Unit UEENEEG006A

SOLVE PROBLEMS IN SINGLE & THREE PHASE LOW VOLTAGE MACHINES

KS01-EG006A

BOOK 1 of 2

TRANSFORMERS

Equation Sheet - Symbols obtained from AS1046

Stage 1: *This list does not contain all equations in the course and transposition may be required.*

	A	B	C	D	E
1	$Q = It$	$F = ma$	$W = Pt$	$W = Fs$	$W = mgh$
2	$\mathbf{V = IR}$	$\mathbf{I = \frac{V}{R}}$	$\mathbf{R = \frac{V}{I}}$		$\mathbf{P = \frac{2\pi nT}{60}}$
3	$P = VI$	$P = I^2R$	$P = \frac{V^2}{R}$		$\eta\,\% = \frac{output}{input} \times \frac{100}{1}$
4	$R = \frac{\rho l}{A}$	$R_2 = \frac{R_1A_1l_2}{A_2l_1}$	$R_h = R_c(1 + \alpha\Delta t)$		
5	$V_T = V_1 + V_2 + V_3$	$R_T = R_1 + R_2 + R_3$	$I_T = I_1 = I_2 = I_3$	$V_1 = V_T\frac{R_1}{R_1 + R_2}$	
6	$V_T = V_1 = V_2 = V_3$	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$	$I_T = I_1 + I_2 + I_3$	$I_2 = I_T\frac{R_1}{R_1 + R_2}$	$R_T = \frac{R_1R_2}{R_1+R_2}$
7	$C = \frac{Q}{V}$	$C = \frac{A\,\epsilon_o\epsilon_r}{d}$	$r = RC$	$C_T = C_1 + C_2 + C_3$	$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$
8	$L = N\frac{\Delta\emptyset}{\Delta I}$	$L = \frac{N^2}{S}$	$r = \frac{L}{R}$	$V = N\frac{\Delta\emptyset}{\Delta t}$	$V = L\frac{\Delta I}{\Delta t}$
9	$e = Blv$	$F = Bil$	$F_m = IN$	$B = \frac{\emptyset}{A}$	$S = \frac{l}{\mu_o\mu_r A}$
10	$E_g = k\emptyset n$	$T = k\emptyset I_a$	$T = Fr$	$H = \frac{F_m}{l}$	$\emptyset = \frac{F_m}{S}$

Equation Sheet - Symbols obtained from AS1046

Electrical Trades Section Miller College
Electrotechnology, ICT & Design Faculty

Stage 2: *This list does not contain all equations in the course and transposition may be required.*

Stage 1: *equations are also used during stage 2*

	A	B	C	D	E
11	$V_{ave} = 0.637V_{max}$	$V_{RMS} = 0.707V_{max}$	$v = V_{max} \sin\theta$	$V_L = \sqrt{3}V_P$	$f = \frac{nP}{120}$
12	$I_{ave} = 0.637I_{max}$	$I_{RMS} = 0.707I_{max}$	$i = I_{max} \sin\theta$	$I_L = \sqrt{3}I_P$	$t = \frac{1}{f}$
13	$I = \frac{V}{Z}$	$V = IZ$	$Z = \frac{V}{I}$		
14	$Z = \sqrt{R^2 + X^2}$	$Z = \sqrt{R^2 + (X_L - X_C)^2}$	$X_L = 2\pi fL$	$X_C = \frac{1}{2\pi fC}$	$\cos\theta = \frac{R}{Z}$
15	$P = VI\cos\theta$	$S = VI$	$Q = VI\sin\theta$	$P = \sqrt{S^2 - Q^2}$	$\cos\theta = \frac{P}{S}$
16	$P = \sqrt{3}V_L I_L \cos\theta$	$S = \sqrt{3}V_L I_L$	$Q = \sqrt{3}V_L I_L \sin\theta$	$\tan\theta = \sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)$	$\theta = \cos^{-1}\lambda$
17	$V' = 4.44\emptyset fN$	$\frac{V_1}{V_2} = \frac{N_1}{N_2}$	$\frac{I_2}{I_1} = \frac{N_1}{N_2}$	$V_{reg}\% = \frac{(V_{NL} - V_{FL})}{V_{FL}} \times \frac{100}{1}$	
18	$N_{syn} = \frac{120f}{P}$	$f_r = \frac{S\% \times f}{100}$	$S\% = \frac{(n_{syn} - n)}{n_{syn}} \times \frac{100}{1}$	$V_{reg}\% = \frac{(V_{NL} - V_{FL})}{V_{NL}} \times \frac{100}{1}$	$T = k\emptyset Ia$
19					
20			$P = \frac{2\pi nT}{60}$	$\eta\,\% = \frac{output}{input} \times \frac{100}{1}$	

Stage 2a: *This list does not contain all equations in the course and transposition may be required.*

Stage 1: *equations are also used during stage 2*

	A	B	C	D	E
21					
22	$V_T = E_G - (I\,R_i)$	$E = \frac{F}{A}$	$E = \frac{I}{d^2}$	$E = \frac{I}{d^2} \times \cos\theta$	$\eta = \frac{F}{P}$
23			$Q_c = P(\tan\theta_1 - \tan\theta_2)$	$X_c = R(\tan\theta_1 - \tan\theta_2)$	
24					

Stage 3: *This list does not contain all equations in the course and transposition may be required.*

	A	B	C	D	E
25	$V_P\text{Y} = 57.7\% V_P\Delta$	$I_P\text{Y} = 57.7\% I_P\Delta$	$I_{motor\ st} = \left(\frac{\%TAP}{100}\right) \times I_{DOL}$	$I_{line\ st} = \left(\frac{\%TAP}{100}\right)^2 \times I_{DOL}$	
26	$I_{ST} = \frac{1}{3} \times I_{DOL}$	$T_{ST} = \frac{1}{3} \times T_{DOL}$	$V_{st} = \left(\frac{\%TAP}{100}\right) \times V_{DOL}$		
27	$I_{ST} = \left(\frac{V_{st}}{V}\right) \times I_{DOL}$	$T_{ST} = \left(\frac{V_{st}}{V}\right)^2 \times T_{DOL}$	$\text{Constant} = \frac{V}{f}$		
28					

Unit Guide – Summary

FULL unit guides can be accessed online at www.training.gov.au

The following information is summarised and is intended to provide a broad overview only.

Unit:

UEENEEG006A Solve problems in single and three phase low voltage machines

Unit Descriptor

This unit covers ascertaining correct operation of single and three phase machines and solving machine problems as they apply to servicing, fault finding, installation and compliance work functions. It encompasses safe working practices, machine connections circuit arrangements, issues related to machine operation, characteristics and protection and solutions to machine problems derived from calculated and measured parameters

Pre-Requisites

Pre-requisites are units of study that must be completed prior to commencing a new unit of study. That is, you must pass subject 'X' before you are allowed to commence subject 'Y'. In some instances, pre-requisite units may be studied concurrently with new units of study.

Pre-requisites for this unit of study are:

- UEENEEE101A Apply Occupational Health and Safety regulations, codes and practices in the workplace
- UEENEEE102A Fabricate, dismantle, assemble of electrotechnology 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. circuit

  UEENEEG106A Terminate cables, cords and accessories for low voltage circuits

Unit Guide – Summary *continued*

Literacy and numeracy skills indicators for this unit – NRS Level 5:

Participants are best equipped to achieve competency in this unit if they have reading, writing and numeracy skills at a level indicated by the following NRS levels.

The National Reporting System (NRS) is a nationally recognised mechanism for determining adult English language, literacy and numeracy levels.

In context for this unit of study these Indicators of Competence (IoC) are not an assessment system, but merely a guide to the specific reading writing and numeracy levels for this unit.

Further information pertaining to the description of each scale is given in Volume 2, Part 3 '*Literacy and Numeracy*', of the UEE11 training package, available at http://training.gov.au

Skill	IoC	**Indicator of Competence**
Reading: Level 5	5.1	Reads and interprets structurally intricate texts in chosen fields of knowledge and across a number of genres, which involve complex relationship between pieces of information and/or propositions.
	5.2	Interprets subtle nuances, infers purpose of author and makes judgements about the quality of an argument.
	5.3	Reads and critically evaluates texts containing data which includes some abstraction, symbolism, and technicality presented in graphic, diagrammatic, formatted or visual form.

Writing: Level 5	5.4	Demonstrates well-developed writing skills by selecting stylistic devices to express complex relationships between ideas and purposes.
	5.5	Generates complex written texts with control over generic structure.

Numeracy: Level 5	5.10	Interprets, selects and investigates appropriate mathematical information and relationships highly embedded in an activity, item or text.
	5.11	Selects and applies a wide range of mathematical strategies flexibly to generate solutions to problems across a broad range of contexts.
	5.12	Analyses and evaluates the appropriateness, interpretations and wider implications of all aspects of a mathematical activity.
	5.13	Uses a wide range of oral and written informal and formal language and representation including symbols, diagrams and charts to communicate mathematically.

Unit Guide – Assessment

***Student Assessment Guidelines* – (SAG's)**

Assessment is an important part of learning at TAFE NSW.

TAFE NSW provides comprehensive information for students regarding assessment. A copy of 'Every Student's Guide to Assessment in TAFE NSW' can be obtained by visiting:

https://www.tafensw.edu.au/courses/assessment/index.htm

The following information provided in this workbook is to assist you in your understanding of the assessment process, by providing and overview of assessment for this unit. Any questions regarding assessment can be addressed by your class teacher.

Course: National Course Code: UEE30811

Qualification and name: Certificate III in Electrotechnology Electrician

TAFE NSW course number: 20222. Version: 1

Requirements to receive the qualification:

To achieve UEE30811 Certificate III in Electrotechnology, learners are required to complete all units from the core and elective units to a weight of 140 points. Core and elective units are shown in the 'Course Outline' contained in the preceding pages of this workbook.

Recognition: If you have completed other relevant training you may be eligible to have units of competency from previous training counted towards completion for this course. Talk to your teacher or head teacher if you think you may be eligible for recognition for units previously completed.

Learner Support: Students who require support to meet their learning goals should discuss their options by talking to their teacher or Teacher/Consultant for students with a disability.

Assessment Results: Results will be made available to you by your class teacher after each assessment event. Results may also be viewed online (final unit results only) by visiting TAFE 'eServices'. See the 'Useful Links' on the 'student contacts' page in the front of this workbook for further information on TAFE eServices. Concerns you may have about your assessment results should be addressed to your class teacher within 3 weeks of receiving a result.

KS01-EG006A - Single and three-phase transformers - Class workbook 1

WORKBOOK SECTION NUMBER	CONTENT	TOPIC NUMBER AS LISTED IN THE FULL UNIT GUIDE
Section 1	Transformer construction	T1
Section 2	Transformer operation	T2
Section 3	Transformer losses, efficiency and cooling	T3
Section 4	Transformer voltage regulation and percent impedance	T4
Section 5	Parallel operation of transformers and transformer auxiliary equipment	T5
Section 6	Auto-transformers and instrument transformers	T6

KS02-EG006A - Alternating current rotating machines - Class workbook 2

Section 1	Operating Principles of three phase induction motors	T1
Section 2	Three phase induction motor construction	T2
Section 3	Three phase induction motor characteristics	T3
Section 4	Single phase motors – split phase	T4
Section 5	Single phase motors – capacitor and shaded pole types	T5
Section 6	Single phase motors – universal	T6
Section 7	Motor protection	T7
Section 8	Three phase synchronous machines: operation principles and construction	T8
Section 9	Alternators and generators	T9

Unit Guide – Assessment

Student Assessment Guide for this unit:

Evidence for competence in this unit shall be considered holistically. The required skills and knowledge relating to this unit will be assessed in following manner:

Unit Number	**UEENEEG006A**
KS Number(s)	**KS01-EG006A (TRANSFORMERS) and KS02-EG006A (Rotation AC Machines)**
Unit Title	**Solve problems in single and three phase low voltage machines**
Superceded	**UEENEEG008B, UEENEEG004B, Electrical Machines - 9080V**

		Event #	Event Name / Timing / Duration	Evidence Method	Wgt.	Out Of %
KS01-EG006A	Transformers Class Workbook 1	1	Quiz (Tx) - Weekly	Formative Assessment	10	100
		2	Tutorial (Tx) Weekly	Formative Assessment	5	100
		3	Skills Practice (Tx) Weekly	Formative Assessment	10	100
		4	Practical exam 1 (Tx) After Section 6 - 1Hr	Formative Assessment	5	100
		5	Theory Exam 1 (Tx) After Section 6 - 1.5Hrs - MUST PASS 60%	Summative Assessment	20	100
		6	Work Performance Evidence (Pass / Fail)	Profiling / Skills Tracker		P/F
KS02-EG006A	Rotating Machines Class Workbook 2	7	Quiz (RM) - Weekly	Formative Assessment	10	100
		8	Tutorial (RM) Weekly	Formative Assessment	5	100
		9	Skills Practice (RM) Weekly	Formative Assessment	10	100
		10	Practical exam 1 (RM) After Section 9 - 1Hr	Formative Assessment	5	100
		11	Theory Exam 1 (RM) After Section 9 - 1.5Hrs - MUST PASS 60%	Summative Assessment	20	100
		12	Work Performance Evidence (Pass / Fail)	Profiling / Skills Tracker		P/F

* ALL 'MUST PASS' events must be passed AND Total Cumulative KS mark must be 60% or greater — KS MARK: [ ]

* Work Performance Evidence (WPE) has been reviewed and satisfies requirements (Pass / Fail) — WPE: [ ]

* Final Competency Result (AC) Achieved competency OR (NC) Not Yet Competent. See note below. — AC / NC: [ ]

Note: *Only award AC if ALL "MUST PASS' events are passed, KS mark 60% or greater AND WPE is Passed*

Section 1

THE IDEAL TRANSFORMER

PURPOSE:

In this section you will learn about mutual induction and the operation of the ideal transformer.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- Describe the principle of mutual induction.
- Describe how an emf is induced in the secondary winding of a transformer.
- Explain the meaning of the terms 'step-down' and 'step-up' transformers.
- Identify the basic component parts of the transformer.
- Calculate the primary and secondary voltages of a single phase transformer given turns, core flux and supply frequency.
- Explain the meanings of the terms 'turns ratio', 'current ratio' and 'voltage ratio'.
- Calculate values of voltage, current and turns for a single phase transformer, using transformer ratios.

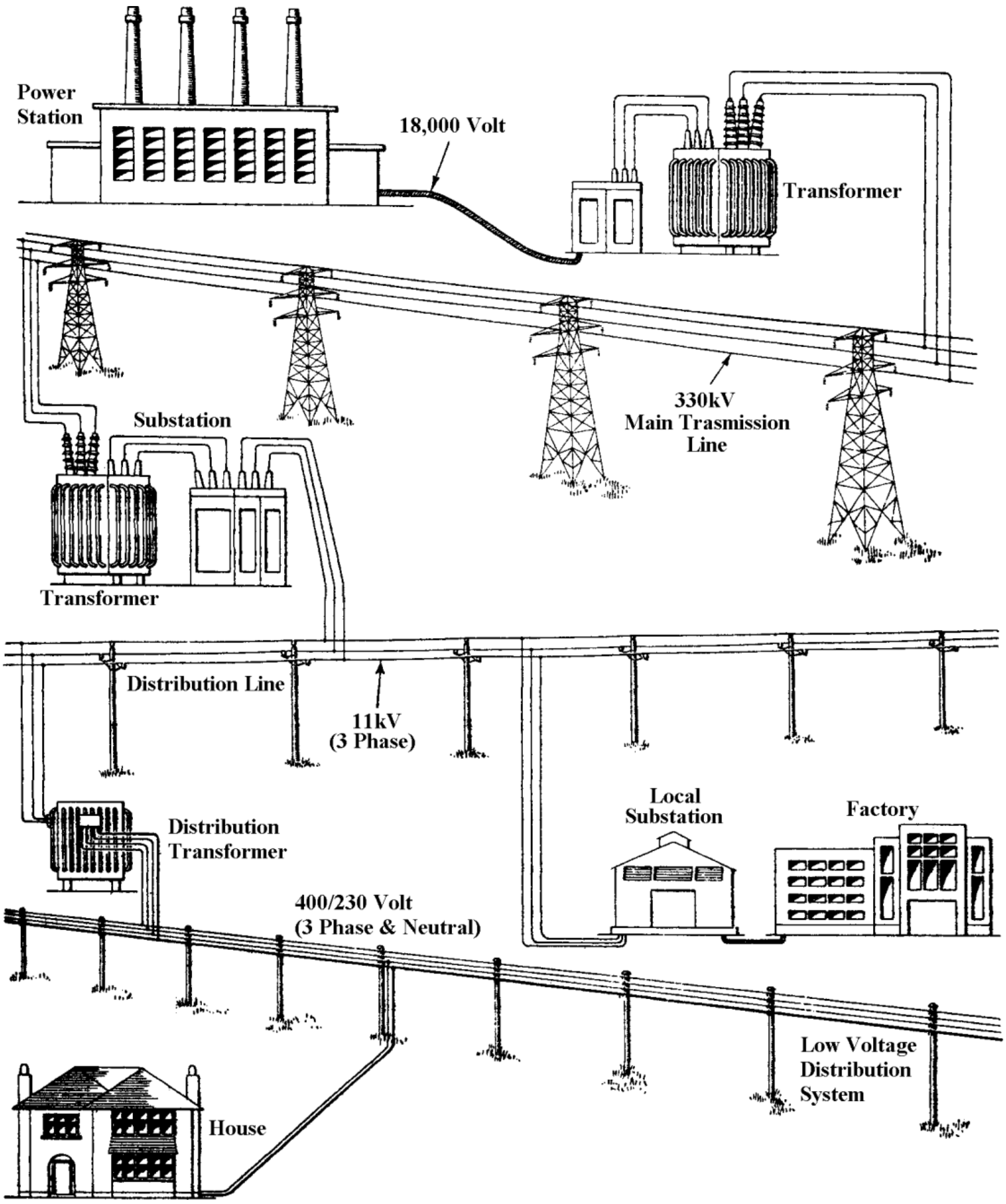
REFERENCES:

- Hampson, J. & Hanssen, S. *Electrical Trade Principles*, 2nd Edition, Section 7
- Jenneson, J.R. *Electrical Principles for the Electrical Trade*, 5th Edition, Pages 335 - 337

1. INTRODUCTION

Generating stations are the source of electrical energy, but for this energy to be utilised, it must be conveyed from the energy source to the consumer. The best way to provide a reliable and economical supply is via a state-wide transmission line grid fed by large power stations.

The state-wide grid system is dependent upon the operation of the transformer to allow the transmission of electrical power over very long distances. Figure 1 illustrates a simplified layout of the grid.



2. THE TRANSFORMER

A transformer is a static machine that is it has no moving parts, where electrical energy in one circuit is transferred to electrical energy of the same frequency in another circuit. See figure 2.

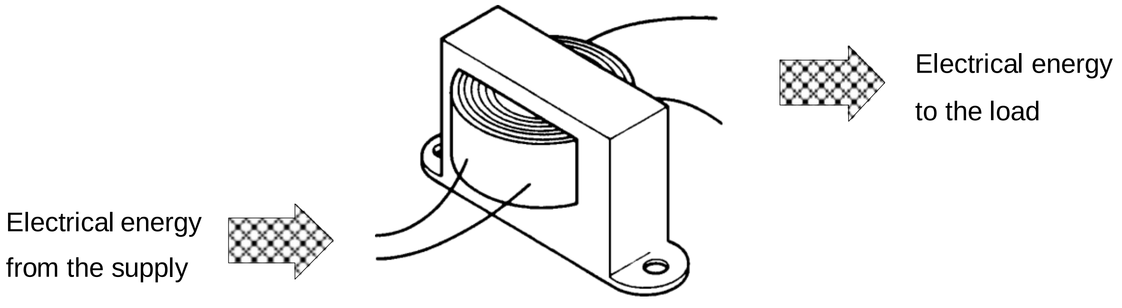
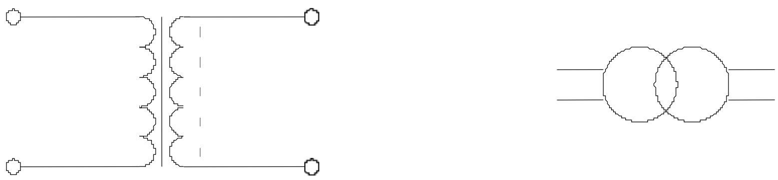


Figure 2

The Australian Standard drawing symbols used to represent transformers are as shown in figure 3.



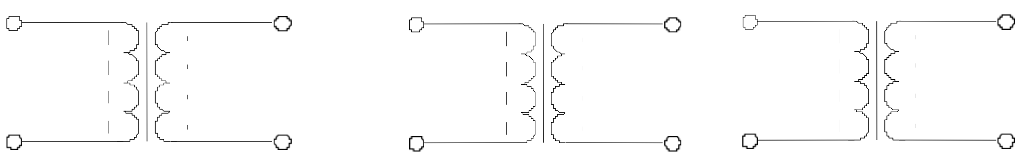
Complete form　　Simplified form

Figure 3

Transformers are used to -

- step down voltage - where the output voltage to the load is lower than the input voltage to the transformer, known as a ***step down transformer***.
- step up voltage - where the output voltage to the load is greater than the input voltage to the transformer, known as a ***step up transformer***.
- provide electrical isolation - In some applications electrical isolation is required without voltage change, that is the input and output voltage are equal, in this case the transformer is referred to as an ***isolation transformer***.

Figure 4 shows an example of each transformer.



Step down transformer　　Step up transformer　　Isolating transformer

Figure 4

3. MUTUAL INDUCTANCE

Consider two coils A and B as shown in figure 5. Coil A is placed within coil B but has no electrical connection with it. A centre zero voltmeter is connected across the terminals of coil B while coil A is connected to a battery through the switch S.

