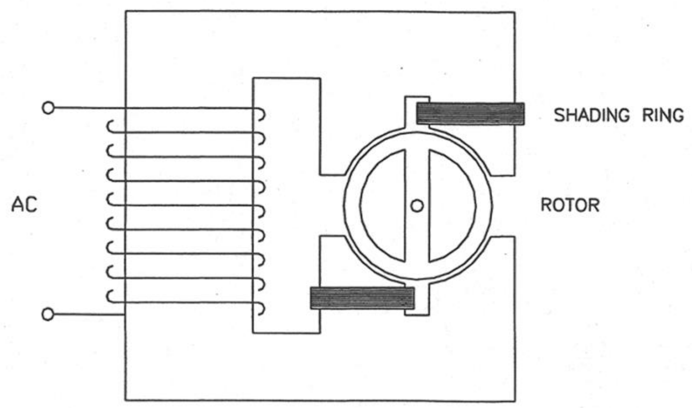


Figure 12 - Single phase hysteresis motor.

47. When a.c. is applied to the stator winding a magnetic field sweeps across the pole face at a rate determined by the frequency of the supply - as in a shaded pole motor. The stator field induces current in the rotor which starts the motor as an induction motor. As the rotor speed up, the stator field continues to induce magnetism in the rotor, but because the rotor has a comparatively high hysteresis its magnetic flux does not fall as the stator field falls, this results in permanent magnetic poles being formed along the crossbar axis and the rotor locks into synchronism at a speed determined by the frequency and the number of stator poles.

48. Hysteresis motors are used in rotating grills, valve control, clocks and timing devices. Due to their small size they are not usually economical to repair - they would be replaced if they developed a fault.

49. Two other types of single phase synchronous motors are; reluctance motors and permanent magnetic motors. Reluctance motors can be found in small aquarium water pumps and small air fans.

Government of Western Australia North Metropolitan TAFE	**Solve problems in single phase and three phase low voltage machines**	Section 9 Work Sheet	G006A SGB 12/2013

Alternators

1. Name six of the major parts of a typical 4 pole diesel driven three phase alternator.
2. What is the basic difference between a 2 pole single phase alternator and a 2 pole three phase alternator?
3. What type of rotor is usually used for low speed (say 300 r/min} three phase alternators?
4. What type of rotor is usually used for-high speed (say 3000 r/min) three phase alternators?
5. Which type of large alternator requires the use of a special thrust bearing? Why?
6. What is the main advantage of a salient pole alternator?
7. Where is the exciter usually located on a large three phase alternator?
8. Why is the d.c. winding located on the rotor of most alternators instead of in the stator?
9. Why is the a.c. winding located in the stator of large three phase alternators?
10. What is the physical relationship between the windings for each phase in a three phase alternator stator winding?
11. Which part of a large alternator is commonly called the 'field' and which part is called the 'armature'?
12. Which type of alternator would you expect to have the least problems associated with cooling the windings?
13. At what speed would a 6 pole three phase alternator have to be rotated to produce an output frequency of 50 Hz?
14. What effect does it have on the output of a single three phase alternator if the d.c. excitation to the rotor is increased?
15. What output frequency would be produced by a 20 pole three phase alternator if it was operated at 360 r/min?
16. What effect would it have on the frequency of the output from an alternator if the speed of the prime mover was increased?
17. What is a 'brushless alternator'?
18. How can the output voltage of a single three phase alternator be increased without changing the speed of the rotor?
19. What is the regulation of a 415 volt alternator if the output voltage on full load falls to 405 volts with a resistive load?

20. What effect does it have on the rated output current from an alternator if the power factor of the load is less than 0.5?

21. What is the maximum POWER which could be taken from a 20 kVA 415 volt alternator if the power factor of the load was 0.5 lagging?

22. What are the three main ratings of an alternator?

23. Why should the output of an alternator be expressed in VA or kVA instead of watts of kilowatts?

24. A three phase alternator is required to supply a 10 kW motor which runs at a power factor of 0.8 on full load.
What is the minimum kVA rating of the alternator required?

25. What is the maximum current which may be drawn from a 415 volt 20 kVA three phase alternator?

26. Why are alternators classified as 'synchronous machines'?

27. State three advantages of Induction generators compared to synchronous generators.

28. State three disadvantages of Induction generators compared to synchronous generators.

29. In order to obtain a power output from an Induction generator at what speed must the rotor be turned?

Synchronous Motors

1. What special operating characteristic does a 'synchronous motor' have that a squirrel cage induction motor does not have?

2. What other type of three phase rotating machine can have a rotor which is similar in appearance to the one in a synchronous motor?

3. Give two reasons why a squirrel cage is incorporated in the rotor of some synchronous motors.

4. What is meant by the term 'Auto-synchronous' when applied to three phase synchronous motors?

5. A synchronous motor is severely overloaded. What would be the most likely result?

6. How does the construction of a high speed synchronous motor differ from that of a low-speed synchronous motor?

7. Synchronous motors are sometimes run on no-load or very light load in an installation. Why is this done?

8. How can the power factor of a synchronous motor be varied?

9. Calculate the full load speed of a 4 pole three phase synchronous motor operating on a 415 volt 50 Hz supply.

10. What is the most common method of enabling a synchronous motor to be self-starting?

11. How many wound poles would there be on the rotor of a typical 4 pole three phase synchronous motor?

12. What effect would it have on the speed of a synchronous motor if the d.c. excitation to the rotor was increased (within designed limits).

13. What is meant by the term 'pull out torque' of a three phase synchronous motor?

14. What are three methods of starting a synchronous motor?

15. What common type of three phase motor can be connected as a synchronous motor if the required control equipment is available?

16. How many slip rings would there usually be on the rotor of a large three phase synchronous motor?

17. Name two types of small single phase synchronous motor?

18. What are two applications for single phase synchronous motors?

Reference:
- *National Curriculum* - EE-Oz Training Standards Australia
- *Graphic of Siemens Three Phase TEFC SCI motor* by Siemens (Section 6 Figure 1)

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- 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)
- http://www.electway.net/news/difference_between_Asynchronous_and_synchronous_generator.html
- Code of Practice – Safe electrical work on low voltage electrical installations
- WA Electrical Requirements

PLEASE NOTE: All attempts to identify and acknowledge the original copyright of images in Section 7 (*Figure 1 Typical split phase induction motor*) and in Section 9 (*Figure 7 – Section view of a brushless alternator*), have been unsuccessful.