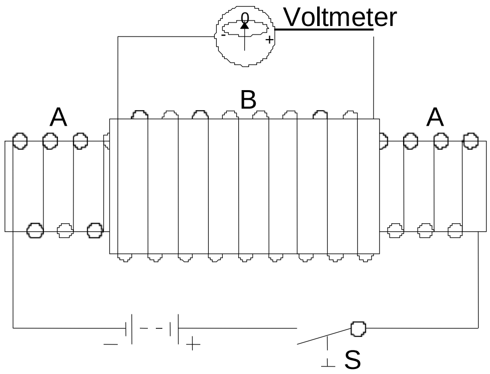


Figure 5

When the switch is closed, the current in coil A builds up a magnetic field, a considerable part of which links coil B. The voltmeter, therefore, gives a momentary deflection which indicates that an emf is induced in coil B. See figure 6.

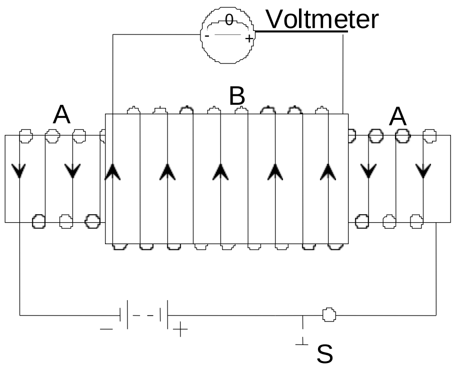


Figure 6

When the switch is closed and the current in coil A begins to build up, the increasing magnetic field produced cuts or links with the turns of both coil A and coil B, so producing an -

____

____

If the current in coil A is interrupted by opening the switch, the amount of flux linking with coil B is again changed by the collapse of the magnetic field and the voltmeter gives a momentary deflection in the opposite direction to the previous movement. See figure 7.

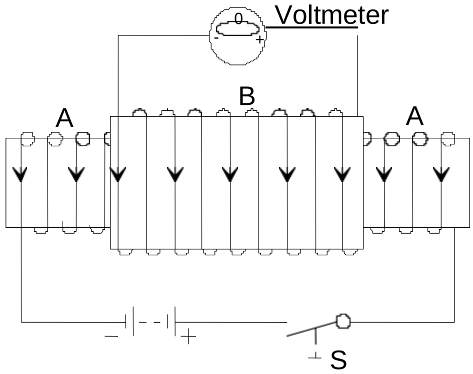


Figure 7

When the switch is opened and the current in coil A begins to collapse, the decreasing magnetic field links with the turns of both coil A and coil B, so producing an -

____

____

Therefore, irrespective of whether the magnetic field of coil A is increasing or decreasing in value, the induced voltages are always an -

- ____
- ____

Accordingly, the emf induced in coil B is called the ***emf of mutual induction*** and that the two magnetically linked coils are said to possess the property of ***mutual inductance***.

In the module Applied Electromagnetism it was stated that, in accordance with Lenz's law the direction of the emf of self induction is always such as to oppose the change producing it. The same law applies to the emf of mutual induction, but the mode of action is different.

The emf of self induction in coil A retards a change of flux by either opposing or assisting the applied emf producing the magnetising current, but in coil B the emf of mutual induction establishes a current (if the circuit is closed) which, by an opposing or assisting mmf (magnetomotive force), retards any change in flux from coil A.

If two electric circuits possess the property of mutual inductance they are said to be ***coupled***. The two coils are said to be -

- ____________________________ or
- ____________________________

depending on whether all, or only a part, of the magnetic flux links with both coils. The tightness of the coupling can be varied by -

- ____
  ____ and
- ____
  ____

In the arrangement shown in figure 7, the induced voltages would only be produced when the current in coil A changes in value, that is at switch on and switch off. If the current in coil A was constant there would be no induced voltages.

If the battery and switch shown in the figure 7 were replaced with an AC supply as shown in figure 8, you would have a transformer in its simplest form. The alternating current in coil A sets up an alternating magnetic flux. This flux links with coil B in which an emf is induced by mutual inductance. This is the principle of operation of the transformer.

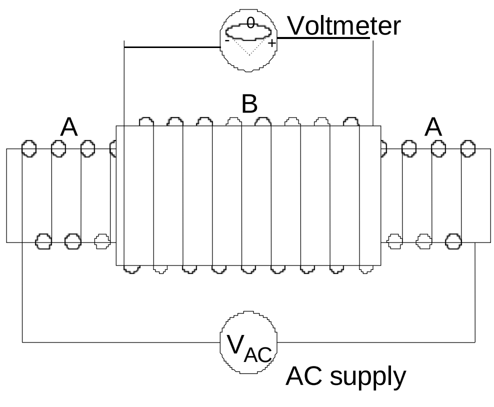


Figure 8

4. TRANSFORMER OPERATION

In its simplest form the transformer consists of two coils of insulated wire that are insulated from each other and wound on a laminated steel core. The basic parts of a transformer are shown in the elementary diagram of figure 9.

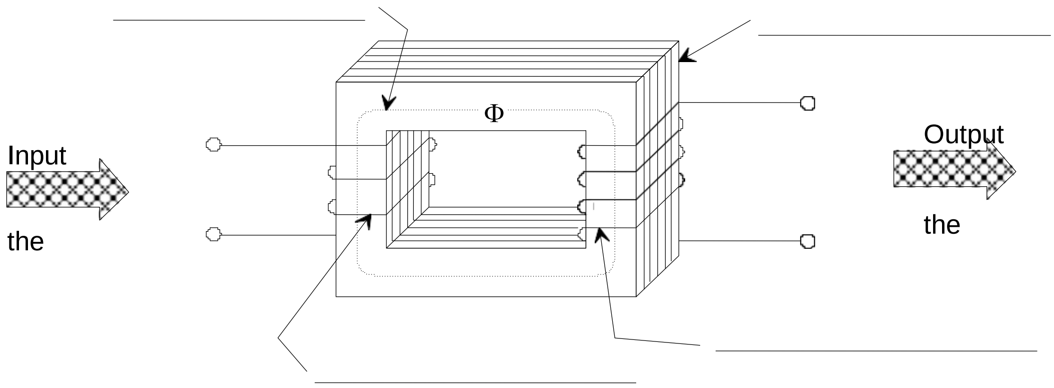


Figure 9

The laminated core is made stampings of sheet steel, usually silicon steel, clamped or bolted together. The primary and secondary windings are shown placed on opposite limbs, or legs, of the core. In practice, however, both coils are placed on the same limb to reduce magnetic leakage and thereby increase the tightness of the coupling between the coils.

The primary and secondary windings can be identified by their connection -

- the primary winding - ____
- the secondary winding - ____

Thus electrical energy enters the transformer through the primary, and leaves it through the secondary. The arrangement is reversible, that is, either coil may be used as primary or secondary, provided the insulation is adequate to withstand the resulting levels of voltage.

Most transformers are designed for widely different primary and secondary voltages, such as a primary voltage V_1 = 240V and a secondary voltage V_2 = 12V. The winding with the higher voltage is called the ***high-tension*** (H.T.) side and the low voltage winding is called the ***low-tension*** (L.T.) side of the transformer.

When the high-tension winding is the primary, the transformer is called a ___________ transformer and when the low-tension winding is the primary, the transformer is called a________________transformer.

The ratio of the primary voltage to the secondary voltage $\frac{V_1}{V_2}$ is called the _________

______________________________.

5. TRANSFORMER EMF EQUATION

When an AC supply is applied to a transformer, the magnetic flux in the core increases and decreases as the current changes, ***which causes an emf to be induced in each winding***, because both are linked by the flux.

By Faraday's law the value of the primary and secondary induced voltages can be determined using the equation -

$V_{AV} = \text{N x } \frac{\Delta\Phi}{\Delta t}$ where: V_{AV} = the average voltage induced in the winding in volts

N = the number of turns on the winding

$\Delta\Phi$ = the change in flux in webers

Δt = the change in time in seconds

Figure 10 illustrates the waveform of transformer core flux. From this diagram it can be seen that the flux change in the time interval t_1 to t_2 is $2\Phi_M$, where Φ_M is the maximum value of the flux wave, in webers.

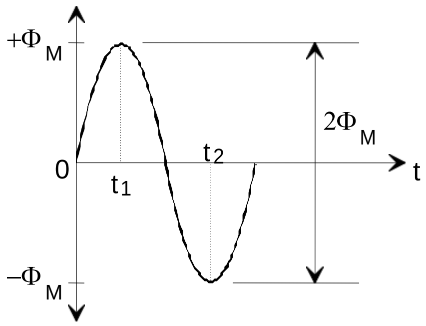


Figure 10

$\Delta\Phi = 2 \text{ x } \Phi_M$

The time interval, t_1 to t_2, represents the time in which this flux change occurs and equals one-half cycle or (0.5 x $^1/_f$) seconds, where *f* is the supply frequency.

$\Delta t = 0.5 \text{ x } \frac{1}{f}$

If N equals the number of turns on the winding, it follows that the average voltage induced in each winding can be determined from -

$$V_{AV} = \text{N x } \frac{2 \text{ x } \Phi_M}{0.5 \text{ x } \frac{1}{F}} = \text{N x } \frac{4 \text{ x } \Phi_M}{\frac{1}{F}} = \text{N x 4 x } \Phi_M \text{ x f volts}$$

From Applied Electricity AC, the effective or rms voltage for a sine wave is 1.11 times the average voltage, therefore –

$$V_{RMS} = 1.11 \times 4 \times \Phi \times f \times N \text{ volts}$$

Since the same flux links with the primary and secondary windings, the voltage induced in each winding can be determined using the above relationship

where: V_1 = primary voltage in volts
V_2 = secondary voltage in volts
Φ = maximum value of core flux in webers (Wb)
f = frequency in hertz (Hz)
N_1 = number of primary turns
N_2 = number of secondary turns

If the secondary is not delivering load current, then -

- the secondary induced voltage is equal to the secondary terminal voltage and if the effects of resistance are neglected,
- the primary induced voltage is equal to the primary applied voltage.

Hence, for no-load conditions the above emf equations can be taken as giving the terminal voltages of the transformer to a high degree of accuracy.

Example: 1

A single phase transformer is wound with 200 turns on the primary and 60 turns on the secondary. The maximum value of core flux is 12.5mWb and the frequency is 50Hz. Determine the -

a) primary voltage
b) secondary voltage.

Example: 2

A single phase transformer is wound with 220 turns on the primary and 40 turns on the secondary. The maximum value of core flux is 45mWb and the frequency is 50Hz. Determine the -

a) primary voltage
b) secondary voltage.

6. THE IDEAL TRANSFORMER

An ideal transformer has no losses, that is -

- neither winding has resistance
- its core is infinitely permeable
- any flux produced by the primary is completely linked by the secondary, and vice versa
- all of the input power fed to the primary is transferred via mutual induction to the secondary, for example, if the input power was 1000W the output power would be 1000W.

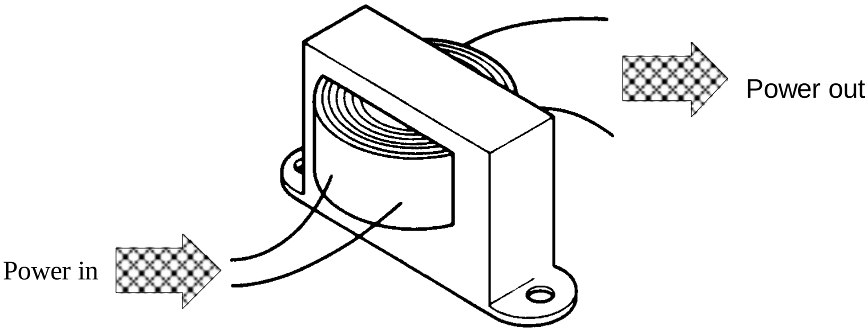


Figure 11

In reality the ideal transformer does not exist. Its operation is considered to allow the understanding of the practical transformer to be achieved a little easier.

7. TRANSFORMER RATIOS

As previously discussed the -

- primary voltage is given by $V_1 = 4.44 \times \Phi \times f \times N_1$
  and
- the secondary voltage by $V_2 = 4.44 \times \Phi \times f \times N_2$

As the core flux is common to both primary and secondary windings -

$\frac{V_1}{V_2} = \frac{4.44 \times \Phi \times f \times N_1}{4.44 \times \Phi \times f \times N_2}$ cancelling the common terms gives $\frac{V_1}{V_2} = \frac{N_1}{N_2}$

Therefore, on no-load and with the effects of winding resistance neglected -

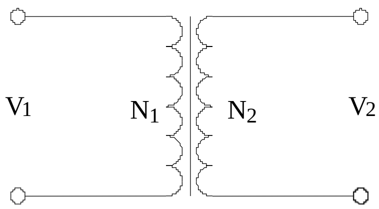


Figure 12

The ratio $\frac{V1}{V_2}$ is called the_______________________________________.

The ratio $\frac{N1}{N_2}$ is called the_______________________________________.

That is, on no-load the____.

Example: 3

A single phase transformer is wound with 750 turns on the primary and 100 turns on the secondary. Determine the transformer primary voltage if the secondary voltage is 32V.

____

____

____

Example: 4

A 240/20V single phase transformer has 480 turns on the primary. Determine the required number of turns on the transformer secondary

____

____

____

When a load is connected across the terminals of the secondary, as shown in figure 13, the load current I_2 is in the direction shown.

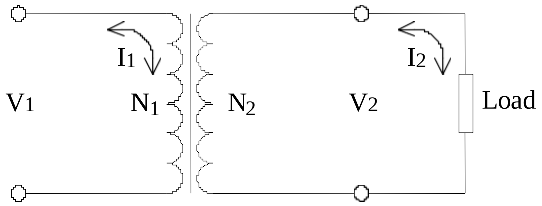


Figure 13

Since the secondary voltage depends on the core flux, it must be clear that the flux should not change appreciably if V_2 is to remain essentially constant under normal load conditions. With the load connected, a current I_2 will flow in the secondary circuit, because the secondary induced voltage will act as a voltage source.

The secondary current produces an mmf (I_2N_2) that creates a flux. This flux has such a direction that at any instant in time it opposes the core flux that created it, hence the secondary mmf tends to reduce the core flux. This means that the flux linking the primary winding reduces and consequently the primary induced voltage. This reduction in induced voltage causes a greater difference between the primary applied voltage and the primary induced voltage, thereby allowing more current to flow in the primary. The fact that the primary current I_1 increases means the primary mmf increases to offset the tendency of the secondary mmf to reduce the core flux. Diagrammatically this can be represented as shown in figure 14.

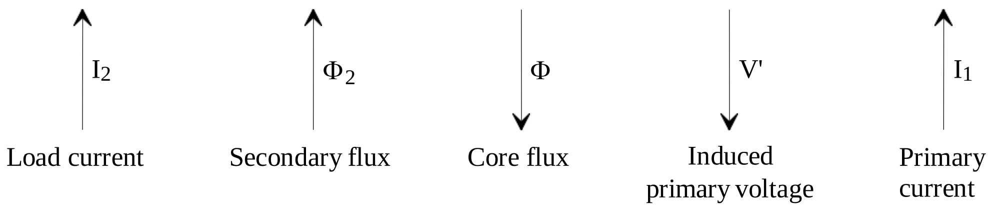


Figure 14

In general, it will be found that the transformer reacts almost instantaneously to keep the core flux essentially constant. Therefore, it can be assumed that the primary ampere-turns are equal to the secondary ampere-turns, as determined by the equation - $I_1N_1 = I_2N_2$, or written in the form of a ratio -

The term $\frac{I2}{I_1}$

is called the transformer_______________________________.

Note, the current ratio is most accurate when________________________________.

Example: 5

A single phase transformer has 500 turns on the primary and 250 turns on the secondary. If the current flowing in the primary is 5A, determine the value of the secondary current.

____

____

____

By comparing the voltage, turns and current ratios, it can be seen that the current ratio is the inverse of the voltage and turns ratios.

Example: 6

For the transformer shown in figure 15, determine the -

a) secondary current
b) transformation ratio
c) primary voltage
d) primary current

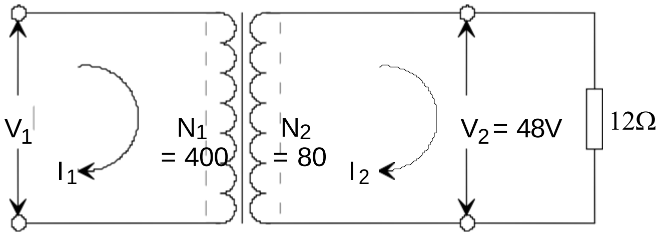


Figure 15

a) ____

____

____

b) ____

____

____

c) ____

____

____

d) ____

____

____

NAME: **Practical 1**

TRANSFORMER RATIOS

PURPOSE:

This practical assignment will be used to examine the voltage and current ratios of a single phase transformer.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Connect a step-down and a step-up transformer.
- Measure the primary and secondary voltages of a transformer.
- Measure the primary and secondary currents of a transformer, on no-load and load.
- Compare the measured voltage and current ratios with the stated turns ratio of a transformer.

EQUIPMENT:

- 1 x variable, single phase AC supply
- 1 x 100VA, 42/24V, single phase transformer
- 1 x 8Ω, 100W wire wound resistor
- 2 x digital multimeters
- 1 x AC current clamp
- 4mm connection leads

– REMEMBER –
– WORK SAFELY AT ALL TIMES –
Observe correct isolation procedures

PROCEDURE

1. STEP DOWN TRANSFORMER

1. Connect the circuit shown in figure 1, using the 42V winding as the primary.

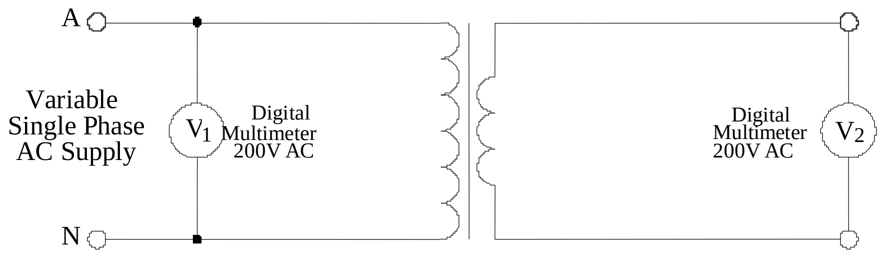


Figure 1

2. Switch on the ac supply and adjust the variac to give a supply voltage of 10V, as indicated by the digital multimeter V_1.
3. Measure the secondary voltage V_2 and record in table 1.
4. Repeat the procedure for each of the primary voltage values shown in table 1.

Table 1

Primary Voltage volts	Secondary Voltage volts	Transformation Ratio V_1/V_2
10V		
20V		
30V		
40V		
Average Transformation Ratio =		

5. Calculate the transformation ratio for each value of primary voltage and record in
table 1.
6. Calculate the average transformation ratio, by adding the four ratios then dividing by 4, record in table 1.
7. **<u>Do not proceed</u>** until the teacher checks your results and completes the progress table.

Progress Table 1

attempt 1	attempt 2	attempt 3
5	2	0

2. CURRENT RATIO

1. Connect the circuit as shown in figure 2, using the 42V winding as the primary.

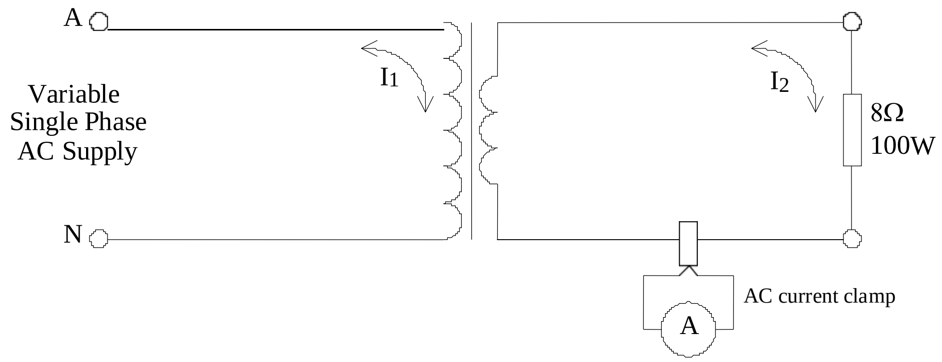


Figure 2

Be careful – the 8Ω load resistor will get very hot

2. Switch on the supply and adjust until the secondary current I_2 is 3A.
3. Using the AC current clamp, measure the primary current I_1 and record in table 2.

Table 2

Primary Current, I_1 amperes	Secondary Current, I_2 amperes	Current Ratio I_2/I_1
	3A	
	0A	

4. Switch off the supply then disconnect the 8Ω load resistor. **Note; the resistor will be hot**.
5. Determine the ratio of secondary current to primary current and record in table 2.
6. Switch on the supply and measure the no-load primary current and record in table 2.
7. **Do not proceed** until the teacher checks your results and completes the progress table.
8. Switch off the supply.

3. STEP UP TRANSFORMER

1. Connect the circuit shown in figure 3 using the 24V winding as the primary.

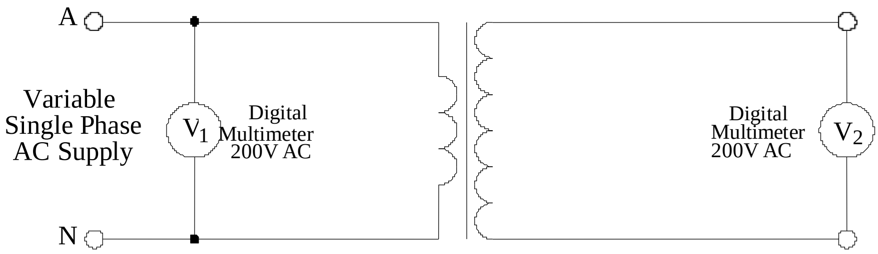


Figure 3

2. Switch on the ac supply and adjust the variac to give a supply voltage of 10V, as indicated by the digital multimeter V_1.
3. Measure the secondary voltage V_2 and record in table 3.

Table 3

Primary Voltage volts	Secondary Voltage volts	Transformation Ratio V_1/V_2
10V		
20V		
30V		
40V		
Average Transformation Ratio =		

4. Repeat the procedure for each of the primary voltage values shown in table 3.
5. Calculate the transformation ratio for each value of primary voltage and record in table 3.
6. Calculate the average transformation ratio, by adding the four ratios then dividing by 4, record in table 3.
7. **Do not proceed** until the teacher checks your results and completes the progress table.

Progress Table 3

attempt 1	attempt 2	attempt 3
5	2	0

8. Switch off the supply, then disconnect the circuit
9. Please return all equipment to its proper place, safely and carefully.

4. OBSERVATIONS:

1. Using the results recorded in table 1 to explain why the transformer in figure 1 is called a step-down transformer.

2. Using the results recorded in table 3 to explain why the transformer in figure 3 is called a step-up transformer.

3. The transformer used in this practical has a turns ratio of 1.75:1. Compare the voltage ratio $\left(\frac{V1}{V2}\right)$ with the stated turns ratio for the transformer, when used as a -

   (a) step-down transformer

   (b) step-up transformer.

4. When used as a step down transformer determine the number of secondary turns on the transformer if the primary side has 2400 turns.

$$\frac{V1}{V2} = \frac{N1}{N2}$$

5. Compare the current ratio $\left(\frac{I2}{I1}\right)$ with the stated turns ratio $\left(\frac{N1}{N2}\right)$ when the transformer was operating with the 8Ω load.

6. Why were the current and turns ratios different?

7. Why did primary current flow when the transformer operated on no-load?

8. Was the transformer used in this practical an ideal transformer. Explain your answer.

THE IDEAL TRANSFORMER

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter on your answer sheet.

The core flux in a double wound transformer cuts the -

a) primary winding only
b) secondary winding only
c) primary winding on one half cycle and the secondary winding on the other half cycle
d) primary and secondary windings simultaneously

The secondary voltage of a transformer is produced by -

a) electrostatic induction
b) current conduction
c) mutual induction
d) self induction

The number of primary winding turns on a transformer is determined by the -

a) supply frequency, voltage and core flux
b) primary current and voltage
c) impedance of the secondary load
d) frequency of the supply only

If a double wound transformer having a voltage ratio of 2:1 is supplied with a 50Hz sine wave to the primary winding, the frequency of the secondary output will be -

a) 25Hz sine wave
b) 25Hz distorted wave
c) 50Hz sine wave
d) 50Hz distorted wave

The number of primary turns on a transformer is governed by the -

a) secondary current
b) primary current
c) primary voltage
d) required ratio of transformation

In an isolation transformer the -

a) secondary voltage is greater than the primary voltage
b) primary voltage is greater than the secondary voltage
c) primary is equal to the secondary voltage
d) primary and secondary voltages are connected to oppose one another

In a step-down transformer the -

a) secondary voltage is greater than the primary voltage
b) primary voltage is greater than the secondary voltage
c) primary is equal to the secondary voltage
d) primary and secondary voltages are connected to assist one another

If the secondary current of a voltage transformer is greater than the primary current, the transformer is known as a/an -

a) isolation transformer
b) step-down transformer
c) step-up transformer
d) auto transformer

The transfer of energy from primary to secondary of a transformer is achieved via -

a) self induction
b) electrostatic induction
c) current conduction
d) mutual induction

As secondary load is increased, the primary current of a transformer -

a) decreases in proportion to the load
b) remains constant
c) increases
d) decreases by a small amount

SECTION B

Blank spaces in the following statements represent omissions. Write the appropriate information on your answer sheet.

Two coils having mutual inductance are said to be______(1)_____.

A transformer that has more turns on the secondary winding than the primary winding is called a______(2)_____transformer.

A transformer in which the secondary voltage is less than the primary voltage is called a _____(3)_____transformer.

A transformer in which the primary and secondary voltages are equal, is called an _____(4)_____transformer.

Because a transformer has no moving parts it is known as a______(5)_____machine.

The primary winding of a transformer is acted upon by two voltages, the applied voltage and the emf of______(6)_____induction.

The voltage induced in the secondary of a transformer is known as the emf of _____(7)_____induction.

If nearly all the flux produced by the primary cuts the conductors of the secondary, the two windings are said to be______(8)_____coupled.

The primary and secondary windings of a transformer can be identified by the fact that the primary is connected to the______(9)_____and the secondary is connected to the _____(10)_____.

When the high tension winding is the primary, the transformer is called a______(11)_____ transformer.

When the low tension winding is the primary, the transformer is called a______(12)_____ transformer.

The ratio of primary voltage to secondary voltage is called the ratio of______(13)_____.

If the effects of resistance are neglected, the primary induced voltage______(14)_____the primary applied voltage.

The ratio of primary turns to secondary turns is called the______(15)_____ratio.

The magnetic flux in the core of a transformer is essentially______(16)_____.

SECTION C

1. The primary winding of a 440/55V transformer has 400 turns. How many turns are there on the secondary winding? (50 turns)
2. 240V is applied to the primary winding of a transformer having 1100 turns. If the secondary has 900 turns, calculate the secondary voltage. (196.3V)
3. A transformer has a turns ratio of 1000:50. Determine the secondary voltage if 240V is applied to the primary. (12V)
4. A 240/32V transformer has a primary current of 0.4A. Calculate the current in the secondary winding. (3A)
5. A single phase transformer steps down from 415V to 32V. Calculate the primary current if the secondary current is 2A. (0.154A)
6. A single phase 240/32V transformer has 300 primary turns and takes a primary current of 1A. Determine the -

   a) secondary turns (40 turns)

   b) secondary current (7.5A)

7. A transformer is wound with 220 turns on the primary and 40 turns on the secondary. The maximum core flux is 0.045Wb and the supply frequency 50Hz. Determine the -
   a) primary voltage (2198V)
   b) secondary voltage (399.6V)
   c) transformation ratio (5.5:1)
8. A transformer with a core flux of 25mWb has a primary winding of 1000 turns and a secondary of 1500 turns. Calculate the secondary voltage if the supply frequency is 50Hz. (8325V)
9. The maximum flux of a 50Hz transformer is 0.001Wb. If the primary is wound with 1080 turns, find the applied primary voltage and then calculate the number of turns required for a 15V secondary. (239.8V, 67.6 turns)
10. A single phase transformer is wound with 80 secondary turns and the primary voltage is 240V. The core flux is 2mWb at a frequency of 50Hz. Determine the -
    a) secondary voltage (35.5V)
    b) primary turns (540.5 turns)
    c) transformation ratio (6.75:1)
11. A 300/32V, 50Hz single phase transformer has 600 primary turns. Determine the maximum value of core flux. (2.25mWb)

SECTION D

1. Redraw the transformer shown in figure 1 then identify the various parts.

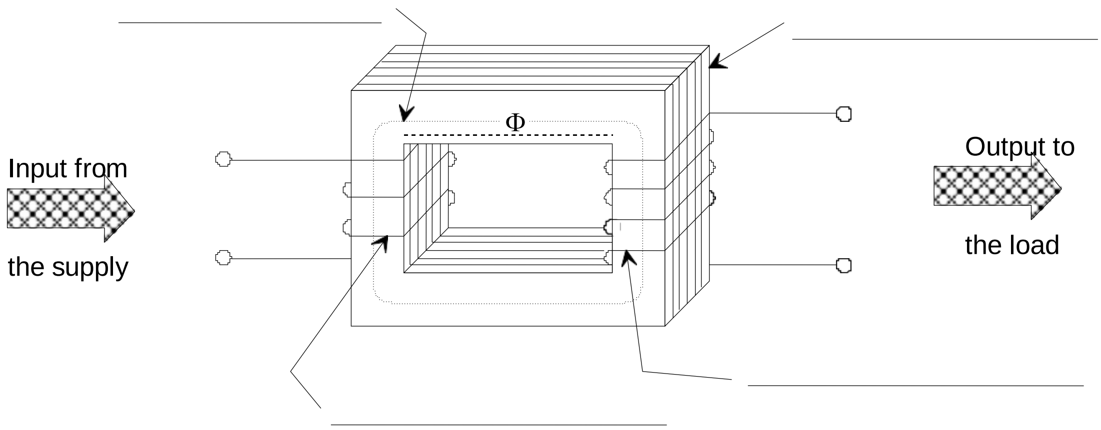


Figure 1

Section 2

THE PRACTICAL TRANSFORMER

PURPOSE:

In this section you will learn about the differences between ideal and practical transformers. In addition the core and winding construction of single and three phase transformers will be covered, along with the no-load operation of the practical transformer.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- Describe the differences between ideal and practical transformers.
- Describe various types of lamination style and core construction.
- Identify different types of winding arrangements.
- Identify the voltages and currents associated with the no-load operation of the practical transformer.
- Determine the no-load current of a transformer given the magnetising and iron loss currents.

REFERENCES:

Hampson, J. & Hanssen, S. *Electrical Trade Principles*, 2nd Edition, Section 7

Jenneson, J.R. *Electrical Principles for the Electrical Trade*, 5th Edition, Pages 337, 339-342 and 354

1. THE PRACTICAL TRANSFORMER

As explained in section 1 the transformer, in its simplest form, consists of two coils of insulated wire that are insulated from each other and wound on a laminated steel core as shown in figure 1.

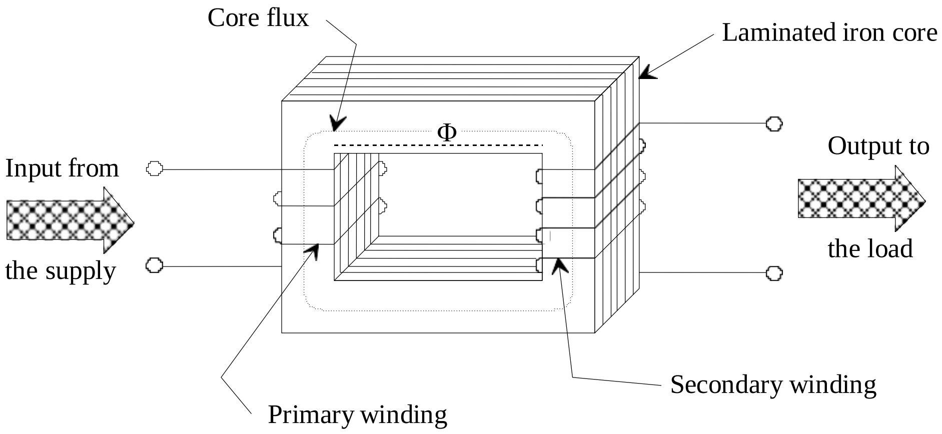


Figure 1

In the case of the ideal transformer it is assumed -

- the windings have zero resistance
- the core is infinitely permeable
- all of the flux produced by the primary is mutually coupled with the secondary
- all of the input power is transferred by mutual inductance to the output.

As a consequence it can be stated -

The transformation ratio = turns ratio = current ratio

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$$

Example: 1

For the ideal transformer shown in figure 1, determine the -

a) secondary current (I_2)

b) primary current (I_1) with the 5Ω load connected

c) primary current (I_1) with no-load applied.

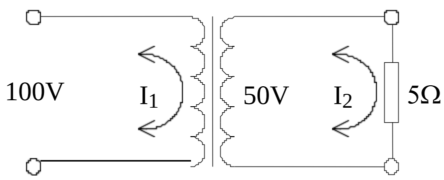


Figure 1

Example 1 shows that primary current (I_1) flows in an ideal transformer only when a secondary current (I_2) flows.

That is, the ideal transformer has a no-load current equal to____________amperes. This is because the ideal transformer has zero losses - neither winding loss nor core loss.

The practical transformer does not have this characteristic.

All practical transformers when operated at no-load will draw a primary current (I_1) from the supply. This occurs because all practical transformers have losses, made up of

- winding loss
- core loss.

2. MAGNETIC LEAKAGE

Most of the magnetic flux produced by the primary current of a transformer passes through the iron core and links with all the turns in both windings, but a certain amount of flux will take various shorter paths even though of greater reluctance, as shown in figure 2.

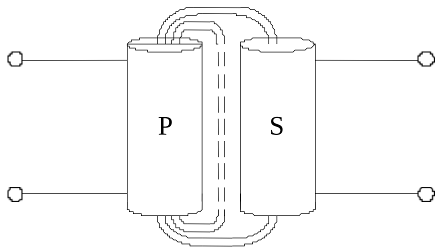


Figure 2

_______________________________ serves no useful purpose and has the effect of adding additional reactance to the windings.

Magnetic leakage increases as load increases, causing a reduction in the secondary voltage for a given primary voltage, as some voltage is dropped in overcoming the additional reactance, thus changing (decreasing) the ratio of transformation slightly.

Except for special purposes, care is taken by designers to keep magnetic leakage to a minimum. In practice both primary and secondary coils are placed on the same limb to reduce magnetic leakage and thereby increase the tightness of the coupling between the coils. See figure 3.

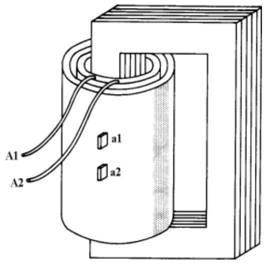


Figure 3

3. CORE CONSTRUCTION

Transformer cores are usually -

- laminated - usually 0.25mm to 0.9mm thick
- constructed of a very high grade of silicon steel (approx. 97% iron + 3% silicon) - the silicon content reduces the magnetising losses, particularly hysteresis loss
- cold rolled and often specially annealed to orient the grain to provide a very high permeability and low hysteresis in the direction of rolling.

Any scheme used for core construction involves the cost of material handling, which is an important fraction of the total cost of a transformer. As a rule-

- the number of butt joints are limited
- joints are tightly made and laminations interleaved so as to minimize the reluctance of the magnetic circuit
- the whole core is built up or stacked to the proper dimension and the laminations are bolted together firmly.

As can be appreciated, core legs of square or rectangular cross section are the result if we stack the laminations to the required core cross section. This permits coils to be fitted on them with either square, rectangular, or circular coil spools or forms.

As the transformer size increases, a point is reached where this construction is unsatisfactory. Therefore, in the larger transformers, a stepped-core arrangement is used to minimize the use of copper and reduce copper loss. See figure 4.

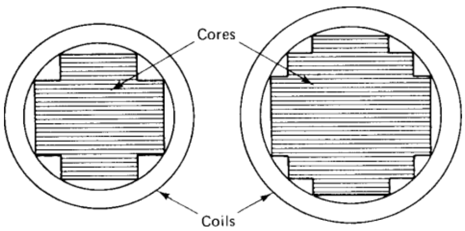


Figure 4

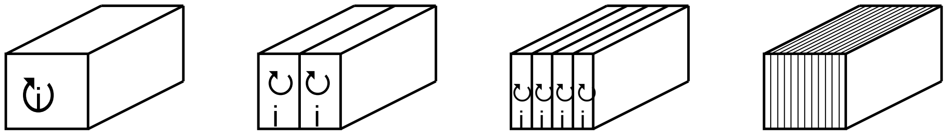
This construction guarantees that each length of copper conductor embraces the maximum cross-sectional area of steel. In practical transformers, the primary and secondary windings have two or more coils per leg. They may be arranged in series or parallel, thereby providing several possible voltages.

Due to the cyclic magnetic forces and forces that exist between parallel conductors carrying current, it is necessary to clamp laminations and impregnate the coils. Insufficient clamping usually results in hum, giving rise to objectionable audible noise.

The magnetic flux established in a transformer core is alternating in nature. When the flux rises and falls, it cuts the conducting iron and induces an emf in the core. As the iron forms a closed circuit, a current will flow. This current is known as an eddy current because it flows or circulates within the iron of the core. The resultant effect of eddy currents is to cause the core to heat. That is energy is taken from the supply that is wasted in heating the core. For this reason eddy currents need to be kept to a minimum.

The core is laminated to reduce__________________________________loss.

Figure 5 shows the effect on eddy currents of laminating the transformer core.



Solid core
Eddy currents large

Lightly laminated core
Eddy currents reduced

Laminating increased
Eddy currents small

Heavily laminated core
Eddy currents very small

Figure 5

Figures 6 and 7 show the lamination stacks for single and three phase transformers.

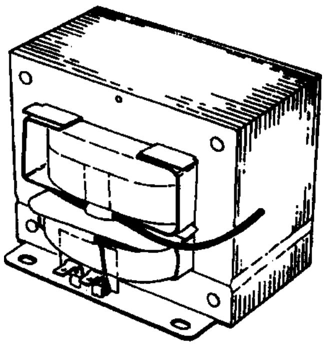


Figure 6

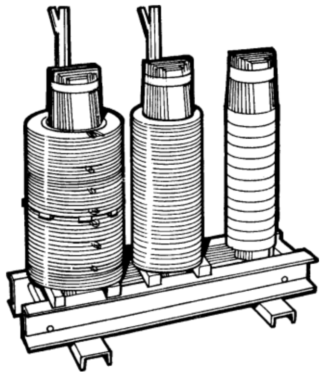


Figure 7

As covered in the module Applied Electromagnetism, a magnetic material such as that used in the core of a transformer, gets warm when it is cyclically magnetised.

The energy required to cyclically magnetise a transformer core is called the ______________ loss, which is proportional to the supply frequency.

To minimise hysteresis loss a material with high permeability and low retentivity, such as soft iron, must be used. In practice the material used is________________________.

Silicon steel laminations are carefully cut, punched where necessary and have any burrs removed by grinding.

Before assembly each lamination is sometimes treated on one side only with an ***insulating varnish*** which resists the action of heat and oil and reduces eddy currents.

The cores are built up by interleaving the laminations in order to reduce the core losses to a minimum.

Transformers are classified as -

- ____________________ type
- ____________________ type
- ____________________ type, according to the type of core construction used.

In the ***core type transformer***, figure 8 -

- the core is in the form of a hollow square made up of laminations.
- the magnetic circuit is to a large extent covered by the coils, which are well exposed.
- each leg, or limb, of the core carries both a primary and a secondary winding.
- the low tension (L.T.) winding is usually nearer to the core because it requires less insulation between itself and the core.
- the high tension (H.T.) winding has the insulation of the low voltage winding, as well as its own, between itself and the core. This is called concentric winding.
- another method is to divide the windings into sections, placing H.T. and L.T. sections alternately on the core, the two end coils being L.T.

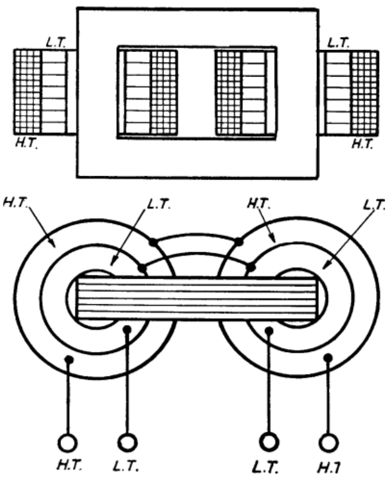
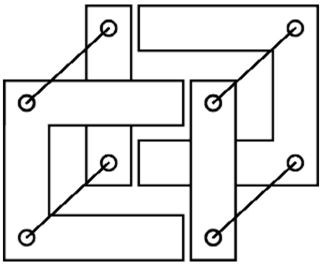


Figure 8

The laminations for the core-type transformer may be made up of 'U' and 'I' shaped laminations, as shown in figure 9.

Figure 10 shows an example of an assembled single phase, core type transformer.



U and I laminations

Figure 9

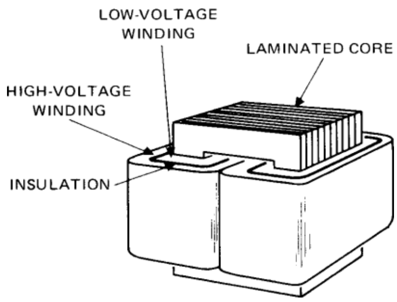


Figure 10

In the ***shell type*** transformer -

- the magnetic circuit covers a large part of the coils and is itself more exposed than in the core type.
- both the primary and secondary windings are mounted on the central limb as shown in figures 11 and 13.
- to minimise the insulation required between the high voltage winding and the core, the low voltage winding is usually wound in two sections and the high voltage winding placed between them. This arrangement also reduces magnetic leakage.
- the central limb has twice the cross-sectional area of the outer limb because the whole magnetic flux passes through the central limb but then divides, half passing through each outer limb.

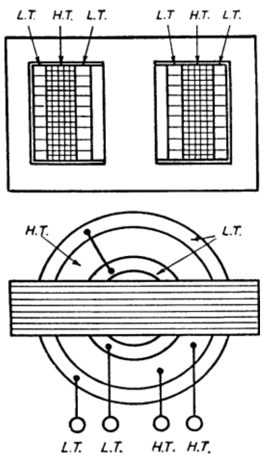
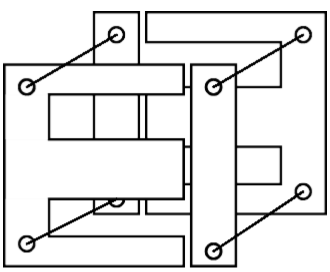


Figure 11

The core for the shell-type transformer is normally made up of 'E' and 'I' shaped laminations, as shown in figure 12.

Figure 13 shows an example of an assembled single phase, shell type transformer.



E and I laminations

Figure 12

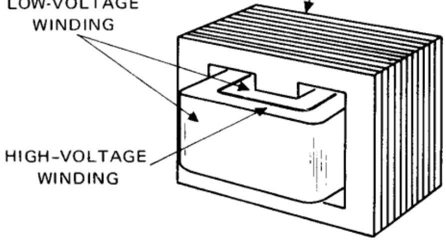


Figure 13

The ***toroidal core*** -

- made from a continuous ribbon of thin metal tape made from a special alloy which has been rolled and cut to best utilise its magnetic properties. It is wound tightly around a former and consolidated under pressure into a solid mass. It is then sliced into two C-shaped pieces, known as C-cores.
- the cut faces are ground to ensure good surface contact between the two halves.
- the C-cores are placed around the transformer windings and clamped with a non-magnetic band.

Figure 13 shows a pair of C-cores prior to assembly.

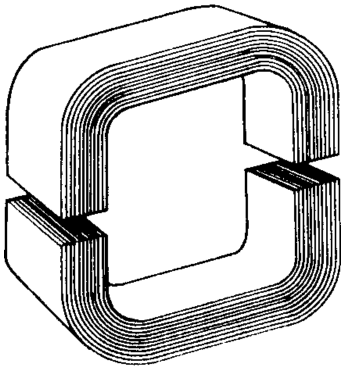


Figure 13

For core type construction a___________of cores is used, while for shell type ___________ are used. Figure 14 shows an assembled toroidal type transformer.

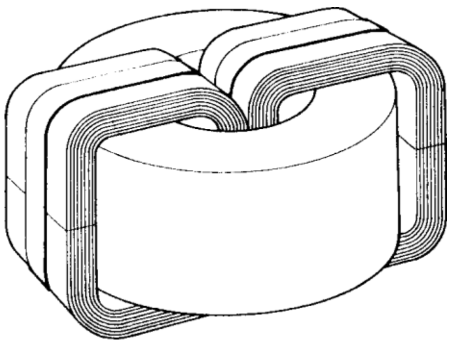


Figure 14

4. TRANSFORMER WINDINGS

The actual placement of the windings on the core of a transformer core depends on the

- type of_____________and the
- intended ____________ of the transformer.

Other factors that influence the winding arrangement are the -

- operating____________________and the
- power___________________of the transformer.

As shown in figure 15 there are three basic types of winding arrangement used in single and three phase transformers, these are the -

- ____________________ winding - in which one winding is wound on top of the other and suitable insulation placed between them.
- ____________________ winding - is used where closely coupled windings are are required, so that magnetic leakage can be reduced to a minimum.
- ____________________ winding - which is being used more often for power transformers.

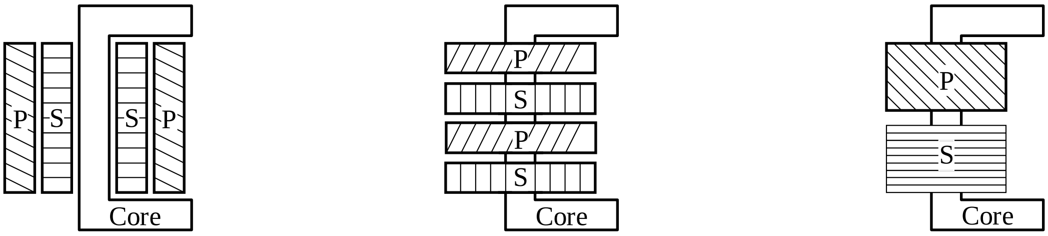


Figure 15

5. TRANSFORMER ON NO-LOAD

When a sinusoidal voltage V_1 is applied to the primary with the secondary open-circuited, as shown in figure 16, there will be no energy transfer from primary to secondary.

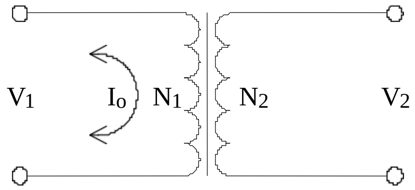


Figure 16

The applied voltage V_1 causes a small current I_O to flow in the primary winding. This no-load current is made up of two components, each having a specific functions -

- ____________________ current ($I\mu$) - magnetises the iron core.
  - lags the primary voltage V_1 by 90º.
- ____________________ current ($I\eta$) - provides the energy required to overcome the hysteresis and eddy current losses. These combined losses are known as the core loss.
  - is in phase with the primary voltage V_1.

The no-load current I_O -

- is usually a few percent of the rated full-load current of the transformer, approximately 2 to 5%.
- the no-load current is equal to the phasor sum of the magnetising current and the iron loss current.

Figure 17 shows the phasor diagram for a transformer operating at no-load. Note, the core flux (Φ) is used as the reference phasor.

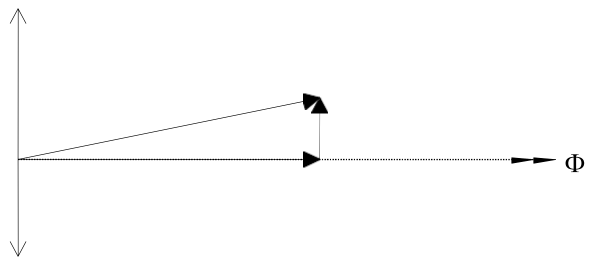


Figure 17

core flux - Φ (the reference)   magnetising current - $I\mu$

applied voltage - V_1 secondary voltage - V_2 iron loss current - $I\eta$

As the magnetising current is considerably greater than the iron loss current, the no-load current lags behind the applied voltage by a very large angle, usually about 85º.

This means that the no-load power factor is very low, approximately 0.087 lag ($\lambda = \cos\phi$).

Example: 2

A 240/110V single phase transformer takes a magnetising current of 4.95A and an iron loss current of 0.52A. Determine the following values for the transformer -

- no-load current (use the scale 1mm = 0.05A)
- no-load phase angle
- no-load power factor.

Example: 3

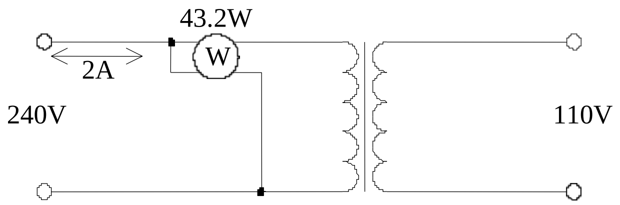
A 240/32V single phase transformer takes a no-load current of 0.8A at a power factor of 0.1 lag. Determine the magnetising and iron loss currents of the transformer.

Scale: 1mm = 0.01A

Example: 4

Determine the magnetising and iron loss currents of the 240/110V transformer for the transformer shown in figure 18.

Scale: 1mm = 0.02A



6. TRANSFORMER EQUIVALENT CIRCUIT

A practical single phase transformer, or one phase of a practical three phase transformer, may be represented by the equivalent circuit shown in figure 19.

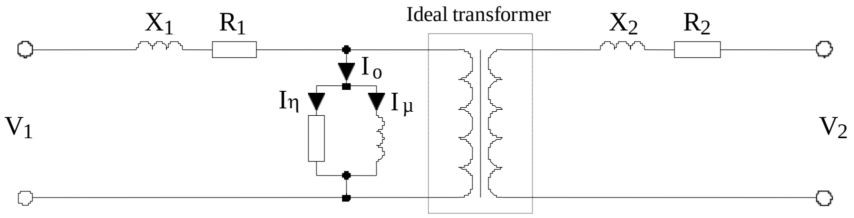


Figure 19

The equivalent circuit makes allowance for the losses incurred within the transformer and is helpful aid in understanding the operation of the transformer, particularly when load is applied or varied.

The component parts of the equivalent circuit are -

- V_1 = primary terminal voltage
- V_2 = secondary terminal voltage
- R_1 = primary winding resistance
- X_1 = primary winding reactance
- R_2 = secondary winding resistance
- X_2 = secondary winding reactance
- I_O = no-load current
- $I\eta$ = core loss current (eddy current + hysteresis loss)
- $I\mu$ = magnetising current.

Example

20kVA, 2400/240V transformer

$R_1 = 0.8\Omega$ $X_1 = 3\Omega$

$R_2 = 0.0084\Omega$ $X_2 = 0.028\Omega$

The equivalent circuit will be used in following sections to explain the operating characteristics of transformers, both single and three phase.

NOTES

******

NAME: **Practical 2**

THE PRACTICAL TRANSFORMER

PURPOSE:

This practical assignment will be used to examine the no-load operation of a single phase transformer.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Measure the winding resistances of a transformer.
- Measure the primary and secondary voltages of a transformer.
- Measure the no-load primary current of a transformer.
- Measure the no-load power taken by a single phase transformer.
- Draw the no-load phasor diagram and determine the magnetising and iron loss currents.

EQUIPMENT:

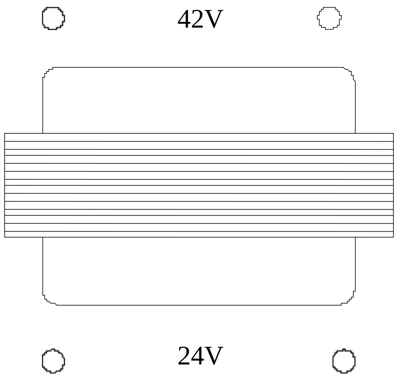
- 1 x variable, single phase AC supply
- 1 x 100VA, 42/24V, single phase transformer
- 1 x wattmeter (1A, 50V)
- 2 x digital multimeters
- 1 x AC current clamp
- 4mm connection leads

– REMEMBER –
– WORK SAFELY AT ALL TIMES –
Observe correct isolation procedures

PROCEDURE

1. WINDING RESISTANCES

1. Using a digital multimeter, measure the winding resistances of the transformer. Record the values in the spaces provided below.



Resistance 42V winding = __________

Resistance 24V winding = __________

Figure 1

2. **Do not proceed** until the teacher checks your results and completes the progress table.

Progress Table 1

attempt 1	attempt 2	attempt 3
5	2	0

2. NO-LOAD OPERATION

1. Connect the circuit shown in figure 2, using the 42V winding as the primary.

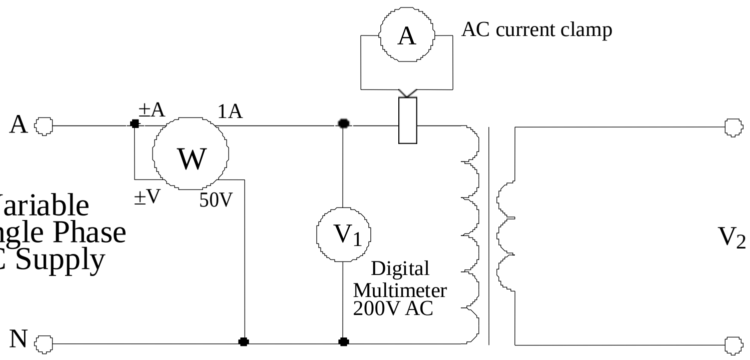


Figure 2

2. Switch on the ac supply and adjust the variac to give a primary voltage of 42V, as indicated by the digital multimeter V_1.

3. Measure the secondary voltage V_2 and record in table 1.

Table 1

Primary Voltage volts	Secondary Voltage volts	Primary Current amperes	No-Load Power watts	Transformation Ratio V_1/V_2
42V				

4. Using the AC current clamp, measure the primary current and record in table 1.
5. Record in table 1 the power taken by the transformer.

   Note, the actual power taken will be = 2 x wattmeter reading
6. **Do not proceed** until the teacher checks your results and completes the progress table.

Progress Table 2

attempt 1	attempt 2	attempt 3
5	2	0

7. Switch off the supply, then disconnect the circuit.
8. Please return all equipment to its proper place, safely and carefully.

3. OBSERVATIONS:

1. Complete table 1 by determining the transformation ratio

   Transformation ratio = $\frac{V1}{V_2}$

   ____

   ____

2. Determine the no-load power factor of the transformer tested.

   $\lambda = \frac{P}{S} = \frac{P}{V\ x\ I}$

   ____

   ____

3. Determine the no-load phase angle of the transformer tested.

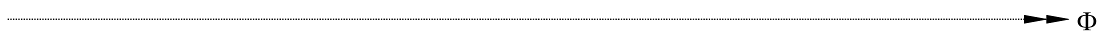
   $\phi = \cos^{-1}\lambda$

   ____

   ____

4. Draw the no-load phasor diagram for the transformer. On your diagram show the -
   a) primary voltage
   b) secondary voltage
   c) no-load current.

   Scales: 1mm = 1V and 1mm = 10mA



5. From your phasor diagram determine the value of the -
   a) magnetising current (Iμ)
   b) iron loss current (Iη)

6. Based on your results, which is the bigger, magnetising current or iron loss current? By how much, was one current bigger than the other?

7. Was the transformer used in this practical an ideal or practical transformer? Explain your answer.

THE PRACTICAL TRANSFORMER

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter on your answer sheet.

1. Practical transformer and ideal transformers differ, in that the practical transformer has -

   a) a perfect transformation ratio
   b) losses
   c) zero hysteresis loss
   d) a better iron loss

2. The core of a transformer is laminated to -

   a) reduce hysteresis loss
   b) reduce eddy current loss
   c) enhance the coupling between windings
   d) make core construction simpler

3. In a transformer, sections of both primary and secondary windings are usually wound on each limb to reduce -

   a) magnetic leakage
   b) iron losses
   c) hysteresis losses
   d) the amount of wire

4. Silicon steel is used for the laminations in a transformer core because it -

   a) has a high resistance
   b) reduces noise
   c) has a high permeability
   d) has a low resistance

5. Silicon steel is used for transformer cores because it -

   a) reduces hysteresis loss
   b) keeps the iron loss to a minimum
   c) is cheaper than ordinary steel
   d) has low resistance

6. The component of no-load current which lags the transformer primary voltage by 90º is the -
   a) magnetising current
   b) iron loss current
   c) secondary current
   d) primary current

7. The material most commonly used for transformer windings is -
   a) aluminium
   b) copper
   c) silicon steel
   d) iron

8. Transformer laminations are prevented from shorting together by -
   a) a varnish or oxide layer on each lamination
   b) a layer of insulation between each lamination
   c) filling the transformer with insulating oil
   d) using spacing blocks to provide air gaps

9. The approximate phase angle of a transformer operating on no-load is -
   a) 0º
   b) 15º
   c) 85º
   d) 180º

10. The no-load current of a transformer is equal to the -
   a) magnetising current only
   b) iron loss current only
   c) phasor difference of the magnetising and iron loss currents
   d) phasor sum of the magnetising and iron loss current

SECTION B

Blank spaces in the following statements represent omissions. Write the appropriate information on your answer sheet.

1. In practice the______(1)_____load current of a transformer is constant.
2. If the two windings of a transformer are wound, one on top of the other, the winding is known a______(2)_____type winding.
3. A single phase transformer which has its windings on the centre limb of the laminations is called a______(3)_____type transformer.
4. Eddy currents in a transformer are caused by_____(4)_____in the iron core.
5. In an unloaded transformer, the magnetising current______(5)_____the primary voltage by approximately______(6)_____degrees.
6. Joints in the laminations of a transformer core are staggered so as to minimise _____(7)_____.
7. The iron core of a core type transformer is constructed using laminations cut to a particular shape, and are called______(8)_____and______(9)_____laminations.
8. In smaller transformers the lamination joints may be butted together, whereas in large power transformers the joints are______(10)_____.
9. Laminations used in the construction of a transformer core are approximately _____(11)_____thick.
10. If a transformer was constructed using a solid iron core the______(12)_____loss would be very large and the transformer would run very hot.
11. Flux established by the primary that does not cut the conductors of the secondary is known as______(13)_____flux.
12. The secondary voltage of a transformer is______(14)_____degrees out of phase with the primary voltage.
13. The only factor that is common to both the primary and secondary windings of a transformer is the core______(15)_____.
14. If a transformer was constructed using a mild steel core the______(16)_____loss would be very large and the transformer would run very hot.

SECTION C

1. What is meant by the term *leakage flux*, and how is it kept to a minimum?
2. A 240/115V single phase transformer has 960 turns on its primary winding. Calculate the number of turns required on the secondary winding. (460 turns)
3. A 240/12V downlight transformer draws a no-load current of 0.6A at a phase angle of 80º lag. Using a scale of 1mm = 10mA, draw the no-load phasor diagram for the transformer and from the diagram determine the -
   a) magnetising current (0.59A)
   b) iron loss current. (0.104A)
4. 4.A single phase 240/415V transformer has a no-load primary current of 0.8A and takes 78W from the supply. Determine the -
   a) no-load power factor (0.406 lag)
   b) no-load phase angle (66º lag)
   c) magnetising current (0.73A)
   d) iron loss current. (0.325A)

   For parts (c) and (d) use a scale: 1mm = 0.01A

5. A single phase transformer steps down from 415V to 32V. Calculate the primary current if the secondary current is 5A. (0.386A)
6. A transformer is wound with 250 turns on the primary and 50 turns on the secondary. The maximum core flux is 0.04Wb and the supply frequency 50Hz. Determine the -

   a) primary voltage (2220V)

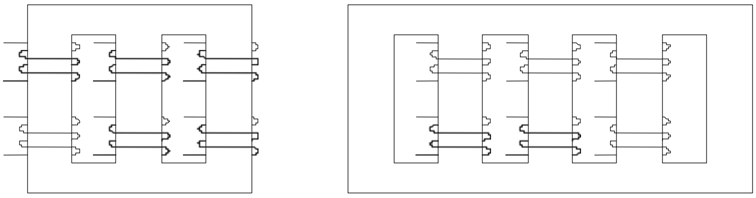
   b) secondary voltage (444V)

   c) transformation ratio (5:1)
7. A 250/500V transformer has a magnetising current of 4.92A and an iron loss current of 0.88A. Determine the no-load primary current and phase angle. (5A, 79.8º lag)

   Scale: 1mm = 0.1A
8. A 300/32V, 50Hz single phase transformer has 500 primary turns. Determine the maximum value of core flux. (0.0027Wb)

SECTION D

1. Identify the two types of transformer core shown in figure 1.



(a) (b)

Figure 1

2. Sketch the winding arrangements for concentric, sandwich and side by side windings.
3. Explain why a stepped core would be used in a large power transformer.
4. List applications for core and shell type transformers.
5. Why are transformer laminations clamped tightly together?

Notes

TRANSFORMER OPERATION

PURPOSE:

In this section you will learn about how transformers are rated and the operation of the practical transformer when delivering load current.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- State the method used to rate transformers.
- Calculate the maximum current that may be delivered by a transformer.
- Describe the relationship between transformer rating and cooling.
- List methods used for natural and forced cooling of transformers.
- Draw the phasor diagram of a loaded transformer, showing the voltage and current components.

REFERENCES:

- Hampson, J. & Hanssen, S. *Electrical Trade Principles,* 2nd Edition, Section 7
- Jenneson, J.R. *Electrical Principles for the Electrical Trade,* 5th Edition, Pages 335 - 337

1. RATING OF TRANSFORMERS

Transformers are rated to supply a given value of -

- _________________________________ at a given frequency and terminal voltage.

For example, 100VA at 24V, 50Hz or 500kVA at 415V, 50Hz.

This means that transformers are designed to carry a certain load safely, with ***temperature rise*** being the limiting factor. The heat developed in the windings of a transformer depends upon the load current that has to be supplied, regardless of the power factor; hence the rating is usually expressed in volt-amperes (VA), that is -

Single phase transformer	Three phase transformer

where:		
where:	S = apparent power in VA	S = apparent power in VA
	V = secondary terminal voltage in volts	V = secondary line voltage in volts
	I = load current in amperes	I = secondary line current in amperes

Example: 1

A single phase 1000/250V, transformer is rated at 10kVA. Determine the full-load secondary current.

____

____

____

What would happen if the transformer in example 1 was called on to deliver a secondary current of 50A over an extended period of time.

The winding designed to deliver a maximum current of 40A, would_______________.

Consequently, transformers are rated in terms of VA for current limiting reasons, since heating effect is proportional to current squared (I^2) and is independent of power factor.

Example: 2

A three phase, 11000/415V transformer is rated at 500kVA. Determine the full-load secondary current.

____

____

____

Example: 3

The 42/24V single phase transformers used in the practical assignments of this module are rated at 100VA. Determine the full load secondary current, given the transformers are designed to deliver 24V at 50Hz.

____

____

____

Example: 4

Determine the full load secondary current of the 33/11kV, 1000kVA transformer shown in figure 1.

____

____

____

____

____

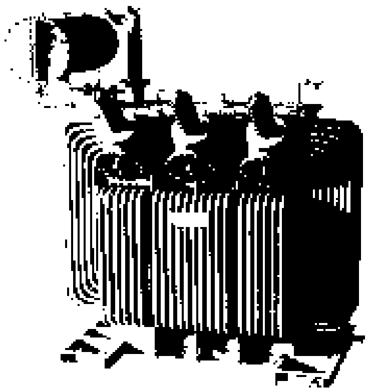


Figure 1

2. TRANSFORMER COOLING

A transformer delivering load current generates heat in the core and the windings. The extent to which the temperature of a transformer increases with load is an important operating factor. The temperature of a transformer should not rise more than 50ºC above the surrounding air temperature.

Transformer rating can be increased if the windings are cooled by some external means. There are two commonly used cooling mediums are -

- ________________________ and/or ________________________.

Water cooling is used but to a lesser extent.

In practice transformers are allocated symbols which indicate the type of cooling used.

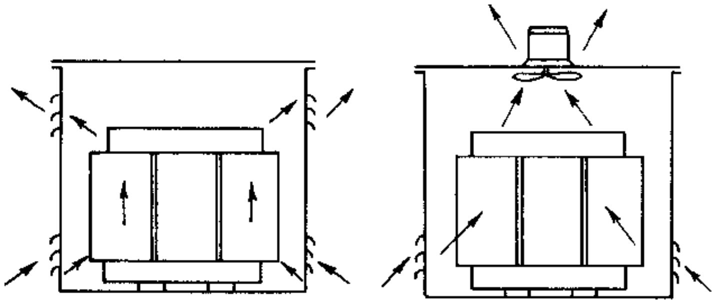
Cooling Medium	
Air	A
Oil	O
Water	W

Type of Circulation	
Natural	N
Forced	F
Forced directed	FD

The order in which cooling symbols are arranged is as shown below.

1st Letter	2nd Letter	3rd Letter	4th Letter
The cooling medium in contact with the windings		The cooling medium in contact with the external cooling system	
Kind of medium	Circulation type	Kind of medium	Circulation type

Figures 2, 3, and 4 show examples of various air and oil transformer cooling methods.

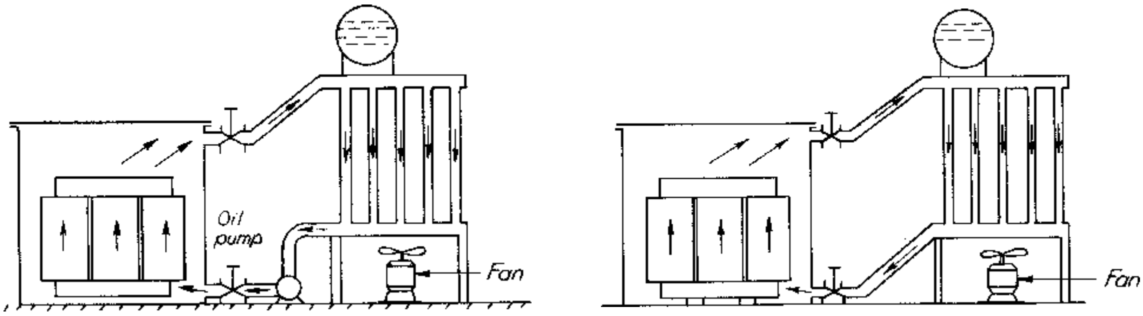


Air Natural
Type AN

Air forced
Type AF

Oil natural, air natural
Type ONAN

Figure 2

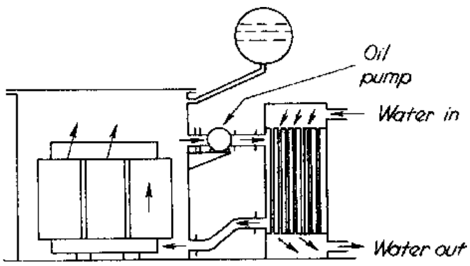


Oil forced air forced
Type OFAF

Oil natural air forced
Type ONAF

Figure 3

Oil forced water forced

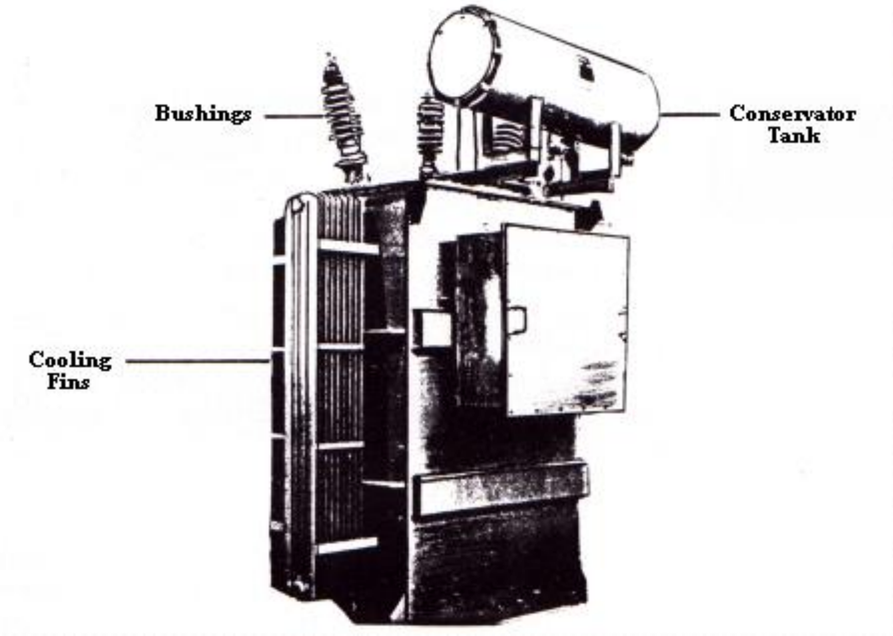


Type OFWF

Figure 4

3. CONSERVATOR TANKS

Some coolant filled transformers have a conservator tank or expansion tank. Coolant flows into and out of the tank as the main tank expands and contracts due to temperature changes.



Conservators have various uses which include acting as a sump to collect impurities in the oil and to remove oxygen and moisture from the oil.

Mounted near the conservator you will generally find a "**Buchholz Relay**". These relays are designed to detect air or gas in the oil and will trigger an alarm which will shut down the transformer before major damage can occur.

Also mounted near the conservator is a "**Beaded silica gel breather**". This breather is designed to remove moisture from the transformer oil before it causes damage. When no moisture is present the beads appear as a blue colour and they change to pink as they draw the moisture from the oil. The beads can be removed and dried with heat and reused once they are blue again.

4. TRANSFORMER ON LOAD

When a load is applied to the secondary of a transformer a current I_2 flows in the secondary windings, as shown in figure 5. The value of this current, and its phase position, depends upon the nature of the load.

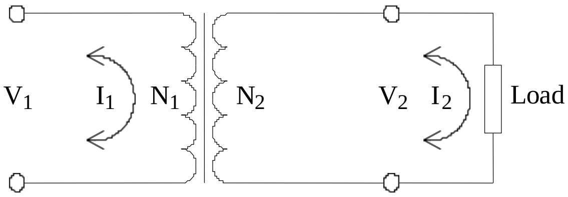


Figure 5

Under load the transformer secondary delivers energy to the load, therefore additional energy must be taken by the transformer primary. As the primary applied voltage is constant, the primary current must increase to supply the additional energy required.

Reference to the equivalent circuit, as shown in figure 6, may assist in visualising transformer operation when load is applied.

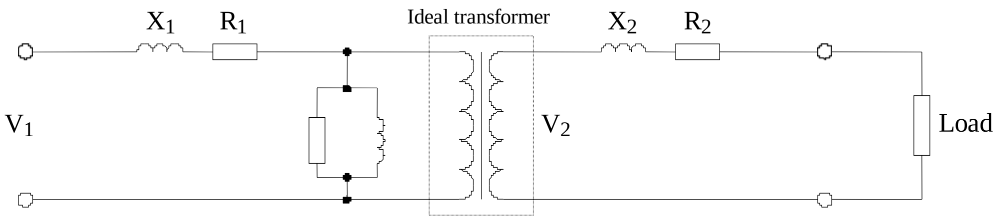


Figure 6

The total primary current taken by the transformer under load conditions is made up of two components, the -

- no-load current (I_O) - magnetises the core and overcomes core loss (hysteresis and eddy current loss)
- load component of primary current (I_1') - supplies the energy required by the load.

The load component of primary current is determined using transformer ratios, as follows –

$$\frac{V_1}{V_2} = \frac{I_2}{I_1} \quad \therefore \quad V_1 \text{x}\, I_1' = V_2 \text{x}\, I_2 \quad \therefore$$

$$\frac{N_1}{N_2} = \frac{I_2}{I_1} \quad \therefore \quad N_1 \text{x}\, I_1' = N_2 \text{x}\, I_2 \quad \therefore$$

The total primary current taken by a transformer supplying a load is equal to the phasor sum of the no-load current and the load component of primary current –

Figure 7 shows the phasor diagram for a transformer 1:1 operating on inductive load and illustrates the phase relationship between the –

* core flux - Φ, which is taken as the reference
* applied voltage – V_1
* secondary voltage – V_2
* load component of primary current – I_1’
* secondary current – I_2
* no-load current - I_O
* primary current – I_1

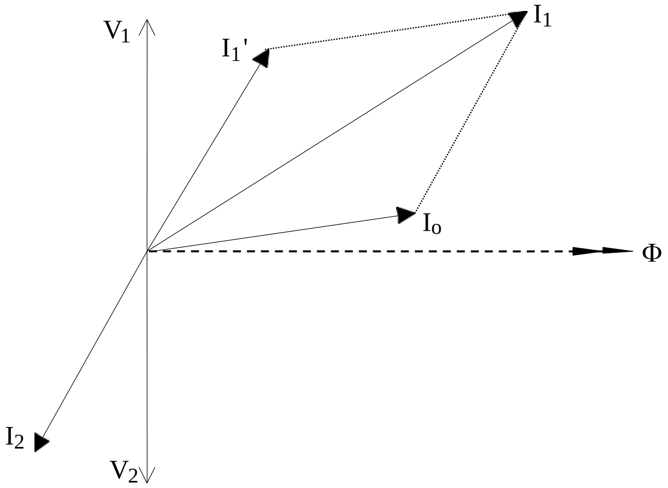


Figure 7

Figure 8 shows the phasor addition of the no-load current and the load component of primary current to determine the transformer primary current when loaded.

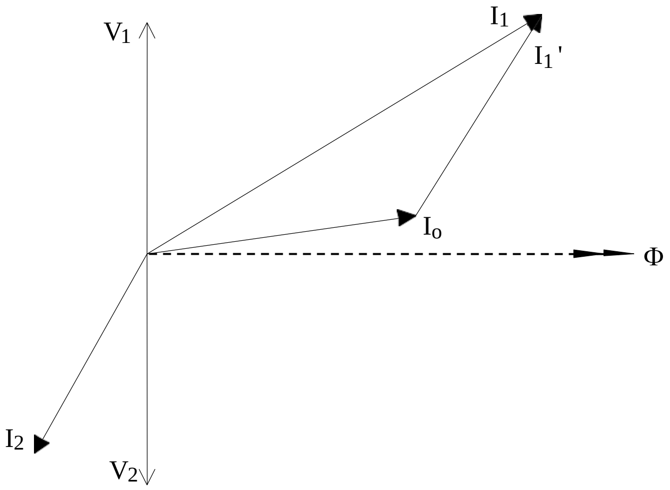


Figure 8

Example: 5

A 240/32V single phase transformer takes a no-load current of 0.8A at a power factor of 0.1 lag. Determine the primary current and power factor if the transformer supplies a load current of 35A at unity power factor.

Scale: 1mm = 0.1A.

Step 1: Determine the no-load phase angle - Φ_o.

Step 2: Determine the secondary or load phase angle - Φ_2.

Step 3: Determine the load component of primary current – I_1'.

Step 4: Locate voltages and currents on the phasor diagram, see figure 9.

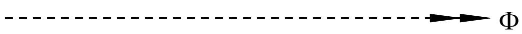


Figure 9

Step 5: Draw the phasor diagram to determine the primary current, by taking the phasor addition of the no-load current and the load component of current. See figure 10.

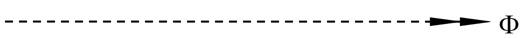


Figure 10

Example: 6

A 240/110V single phase transformer takes a no-load current of 2A at a power factor of 0.09 lag. Determine the primary current and power factor if the transformer supplies a load current of 15A at a power factor of 0.85 lag.

Scale: 1mm = 0.1A.

Step 1: Determine the no-load phase angle - Φ_O.

Step 2: Determine the secondary or load phase angle - Φ_2.

Step 3: Determine the load component of primary current – I_1'.

Step 4: Locate voltages and currents on the phasor diagram, see figure 11.

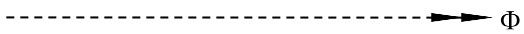


Figure 11

Step 5: Draw the phasor diagram to determine the primary current, by taking the phasor addition of the no-load current and the load component of current. See figure 12.

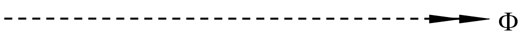


Figure 12

Example: 7

A three phase, 6600/415V, delta star transformer has a no-load phase current of 2.75A and operates with a no-load phase angle of 85º. When supplying an inductive load the secondary phase current is 696A at a phase angle of 30º lag. If the transformation ratio is 27.5:1, determine the primary phase current. Scale: 1mm = 0.3A.

Step 1: Determine the load component of primary current – I_1'.

Step 2: Locate voltages and currents on the phasor diagram, see figure 13.

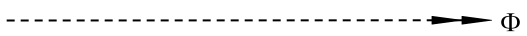


Figure 13

Step 3: Draw the phasor diagram to determine the primary current, by taking the phasor addition of the no-load current and the load component of current. See figure 14.

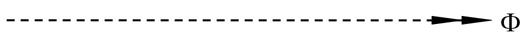


Figure 14

5. SURGE PROTECTION

A power surge or an increase in voltage supplying a transformer can have detrimental effect on its operation and can even destroy a transformer.

Transformers need to be protected from power surges and this is done by the use of valve type surge diverters which consist of two series connected elements. The first element is a series of ‘spark gaps’ followed by a valve element consisting of voltage dependant resistors or VDR. When a high voltage occurs it flashes over the spark gaps and discharges to ground through the VDR.

Figure 15 shows an example of a valve type diverter

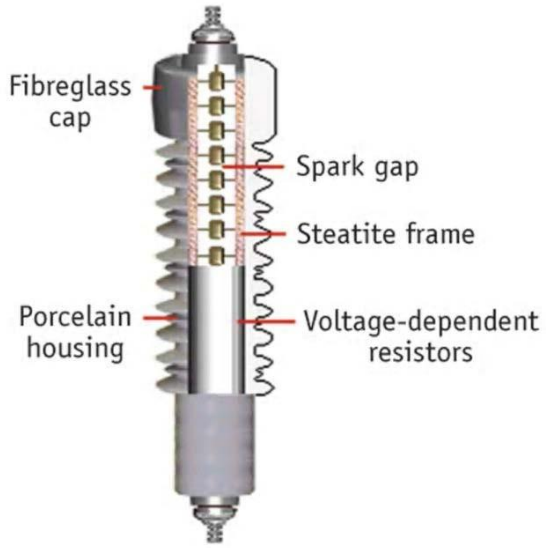


Figure 15

Notes

*****

TRANSFORMER OPERATION

PURPOSE:

This practical assignment will be used to examine the no-load and full load operation of a single phase transformer.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Measure voltages, currents and powers associated with a transformer.
- Using test results, determine the load component of primary current.
- Verify the primary current of a transformer is equal to the phasor sum of the no-load current and the load component of primary current.
- Using test results draw the phasor diagram for a transformer identifying the associated voltages and currents.

EQUIPMENT:

- 1 x variable, single phase, 50Hz AC supply
- 1 x 100VA, 42/24V, single phase transformer
- 1 x 100VA transformer load panel
- 1 x wattmeter (1A, 50V)
- 2 x digital multimeters
- 1 x AC current clamp
- 4mm connection leads

– REMEMBER –
– WORK SAFELY AT ALL TIMES –
Observe correct isolation procedures

PROCEDURE

1. NO-LOAD OPERATION

1. Connect the circuit shown in figure 1, using the 42V winding as the primary.

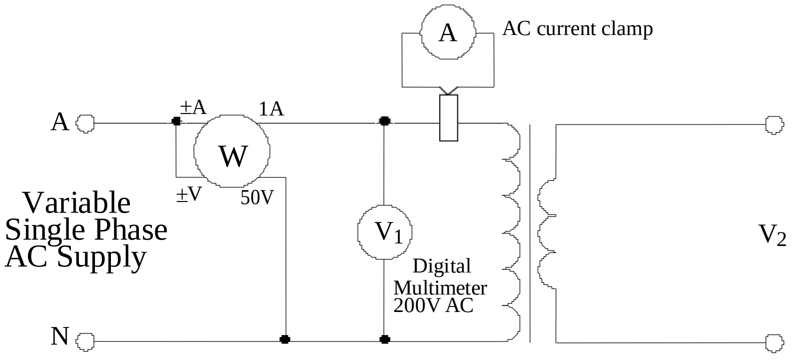


Figure 1

2. Switch on the ac supply and adjust the variac to give a primary voltage of 42V, as indicated by the digital multimeter V1.
3. Measure the secondary voltage V2 and record in table 1.

Table 1

Primary Voltage volts	Secondary Voltage volts	Primary Current amperes	No-Load Power watts	Transformation Ratio V_1/V_2
42V				

4. Using the AC current clamp, measure the primary current and record in table 1.
5. Record in table 1 the power taken by the transformer.

   Note, the actual power taken will be = 2 x wattmeter reading

6. **Do not proceed** until the teacher checks your results and completes the progress table.

Progress Table 1

attempt 1	attempt 2	attempt 3
5	2	0

7. Switch off the supply.

2. FULL LOAD OPERATION

1. Connect the transformer as shown in figure 2.

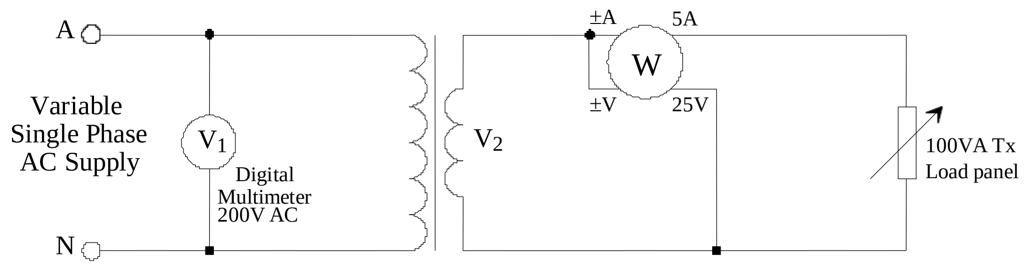


Figure 2

2. Switch on the ac supply and adjust the variac to give a primary voltage of 42V, as indicated by the digital multimeter V_1.

3. Adjust the load panel for a full load current of 4.17A.

   Note, be sure to maintain the primary voltage of 42V.

4. Measure and record in table 2 the full load primary current.

Table 2

Primary Voltage volts	Primary Current amperes
42V	

5. Measure the secondary voltage and current and record in table 3.

Table 3

Secondary Current amperes	Secondary Voltage volts	Load Power watts	Secondary Power Factor	Secondary Phase Angle degrees
4.17A				

6. Measure the power supplied to the load and record in table 3.

   Note, **power = wattmeter reading x 5**

7. **<u>Do not proceed</u>** until the teacher checks your results and completes the progress table.

Progress Table 2

attempt 1	attempt 2	attempt 3
5	2	0

8. Switch off the supply then disconnect the circuit.

9. Please return all equipment to its proper place, safely and carefully.

3. OBERVATIONS:

1. Using the results recorded in table 1, calculate the no-load primary power factor and record in table 1.

   $\lambda = \frac{P}{S} = \frac{P}{V \times I}$

   ---

2. Determine the primary no-load phase angle of the transformer. Record in table 1.

   $\Phi = \cos^{-1}\lambda$

3. Using the results recorded in table 3, calculate the transformer full load secondary power factor and record in table 3.

   $\lambda = \frac{P}{S} = \frac{P}{V \times I}$

4. Determine the full load, secondary phase angle, then record in table 3.

   $\Phi = \cos^{-1}\lambda$

5. Determine the load component of primary current I_1' of the transformer, when operating at full load.

   $I_1' = \frac{V_2 \times I_2}{V_1}$

6. Draw the phasor diagram for the transformer, when operating at full load. On your diagram show the -

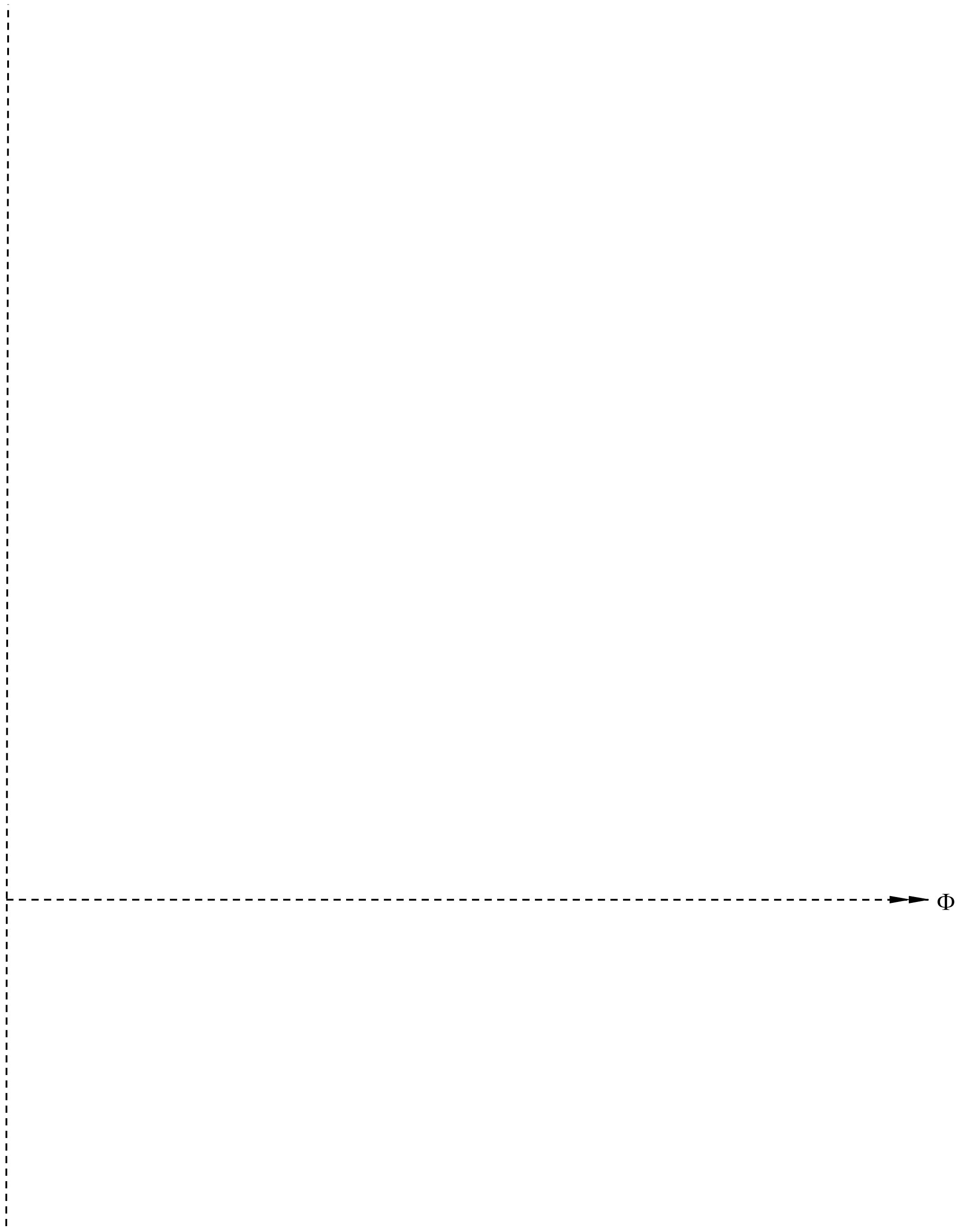
   a) primary and secondary voltages

   b) no-load current (I_O)

   c) load component of primary current (I_1')

   d) primary current $I_1 = I_O + I_1'$

   Scales: 1mm = 0.5V and 1mm = 25mA



7. From your phasor diagram determine the value of the -

   a) magnetising current ($I\mu$)

   b) iron loss current ($I\eta$)

   c) primary current (I_1)

   d) primary phase angle (ϕ_1)

8. Compare the measured value of primary current from your phasor diagram, to that measured using the AC current clamp.

9. Based on your results, is the primary current taken by a transformer equal to the phasor sum of the no-load current and load component of primary current?

Tutorial 3 **NAME:**

TRANSFORMER OPERATION

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter on your answer sheet.

1. The primary and secondary voltages of a transformer are -

   a) in phase
   b) 90º out of phase
   c) 120º out of phase
   d) 180º out of phase

2. In a transformer the component of no-load current which lags the primary voltage by 90º is the -

   a) magnetising current
   b) iron loss current
   c) secondary current
   d) primary current

3. In general the power factor of the primary side of a transformer with an inductive secondary load is -

   a) lower than
   b) equal to
   c) higher than
   d) unrelated to the power factor of the secondary winding.

4. The primary and secondary currents of a transformer are "**approximately**" -

   a) in phase
   b) 60º out of phase
   c) 90º out of phase
   d) 180º out of phase

5. The no-load power factor of a transformer is approximately -

   a) 0.1
   b) 1.0
   c) 0.9
   d) 0.707

6. Transformers are rated in terms of the -

   a) true power out
   b) true power in
   c) apparent power out
   d) apparent power in

7. In order to obtain maximum cooling effect a transformer tank should be -

   a) plain
   b) finned
   c) tubed
   d) painted in a light colour

8. An oil filled transformer which is cooled by means of a fan blowing across the radiators on the tank is termed -

   a) ONAN
   b) OFAF
   c) OFAN
   d) ONAF

9. Transformer oil is used to -

   a) aid cooling of the transformer
   b) enhance the level of insulation
   c) keep the windings free of moisture
   d) aid cooling and enhance the level of insulation

10. As the load on the secondary of a transformer increases -

    a) secondary current increases and primary current decreases
    b) secondary current decreases and primary current decreases
    c) secondary current increases and primary current increases
    d) secondary current decreases and primary current increases

SECTION B

Blank spaces in the following statements represent omissions. Write the appropriate information on your answer sheet.

The power factor of the primary of a lightly loaded transformer is generally _____(1)_____than the power factor of the secondary load because of the effect of the _____(2)_____current.

Transformers are usually rated in______(3)_____.

The main function of oil in a transformer is to______(4)_____the transformer.

The cooling mediums used in transformers are designated with the letters A, O and W. The letter A stands for______(5)_____, the letter O______(6)_____and the letter W _____(7)_____.

Cooling methods used in conjunction with transformers are designated by the letters N and F. The letter N stands for______(8)_____and the letter F______(9)_____.

The rating of a transformer is determined by its ability to dissipate heat under _____(10)_____load conditions.

The primary current of a transformer is made up of two main components, the no-load current and the______(11)_____component of primary current.

A transformer that is cooled using only the surrounding air and oil in and around the windings, would be classified as______(12)_____.

The load component of primary current is determined using the secondary current and the______(13)_____ratio or the______(14)_____ratio.

The primary current of a transformer is equal to the______(15)_____sum of the no-load current and the load component of primary current.

If a 100kVA transformer is required to deliver 110kVA for an extended period, it is most likely that the transformer windings would______(16)_____.

SECTION C

1. Question 14.15, page 355, Electrical Principles for the Electrical Trades.

   (N_1 = 1833.3 turns, N_2 = 41.67 turns, I_1 = 5.25A, I_2 = 230.94A)

2. A single phase 240/32V transformer is to supply a low voltage lighting circuit. The no-load current of the transformer is 2A at a power factor of 0.1 lag. If the lights takes a current of 40A at unity power factor, determine the -

   a) primary current (5.9A)
   b) primary phase angle (20º lag)
   c) primary power factor. (0.94 lag)

   Scale: 1mm = 0.1A

3. A 33/11kV, 20MVA transformer is used in a zone substation. Neglecting any losses determine the -

   a) full load secondary line current (1049.7A)
   b) full load primary line current (349.9A)

4. A 240/12V downlight transformer has a rating of 100VA. Determine the -
   a) full load secondary current (8.33A)
   b) number of 50W lamps that may be supplied from the transformer. (2)

5. A 240/110V single phase transformer takes a no-load current of 2.5A at a power factor of 0.1 lag. If the transformer supplies a load current of 20A at a power factor of 0.866 lag, determine the -
   a) load component of primary current (9.17A)
   b) primary current (10.82A)
   c) primary phase angle (41°) Phasor diagram scale; 1mm = 0.1A
   d) primary power factor (0.75 lag)

SECTION D

1. What methods of cooling are used on the transformer shown in figure 1?

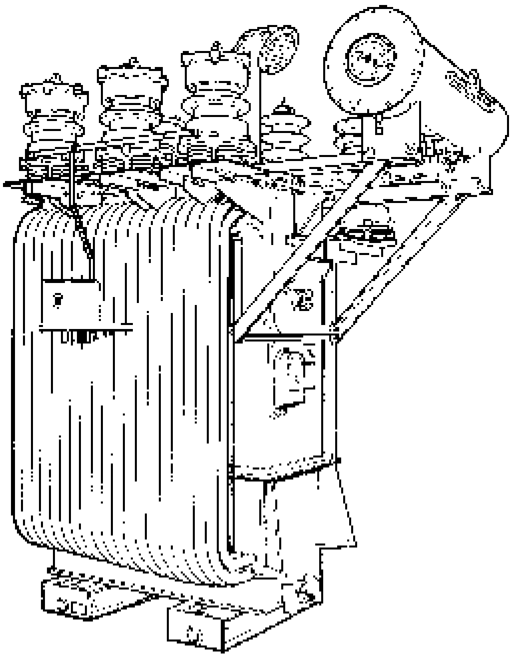


Figure 1

2. Is the transformer shown in figure 1, a single or three phase transformer?

Section 4

TRANSFORMER IMPEDANCE, REGULATION AND EFFICIENCY

PURPOSE:

In this section you will learn about how the internal impedance of a transformer affects its operation

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- Explain the reasons for variation in transformer secondary voltage.
- Define the term voltage regulation as applied to a transformer.
- Calculate the voltage regulation of a transformer.
- Explain the meaning of the terms impedance and percentage impedance, as applied to a transformer.
- Calculate the impedance and percentage impedance of a transformer.
- Describe the tests used to determine the regulation and impedance of a transformer.
- Describe the power losses that occur in a transformer.
- Describe the tests used to determine the losses in a transformer.
- State typical values of transformer efficiency.
- Calculate the efficiency of single and three phase transformers.
- Define the all day efficiency of a transformer.

REFERENCES:

- Electrical Principles for the Electrical Trades. 5th Edition. Jenneson J.R. Pages 339, 347-348.

1. TRANSFORMER VOLTAGE REGULATION

When transformer load is applied or changed, the secondary terminal voltage (V_2) changes. See figure 1.

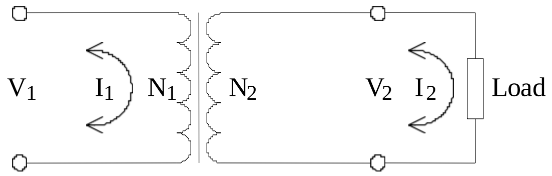


Figure 1

The change in voltage is caused by the resistance and reactance of the two windings; that is the impedance. Figure 2 shows the transformer equivalent circuit.

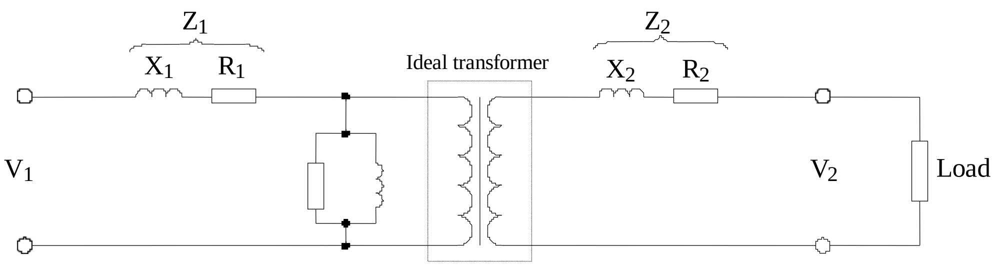


Figure 2

Assuming the applied primary voltage (V_1) is constant and load is increased -

- secondary current (I_2) - ______________________
- load component of primary (I_1') - ______________________
- primary current (I_1) - ______________________
- voltage drop across primary impedance (Z_P) - ______________________
- voltage applied to primary of ideal transformer - ______________________
- voltage induced in secondary of ideal transformer - ______________________
- voltage drop across secondary impedance (Z_S) - ______________________
- secondary terminal voltage (V_2) -______________________.

Therefore, in this case, as load is increased secondary terminal voltage decreases.

> The voltage regulation of a transformer is the change in the secondary terminal voltage when a load of stated current and power factor is applied or removed.
>
> This is usually expressed as a percentage of the open circuit secondary voltage.

At no-load the voltage ratio of a transformer is equal to the ratio of primary turns to secondary turns, but as load is applied to the secondary, the terminal voltage decreases

because some voltage is dropped across the impedance of the transformer windings. The change in secondary voltage is almost directly proportional to the change in secondary load current.

$$\text{Voltage Regulation \%} = \frac{\text{Change in secondary terminal voltage}}{\text{No-load secondary voltage}} \text{ x } 100$$

Where: V_{NL} = secondary no-load voltage
V_L = secondary load voltage

Example: 1

The no-load secondary voltage of a transformer is 300V and at full-load the secondary voltage drops to 293V. Determine the transformers percentage voltage regulation.

Example: 2

The open circuit secondary voltage of a transformer is 250V and at full-load the voltage drops to 244.5V. Determine the percentage regulation.

____

____

Example: 3

A step down transformer with an open circuit ratio of 6600/415V has a regulation of 3.14% at full-load. What is the secondary terminal voltage of the transformer at this load?

____

____

____

Transformers are usually designed with a regulation so small that the secondary voltage will not fall greatly when an increase of load occurs.
The secondary power factor has a considerable effect on the regulation of a transformer therefore a transformer is specified as having a certain regulation at a stated power factor.
Since the power factor of the usual industrial load is approximately 0.8 lag, this is usually specified as the secondary power factor.

2. TAP CHANGERS

Most distribution and large power transformers are fitted with tap changing devices which -

- add turns to the secondary winding

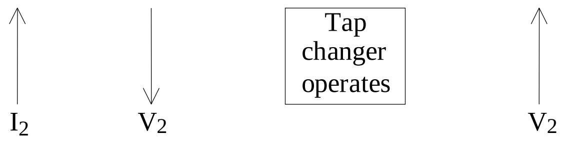
  or

- cut out turns from the primary winding as the load current increases.

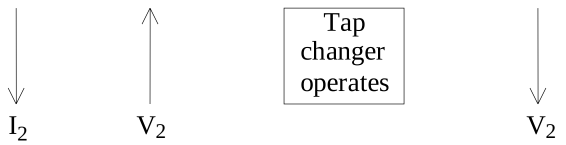
By this means, the secondary terminal voltage is kept practically constant.

That is, a tap changer adjusts the turns ratio $\left(\frac{N_1}{N_2}\right)$ which in turn adjusts the transformation ratio $\left(\frac{V_1}{V_2}\right)$

- for an increase in load current -



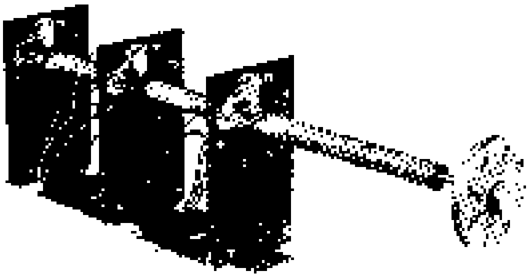
- for a decrease in load –



There are two broad categories of tap changer -

- ____________________ tap changer
- ____________________ tap changer.

Figure 3 shows two views of an ***off load tap changer*** that would be fitted to a three phase, 11kV/415V distribution transformer. The tap changer would be connected to the primary winding.



An off load tap changer, as the name suggests, allows the turns ratio of the transformer to be adjusted for a specific secondary voltage when the transformer is not delivering load current.

Off load tap changing is usually provided on distribution transformers so that the voltage level to consumers can be kept within acceptable limits. The changing of taps is via a hand driven mechanism and must be operated with the transformer disconnected from the load.

In the case of transformers with high voltage primary windings, such as 11kV distribution transformers, off load tap changing must be carried out with the transformer isolated and de-energised.

Figure 4 shows the switching arrangement for one phase of the tap changer in figure 3.

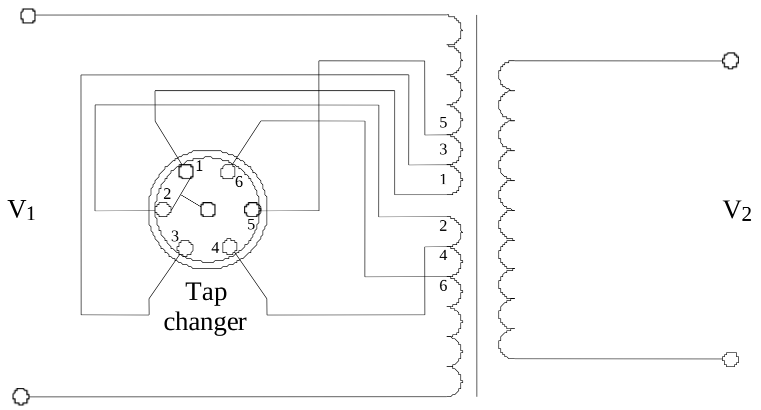


Figure 4

The 5-position tap changer of figure 4 would have the switching position arrangements shown in figure 5.

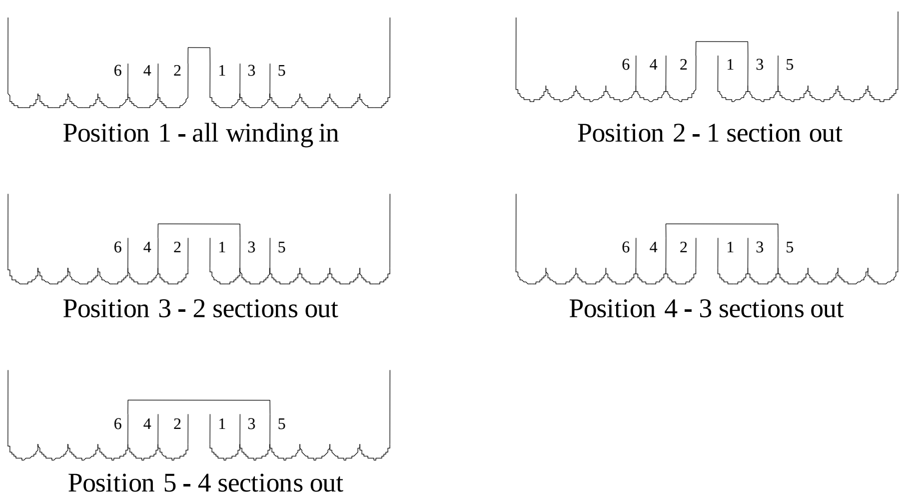
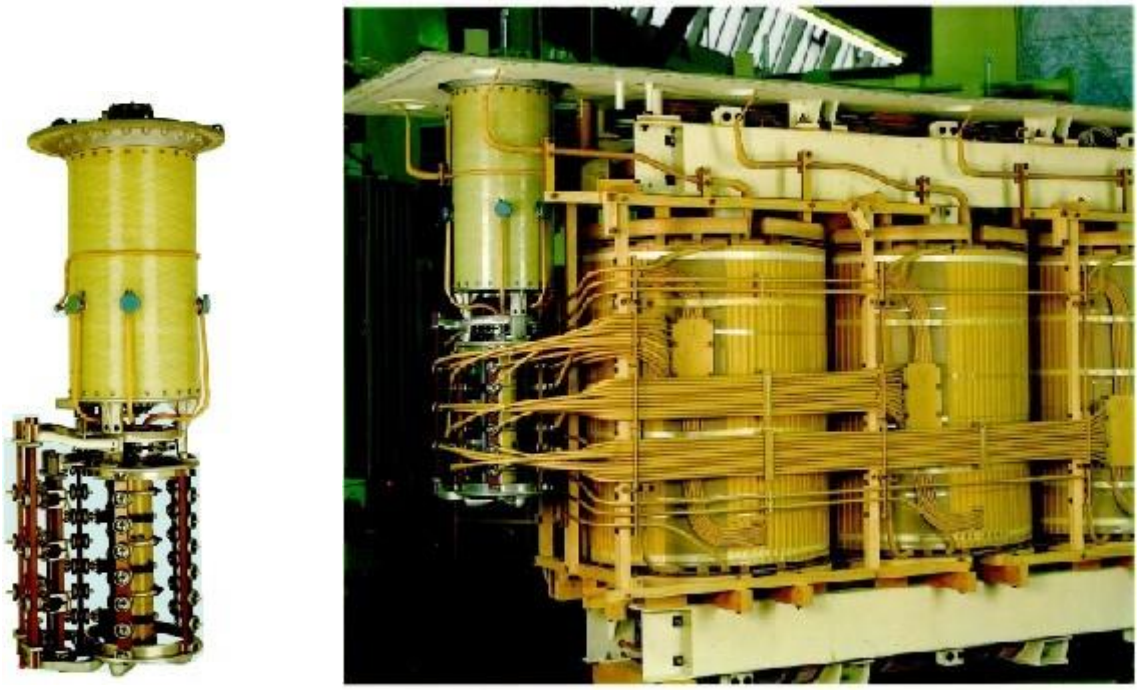


Figure 5

On load tap changers are usually fitted to larger power transformers. Figure 6 shows an example of an on load tap changer.

The arrangement to the left is the tap changer only and that to the right shows the tap changer in relation to the transformer windings.



On load tap changers usually -

- have a motor driven tap changing mechanism
- employ resistors or reactors to limit short circuit currents during tap changing
- operate under automatic control via sensitive voltage control relays, which are fed from voltages transformers off the secondary side of the power transformer.

3. TRANSFORMER IMPEDANCE

In determining the performance of a transformer, the impedance of the transformer caused by its core and windings, must be considered. The effect of this impedance is to cause a drop in the secondary voltage of the transformer, depending on the current flow.

Transformers are designed to have a predetermined secondary voltage drop at full-load current. The nameplate on a transformer gives the impedance, expressed as a percentage of its rated voltage.

For example, a transformer connected for a 240V output, with a 2.2% impedance, will deliver 2.2% less than 240V or 234.7V at full-load.

Transformer impedance can be determined by a test known as the ________________ test.

If, as shown in figure 7, a transformer is operated with its secondary short circuited and the primary voltage is slowly increased until rated primary and secondary current flows, the transformer ***impedance voltage*** may be determined.

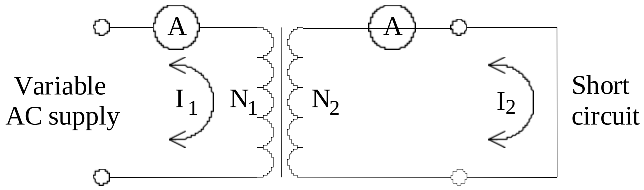


Figure 7

The impedance voltage is that voltage required to cause rated current to flow through the impedance of the windings. The impedance voltage is small, typically 3% to 5% of rated voltage.

Once the impedance voltage is known, transformer impedance may be determined by application of Ohms Law.

where: V_{SC} = short circuit voltage required to circulate rated current

I_R = rated current of the winding to which the test voltage is applied

The test for determination of the impedance voltage may be carried out on either winding, that is -

- voltage applied to the primary, with the secondary shorted
- voltage applied to the secondary, with the primary shorted.

In addition to the transformer impedance being stated as an ohmic value, it is commonly nominated as a percentage value, for example, transformer impedance, %Z = 4%.

where: %Z = percentage impedance of the transformer

V_{SC} = short circuit voltage applied to the transformer

V = rated voltage of transformer winding to which the test voltage is applied

Example: 4

A 3 phase Delta/Star 5MVA, 33kV/11kV transformer is tested with the secondary short circuited. A voltage of 1.65kV is required to cause full load current to flow. Determine the transformer -

a) rated primary current
b) impedance
c) percentage impedance

Example: 5

A single phase 5kVA, 240V/415V step up transformer required 10V applied to the primary to cause rated current to flow in the short circuited secondary. Determine the -

a) rated primary current
b) impedance
c) percentage impedance.

4. PROSPECTIVE SHORT CIRCUIT CURRENT

If during the short circuit test, the voltage was raised to the rated voltage (100%) the transformers short circuit current would flow. So we can use the short circuit test and the percentage impedance to calculate the prospective short circuit current of a transformer.

ie: If during a short circuit test, 5% of rated voltage causes rated current to flow, 100% will cause short circuit current to flow.

$$I_{SC} = \frac{100}{Z\%} \text{ x } I_{Rated}$$

Example: 6

A single phase transformer has a rated secondary current of 40 Amperes and a percentage impedance of 8%. Find the prospective short circuit current of the transformer.

Example: 7

A three phase 11kV/430V delta/star transformer is rated at 450kVA and has a Z% of 5%.

a) Find the rated secondary line current.

b) Find the prospective short circuit current of the transformer.

Section 4 Transformer Regulations and Efficiency

5. TRANSFORMER EFFICIENCY

Figure 8 illustrates the flow of power through a transformer.

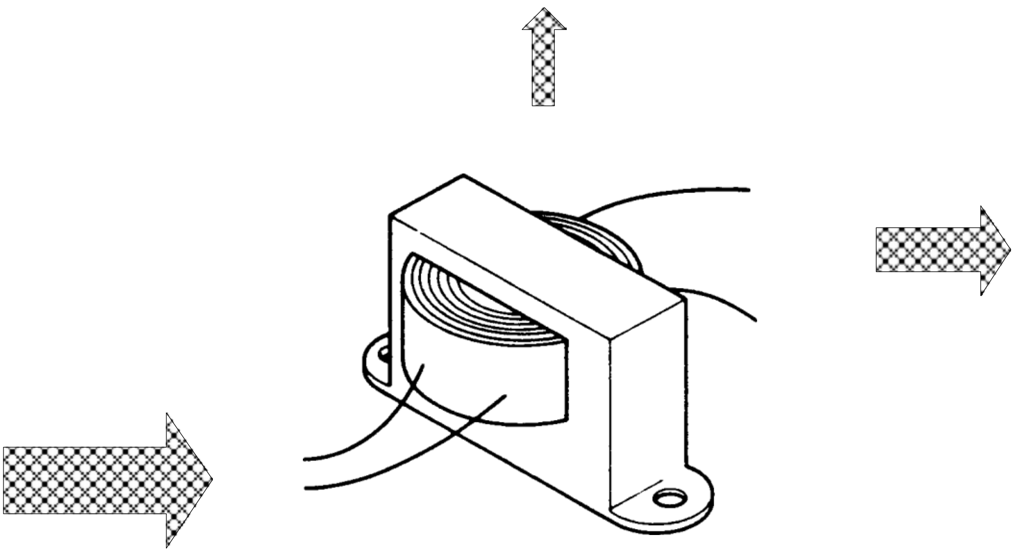


Figure 8

The output of a transformer is always less than the input because of the losses in the iron core and the resistance of the windings.

From the arrangement shown in figure 8 it can be seen -

Input power, P_{IN} =	Output power, P_O =

All losses cause the temperature of a transformer to rise. Transformer losses are due to-

- ______________________________ -
- ______________________________ -

Known as the iron losses. Considered to be constant, irrespective of load

- ______________________________ - varies with load.

To determine the input and output powers of single and three phase transformers -

Single phase

Input power, P_{IN} =	Output power, P_O =

Three Phase

Input power, P_{IN} =	Output power, P_O =

The efficiency of a transformer is given by the equation -

where: $\eta\%$ = transformer percentage efficiency

P_O = output power in watts

P_{IN} = input power in watts

Example: 8

A three phase distribution transformer supplies 675kW at full load. If the input power to the transformer at this load is 695kW, determine the efficiency of the transformer.

____

____

____

Example: 9

A single phase 11kV/240V transformer supplies a load current of 25A at a power factor of 0.75 lag. If the transformer iron losses are 300W and the copper losses at this load 400W, determine the transformer efficiency at this load.

____

____

____

____

____

____

____

____

____

____

The usual method of determining the efficiency of a transformer is to obtain the losses by testing, using the -

- open circuit test - to determine the _____________________________________
- short circuit test - to determine the_____________________________________.

Typically, the efficiency of transformers is very high. In the case of distribution and power transformers, in the range of 95% to 98%.

6. SHORT CIRCUIT TEST FOR COPPER LOSSES

The copper losses of a transformer can be obtained from what is called the short circuit test. For this test the secondary winding is short circuited through an ammeter. A wattmeter, an ammeter and a voltmeter are connected in the primary circuit as shown in figure 9.

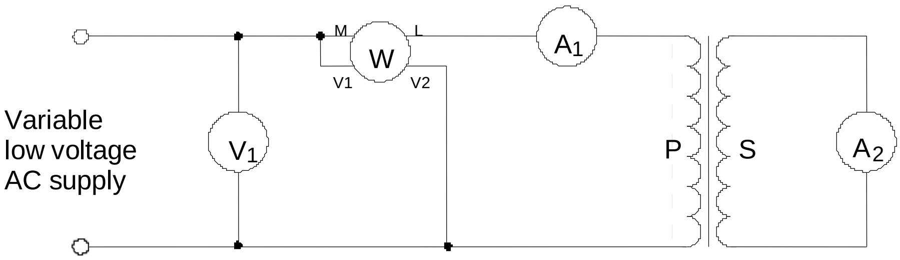


Figure 9

The short circuit test is carried out in accordance with the following -

- a low voltage at the correct frequency is applied to the primary
- the primary voltage is slowly increased until the ammeters show full-load values
- the wattmeter then indicates the full-load copper losses for the transformer

As the secondary is bridged by a low resistance, the output voltage is practically zero and the output power negligible. The flux through the core is negligibly small and therefore the iron losses too can be neglected.

When applied using the method described above, the full load copper loss of the transformer is determined.

Since the copper losses vary as the square of the load ($P_{CU} = I^2R$), their value at any fraction of full-load may be calculated readily.

To determine the copper loss at any fraction of full-load -

CU loss = (Fraction of load)^2 x Cu loss at full load

Example: 10

A transformer has a full load copper loss of 350W. Determine the copper loss at ¼, ½ and ¾ of full-load.

____

____

____

____

Example: 11

A single phase transformer has a full-load copper loss of 600W. Determine the transformer copper loss when operating at ¼, ½ and ¾ of full-load.

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7. OPEN CIRCUIT TEST FOR IRON LOSSES

If the secondary of a transformer is open circuit and the primary supplied with rated voltage and frequency, a wattmeter connected in the primary as shown in figure 10 will indicate the iron losses.

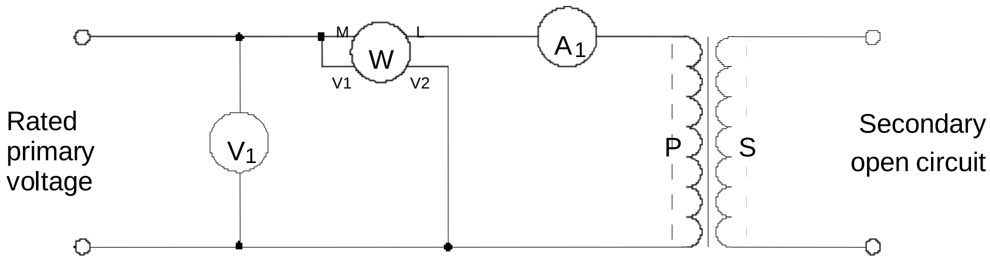


Figure 10

When the secondary of a transformer is open circuit, the primary winding acts as a choke having a high reactance and only a very small current is taken. This current is called the no-load current, and is the current required to magnetise the core to the desired flux density and provide the energy to overcome the losses in the iron core.

Because of the small value of this no-load current, the copper loss in the open circuit test is negligible. Therefore the whole of the power input, as indicated by the wattmeter, is taken to represent the iron losses.

The iron losses of a transformer remain practically constant at all loads if the -

- ___________________________________ and
- ___________________________________ remain constant.

If the applied voltage to the transformer is constant, the transformer voltages will be constant, hence the core flux and the iron losses are very nearly constant at all loads.

Example: 12

Determine the efficiency at full, ¾, ½ and ¼ load of a 50kVA transformer supplying purely resistive loads, if its full-load copper losses are 700W and the iron losses 250W.

8. MAXIMUM EFFICIENCY OF A TRANSFORMER

The efficiency of a transformer is high, typically in the range 95 to 98% for high output transformers. This implies that the transformer losses are as low as 2 to 5% of the input power.

The core loss in a transformer is a constant loss for all load conditions. The copper loss varies proportionally to the square of the load current. It is therefore a simple matter to plot the efficiency versus load current curve for transformer, see figure 11.

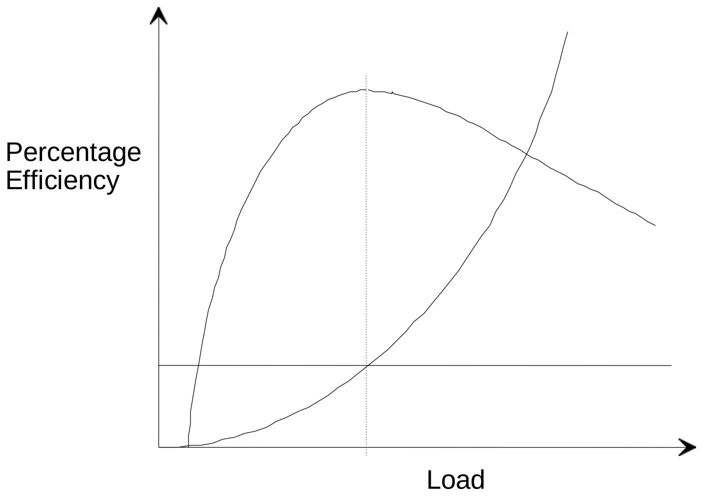


Figure 11

Because of the relationship between the iron and copper losses, it can be shown that the efficiency of a transformer is at a maximum when the fixed losses are equal to the variable losses.

> In other words, the maximum efficiency of a transformer occurs at the load that makes the –
>
> - ________________________ equal to the __________________________

9. ALL DAY EFFICIENCY

The all day efficiency of a transformer averages out the efficiency over a 24 hour period, by comparing the total energy output to the total energy input. A transformer running on light load for extended periods reduces the all day efficiency and so costs money.

To determine the all day efficiency for a transformer -

where: η% (all day) = all day efficiency expressed as a percentage
kWh_O = energy output for 24 hours in kWh (kilowatt hours)
kWh_{IN} = energy input for 24 hours in kWh (kilowatt hours)

The energy taken or delivered by a transformer is based on the power in kW times the duration of operation measured in hours.

where: kWh = energy measured in kilowatt hours
kW = power taken or delivered in kW
t = time taken to consume or deliver power in hours

Example: 13

Calculate the all day efficiency for a transformer whose daily output is 2150kWh and the daily losses are 148kWh.

___

___

___

Example: 14

Calculate the all day efficiency for a 750kVA, 11kV/415V distribution transformer that operates with the following energy levels and times -

8 hours delivering 750kW with an input of 772kW = ____________________________

2 hours on no-load, taking 15kW =____________________________

6 hours delivering 325kW with an input of 353kW = ____________________________

8 hours delivering 560kW with an input of 598kW = ___________________________

____

____

____

____

____

____

____

____

____

____

____

It is important that transformers are not allowed to operate for extended periods of time on either no-load or light load. If this can be avoided, the all day efficiency will be improved.

The best all day efficiencies are achieved when transformers are operated at or near full-load for the entire day.

NAME: **Practical 4**

TRANSFORMER IMPEDANCE, REGULATION AND EFFICIENCY

PURPOSE:

This practical assignment will be used to determine the iron loss, copper loss and the efficiency of a single phase transformer

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Carry out the transformer open circuit test to determine iron loss.
- Carry out the transformer short circuit test to determine copper loss.
- Carry out the transformer load test.
- Determine the regulation of a transformer.
- Determine the percentage impedance of a transformer.
- Determine the ohmic impedance of a transformer.
- Determine the prospective short circuit current of a transformer.
- Determine the efficiency of a transformer.

EQUIPMENT:

- 1 x variable, single phase, 50Hz AC supply
- 1 x 100VA, 42/24V, single phase transformer
- 2 x wattmeters (50V, 5A)
- 1 x 100VA transformer load panel
- 2 x digital multimeters
- 1 x AC current clamp
- 4mm connection leads

– REMEMBER –
– WORK SAFELY AT ALL TIMES –
Observe correct isolation procedures

PROCEDURE

1. OPEN CIRCUIT TEST

1. Connect the circuit shown in figure 1, using the 42V winding as the primary.

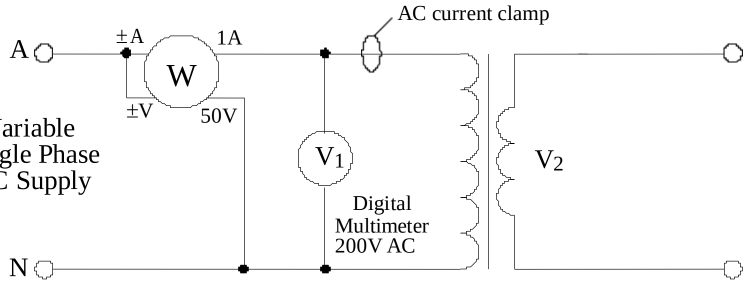


Figure 1

2. **<u>Do not proceed</u>** until the teacher checks your circuit and completes the progress table.
3. Switch on the AC supply and adjust the variac to give a primary voltage of 42V, as indicated by the digital multimeter V_1.

Progress Table 1

attempt 1	attempt 2	attempt 3
5	2	0

4. Measure the no-load input power and record. The power taken equals the iron loss of the transformer. **Note: Power = 2 x wattmeter reading**

Transformer iron loss =__________watts

5. Measure the no-load primary current and record.

No-load primary current =________amps

6. Switch off the supply.

2. SHORT CIRCUIT TEST

1. Adjust the variac for **minimum** output.
2. Connect the transformer as shown in figure 2, using the 42V winding as the primary and with a 4mm lead shorting the secondary.

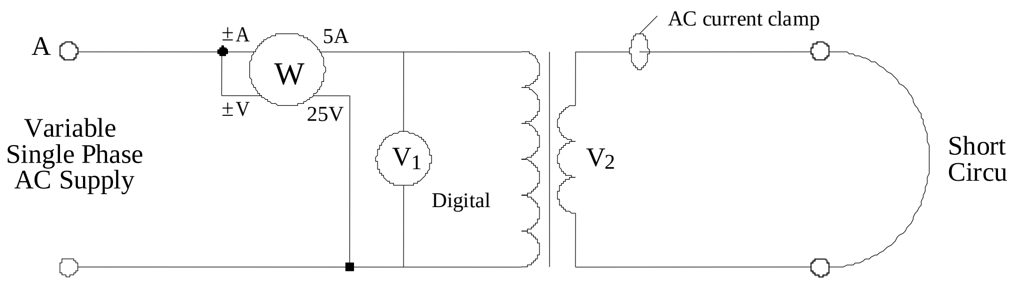


Figure 2

3. **Do not proceed** until the teacher checks your results and completes the progress table.

4. Switch on the AC supply and **slowly** adjust the variac until full-load current (4 .2 A) flows in the transformer secondary. **Note: Power = 5 x wattmeter reading**
5. Measure the power taken by the transformer and record. The power taken equals the copper loss of the transformer.

Transformer copper loss =___________Watts

6. Measure the voltage required to cause rated current to flow in the transformer and record.

Voltage (short circuit) =___________Volts

7. Adjust the variac for minimum output.
8. Switch off the supply.

3. LOAD TEST

1. Connect the circuit as shown in figure 3, using the 42V winding as the primary.

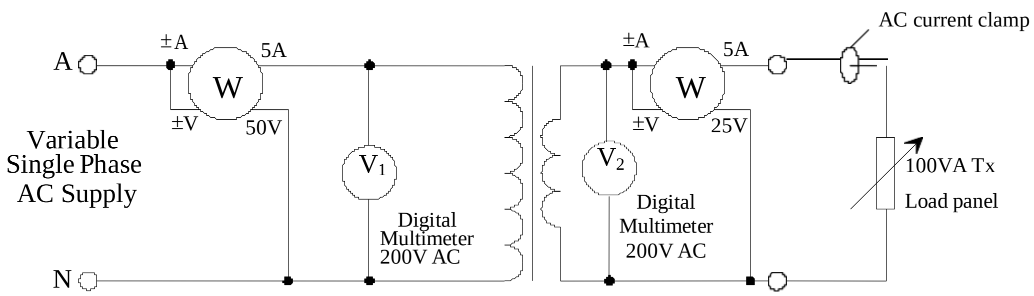


Figure 3

2. Make the following adjustments on the load panel - coarse control to position 1

   - fine control fully anticlockwise.

   These settings will give no-load operation.

3. Switch on the AC supply and adjust the variac to give a primary voltage of 42V, as indicated by the digital multimeter V_1.
4. Measure the primary input power and record in table 1.
   Note: Input power = 10 x wattmeter reading
5. Adjust the load panel for a secondary current of 1A.
   Be sure to maintain the primary voltage at 42V.
6. Measure the primary input and secondary output powers and the secondary output voltages, record in table 1.
   Note: Output power = 5 x wattmeter reading

Progress Table 2

attempt 1	attempt 2	attempt 3
5	2	0

7. Repeat the procedure for each value of load current listed in table 1.

Table 1

Load Current amperes	Input Power watts	Output Power watts	Output Volts
0			
1			
2			
3			
4.2 (Full load)			
4.5			

8. **<u>Do not proceed</u>** until the teacher checks your results and completes the progress table.

Progress Table 3

attempt 1	attempt 2	attempt 3
5	2	0

9. Switch off the supply and disconnect the circuit.
10. Please return all equipment to its proper place, safely and carefully.

4. OBSERVATIONS:

1. From your results in the Iron loss test, procedure 1. Determine the power factor and phase angle of the no load current of the transformer.

$\lambda = \frac{P}{VI}$ $\Phi = \cos^{-1}\frac{P}{VI}$

3. From the Short Circuit Test, procedure 2. Determine the percentage impedance of the transformer.

$$Z\% = \frac{VSC}{V_{rated}}$$

4. Using the percentage impedance determine the fault current that would flow in the secondary if the transformer was short circuited while rated voltage was applied.

$$I_{SC} = \frac{100}{Z\%} \text{ x } I_{rated}$$

5. What limits the fault current when a transformer is short circuited?

6. Using the results from procedure 1 and 2 determine the total power loss at full load.

$P_{Loss} = P_{Fe} + P_{Cu}$

7. Using the results from the Load Test, procedure 3. Determine the losses of the transformer at full load.

$P_{Loss} = P_{In} - P_{Out}$

8. The results of 6 and 7 should be the same. Are they? If not why not?

9. Using your results from the load test, procedure 3, determine the transformer efficiency at each value of load current.

$\eta\% = \frac{PO}{P_{IN}} \text{ x } 100$

10. On the axis shown in figure 4, plot the efficiency curve for the transformer tested.

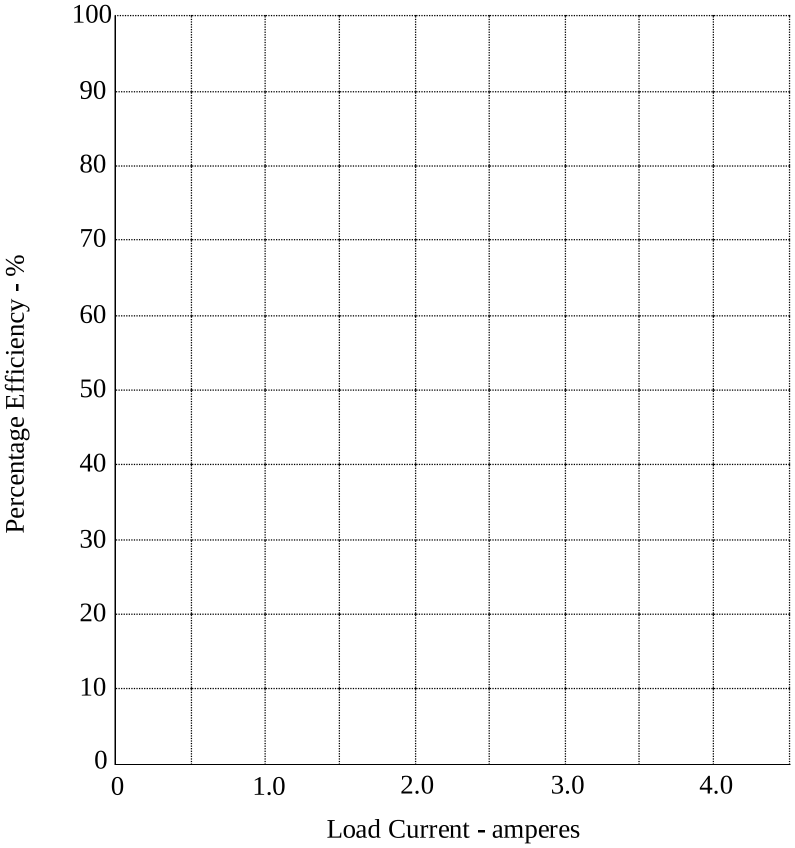


Figure 4

11. From your efficiency curve, determine the load current at which maximum efficiency occurred?

12. If the load on the transformer was increased beyond full-load, what would happen to the transformers efficiency? Explain why this would be the case.

13. What is there about the operation of the transformer that identifies it has losses?

14. Using your results from the load test, procedure 3, determine the voltage regulation of the transformer.

$$\%V_{Reg} = \frac{VNL-VFL}{V_{NL}} \text{ x } 100$$

15. What causes the voltage output of a transformer to fall as load current increases?

Tutorial 4 **NAME:**

TRANSFORMER IMPEDANCE, REGULATION AND EFFICIENCY

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter on your answer sheet.

1. The efficiency of a transformer -

   a) is constant over the load range
   b) has a maximum of 90%
   c) varies with load
   d) varies with the iron losses

2. The impedance of a transformer -

   a) causes secondary voltage to drop when load current increases
   b) limits fault current when secondary is short circuited
   c) is determined by the core material and winding resistance
   d) all of the above

3. The iron loss of a transformer at rated voltage and frequency is -

   a) proportional to the load current
   b) proportional to the square of the load current
   c) practically constant at all times
   d) dependent on the power factor of the load

4. The voltage drop within a transformer can be allowed for by-

   a) using a tap changer to boost the secondary voltage
   b) increasing the primary voltage
   c) reducing the coupling between windings
   d) increasing the turns on the primary

5. The iron loss of a transformer can be determined by measuring the power taken by the transformer when -

   a) the secondary is short circuited
   b) normal load is applied to the secondary circuit
   c) the secondary is open circuit and half normal voltage is applied to the primary winding
   d) the secondary is open circuit and normal voltage is applied to the primary winding

6. If the load on a transformer is doubled the iron losses are -
   a) doubled
   b) halved
   c) constant
   d) decrease slightly
7. The short circuit test on a transformer is used to determine -
   a) ohmic impedance
   b) percentage impedance
   c) copper losses
   d) all of the above
8. A single phase transformer is rated at 20kVA at 100V. The true power output at full-load and 0.8 power factor is -
   a) 25kW
   b) 20kW
   c) 16kW
   d) 8kW
9. The all day efficiency of a transformer is the ratio of the -
   a) input energy over 24 hours to the output energy over 24 hours
   b) output kVA over 24 hours to the input kVA over 24 hours
   c) input kVA over 24 hours to the output kVA over 24 hours
   d) output energy over 24 hours to the input energy over 24 hours
10. If a transformer operates for long periods during a day with no-load, the all day efficiency of the transformer is -
   a) high
   b) very low
   c) not affected by no-load operation
   d) reduced slightly

SECTION B

Blank spaces in the following statements represent omissions. Write the appropriate information on your answer sheet.

Transformers are rated in______(1)_____because this allows the power factor of the load to be ignored.

Maximum efficiency of a transformer occurs at the load which makes the _____(2)_____equal to the______(3)_____.

The short circuit test on a transformer is used to determine the______(4)_____losses.

The copper losses of a transformer are 400W at full-load. If the load is reduced to half load, the copper losses are______(5)_____watts.

Copper losses in a transformer vary as the______(6)_____of the current.

The______(7)_____losses in a transformer are constant for all loads at rated voltage and frequency.

When measuring the iron losses of a transformer, the secondary winding must be _____(8)_____.

The efficiency of a transformer is the ratio of the______(9)_____power to the _____(10)_____power.

Subtracting the output power from the input power gives the______(11)_____of a transformer.

To achieve the best all day efficiency, a transformer should be operated at or near _____(12)_____load for the entire day.

Voltage regulation of a transformer is voltage drop between no load and full load expressed as a_______(13)_____of no load volts.

Typical values of transformer efficiency fall within the range______(14)_____to _____(15)_____.

The voltage required to cause rated current to flow during a short circuit test expressed as a percentage of rated voltage is known as______(16)_____.

SECTION C

1. Calculate the efficiency of a 500kVA distribution transformer when operating at full-load with a power factor of 0.9 lag. The total losses are 15kW. (96.8%)
2. A transformer when tested using the open circuit test had an iron loss of 3700W and when tested using the short circuit test had a copper loss of 2100W. Determine the total transformer loss. (5800W)
3. A 10MVA transformer operates with a power factor of 0.85. The transformer iron losses are 120kW and the copper losses 95kW. Calculate the efficiency of the transformer. (97.5%)
4. A 33kV/11kV, three phase transformer with a rating of 500kVA has a voltage regulation of 6% at a power factor of 0.8. Determine the secondary line and phase voltage of the transformer at full load 0.8 power factor if the no load line voltage is 11kV. (V_L=10340V, V_P= 5970V)
5. A 33kV/11kV, three phase transformer with a rating of 500kVA has a percentage impedance of 4.5%. Determine the secondary prospective short circuit current of the transformer. (583A)

6. Determine the full load efficiency of a transformer supplying full load output of 15kW at unity power factor, if the transformer has iron losses of 400W and copper losses of 800W when tested at full load. (92.6%)

7. A 50kVA transformer has a full load copper loss of 460W and an iron loss of 220W. Determine the -

   a) iron loss when delivering 25kVA (220W)

   b) copper loss when delivering 25kVA. (115W)

8. Calculate the all day efficiency for a 750kVA, 11kV/415V distribution transformer that operates with the following energy levels and times -
   8 hours delivering 800kW with an input of 810kW
   2 hours on no-load, taking 20kW
   6 hours delivering 350kW with an input of 370kW
   8 hours delivering 600kW with an input of 615kW. (97.36%)

SECTION D

1. Re-draw the components in figure 1 to show the connections required to carry out a short circuit test on the transformer.

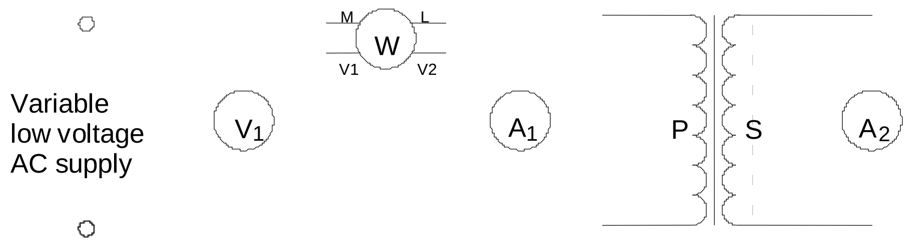


Figure 1

2. Re-draw the components in figure 2 to show the connections required to carry out an open circuit test on the transformer.

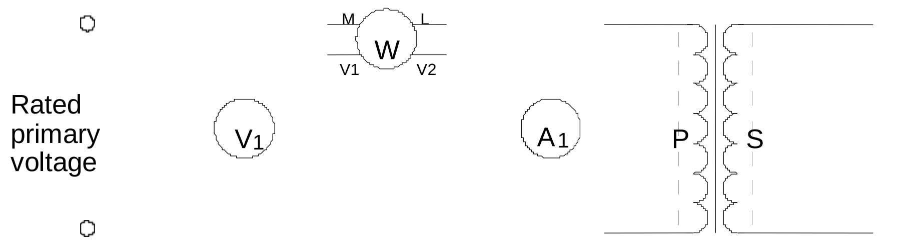


Figure 2

3. Draw a set of axis showing percentage efficiency versus load for a transformer. On your axis show the characteristics for efficiency, copper loss and iron loss. Also show the condition required for maximum efficiency.

TRANSFORMER POLARITY & PARALLELING

PURPOSE:

In this section you will learn about the common winding connections used in three phase transformers. In addition you will examine the need for parallel operation of single and three phase transformers.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- State the method used to label transformer windings.
- List the advantages of using a single three phase transformer over three single phase transformers.
- State the meaning of the term polarity as applied to a transformer.
- Add polarity marks to transformer windings.
- Explain the need for parallel operation of transformers.
- List the conditions required for transformers to be paralleled.
- State the significance of transformer vector groups.
- Calculate the load sharing of transformers.
- State the significance of transformer vector groups in relation to the parallel operation of three phase transformers.
- State the phase shift of a transformer given the transformer's vector group.
- Describe the effects of harmonics on transformers and the methods used to reduce harmonics.
- Interpret transformer nameplate information.
- Describe the safety precautions to be observed when working with high voltages associated with transformers.

REFERENCES:

- Hampson, J. & Hanssen, S. *Electrical Trade Principles*, 2nd Edition, Section 7
- Jenneson, J.R. *Electrical Principles for the Electrical Trade,* 5th Edition, Pages 335 - 337

1. TRANSFORMER TERMINAL MARKING

Australian Standard AS2374.1 - 1997, Power Transformers, sets out the standards for the marking of terminals on transformers. The method described uses a combination of letters and numbers to identify the starts and finishes of the windings.

For single phase transformers -

- the high tension winding is identified with the letter 'A' and the starts and finishes with the subscript numbers 1 and 2

For example, A_1 and A_2

- the low tension winding is identified with the letter 'a' and the starts and finishes with the subscript numbers 1 and 2.

For example, a_1 and a_2

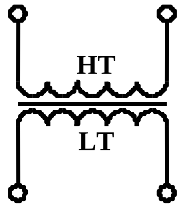


Figure 1

In the case of three phase transformers -

- the high tension windings are identified with the letters A, B, C and the starts and finishes with the subscript numbers 1 and 2

For example, A_1, B_1, C_1

- the low tension windings are identified with the letters a, b, c and the starts and finishes with the subscript numbers 1 and 2.

For example, a_1, b_1, c_1

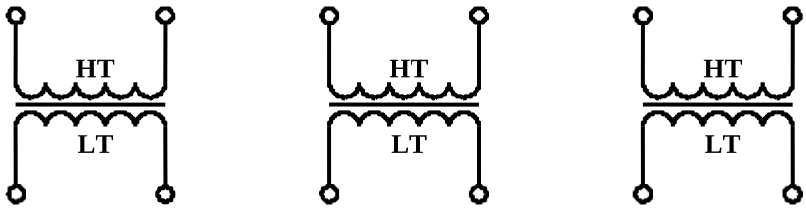


Figure 2

2. THREE-PHASE TRANSFORMER

Three phase transformers are mostly of the core type, with the concentric primary and secondary windings of each phase on a located on separate legs of the iron core. For very large transformers a five limbed core is used, with the two outer legs providing a parallel magnetic path for the phase fluxes.

The construction of the core type of three-phase transformer is shown in figure 3.

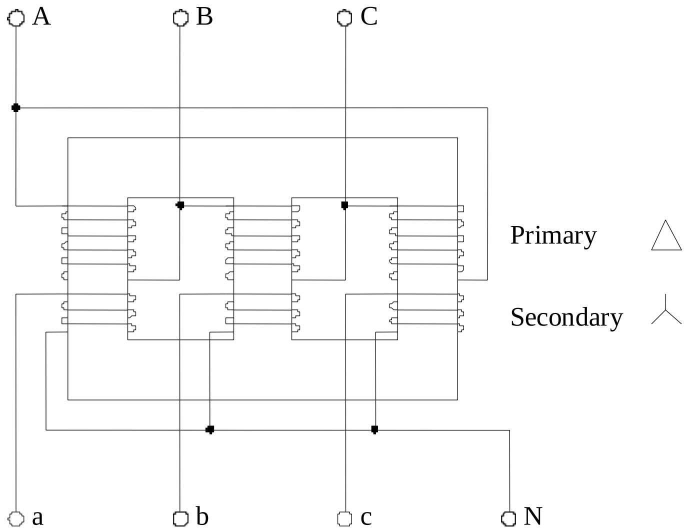


Figure 3

The phase of the flux bears the same relationship to the applied voltage in each of the three limbs, consequently the algebraic sum of the fluxes, either positive or negative, is zero at any instant, just as the algebraic sum of the applied voltages is zero at any instant. These flux curves are shown in figure 4.

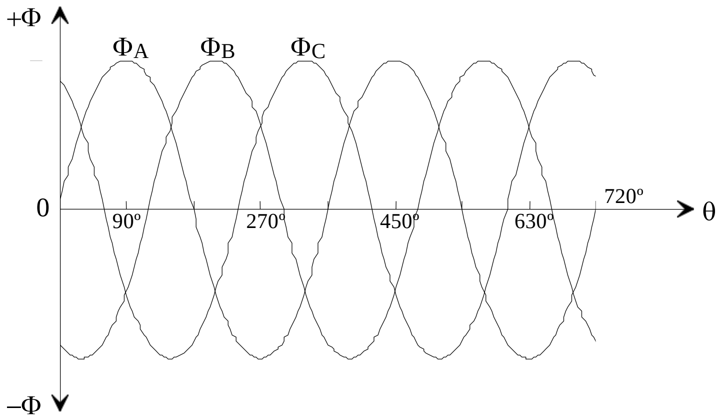


Figure 4

From the curves it can be observed that the flux in any limb is always equal to the sum of the fluxes in the other two limbs, in the opposite direction. By winding a secondary on each limb, a three phase supply can be obtained, since each secondary voltage is induced by one of the sinusoidal flux waves.

The connections available are star, delta and inter-star (zig-zag star) and these connections can be made on either primary or secondary. Hence there are various combinations -

star/star	delta/delta
star/delta	delta/star - most common
star/inter-star	delta/inter-star

Only star and delta connections will be considered in this module.

Note, the turns ratio is a primary **phase winding** to secondary **phase winding** ratio. So the voltage ratio must be primary **phase voltage** to secondary **phase voltage.**

Example: 1

A three phase transformer has a transformation ratio of 6.6kV/240V. Draw the connections required to supply a 415V delta connected load.

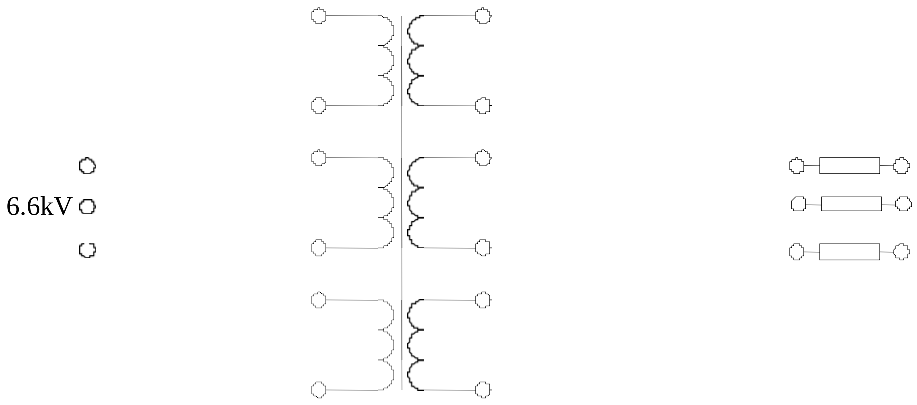


Figure 5

3. THREE PHASE V THREE SINGLE PHASE TRANSFORMERS

A three phase transformer -

- costs less
- occupies less floor space
- is lighter
- is more efficient

than three separate single-phase transformers of the same total output.

These advantages are offset by the fact that a complete three-phase transformer is often necessary as a spare in case of a breakdown, while with three single-phase transformers a single unit (of one-third total output) is sufficient as a spare. The bank of three transformers, if delta-delta connected, has an advantage in case of a breakdown. Part of the load can be carried temporarily by using two of the transformers in V-V or open delta.

4. VECTOR GROUPING

A three phase power transformer may be made up of a combination of two or more windings each of which may be connected in star or delta.

Depending on the connections used for the primary and secondary windings, there exists a certain phase relationship between the voltages applied to the transformer primary and the secondary voltages.

This phase relationship can be -

- 0º
- 180º
- -30º
- +30º

depending on the method of connection.

Each of the four phase displacements can be achieved by standard methods. The standard methods are set out in AS2374.1 - 1997 Power Transformers, as "Vector Groups".

There are four vector groups and each group includes the methods of connection of the primary and secondary windings which give the same phase displacement between windings.

Section 5 – Transformer Polarity & Paralleling

The group of connections and the phase displacement are identified by the use of three symbols which in order have the following significance –

Table 1

1st Symbol	2nd Symbol	3rd Symbol
primary winding D, Y	secondary winding d, y	phase displacement expressed as the clock hour number 0, 6, 1, 11

Thus there are such combinations as -

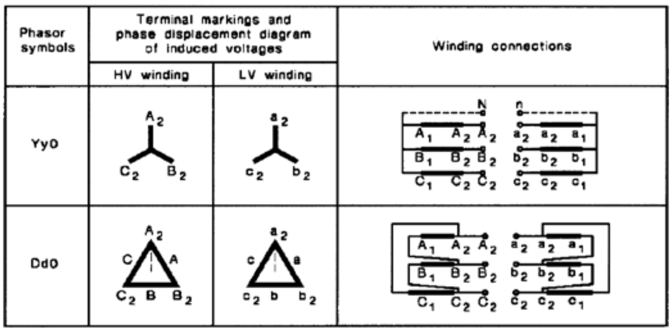
- Yy1
- Dd6
- Dy11.

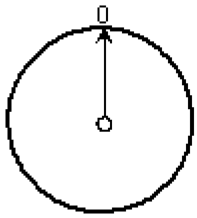
The four vector groups are shown in tables 2 to 5.

Group 1 - the primary and secondary line voltages are in phase.

Table 2

Group 1 – Phase Displacement = 0^0 Clock hour figure = 0

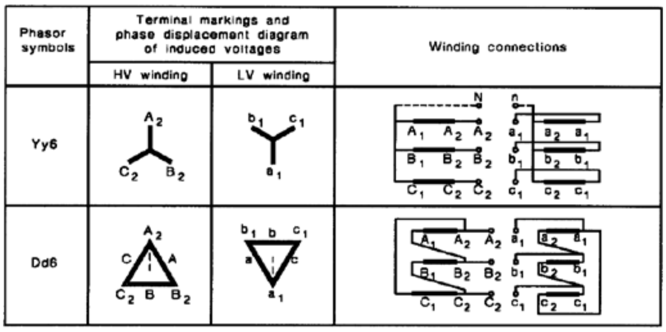


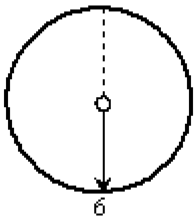


Group 2 - the secondary line voltage is 180º out of phase with the primary line voltage.

Table 3

Group 2 – Phase Displacement = 180^0 Clock hour figure = 6

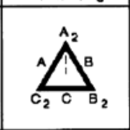
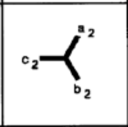
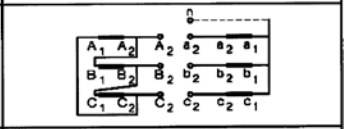
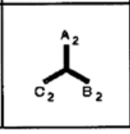
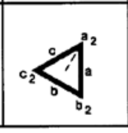
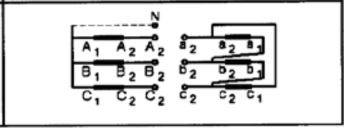


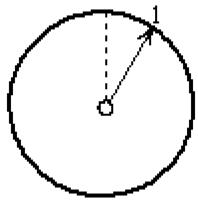


Group 3 - the secondary line voltage lags the primary voltage by 30^0

Table 4

Group 3 – Phase Displacement = -30^0 Clock hour figure = 1

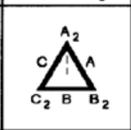
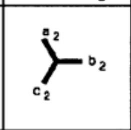
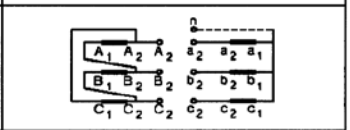
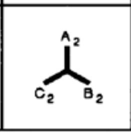
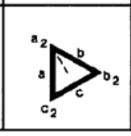
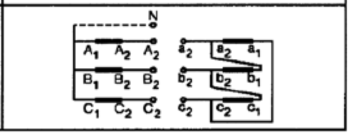
Phasor symbols	Terminal markings and phase displacement diagram of induced voltages		Winding connections
	HV winding	LV winding	
Dy1			
Yd1			

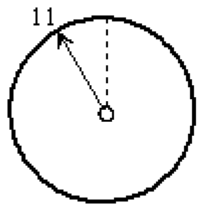


Group 4 - the secondary line voltage leads the primary voltage by 30^0

Table 5

Group 4 – Phase Displacement = $+30^0$ Clock hour figure = 11

Phasor symbols	Terminal markings and phase displacement diagram of induced voltages		Winding connections
	HV winding	LV winding	
Dy11			
Yd11			



Two or more three phase transformers that are to be paralleled, must come from the same vector group.

5. PARALLEL OPERATION OF TRANSFORMERS

Transformers are connected in parallel to provide additional __________________________, that is, to have the capacity to supply a greater current to a single load or to supply a greater number of individual loads.

That is, transformers are paralleled when the load becomes too high for one transformer to supply. In such cases transformers are connected in parallel and the parallel group shares the load.

Load sharing by transformers of equal rating is dependent upon the respective impedances of the transformers and may be determined in the following manner -

where: Load Tx_A = load taken by transformer A
Load Tx_B = load taken by transformer B
$Load_T$ = overall load to be supplied
$\%Z_A$ = impedance of transformer A
$\%Z_B$ = impedance of transformer B

Example: 2

Two transformers A and B of equal rating share a total load current of 300A. If transformer A has an impedance of 5.1% and transformer B an impedance of 4.3%, determine the load taken by each transformer.

____
____
____
____
____
____
____
____
____
____

Example: 3

Two delta/star transformers are required to supply a load of 2000kVA. If transformer A has an impedance of 5.4% and transformer B an impedance of 6.7%, determine the load taken by each transformer.

Provided the conditions for satisfactory operation of transformers in parallel are met, the transformers may be paralleled.

6. CONDITIONS FOR PARALLEL TRANSFORMER OPERATION

For transformers to operate satisfactorily in parallel the following conditions must be fulfilled.

For single-phase transformers to be paralleled, the following must be identical-

- secondary voltage
- polarities
- regulation curves.

In the case of three-phase transformers that are to be paralleled, the -

- secondary voltage
- polarities must be identical
- regulation curves must be similar
- phase sequences must be identical
- methods of connection must be suitable (same vector grouping).

If the regulation curves are too dissimilar -

- the secondary voltages of the transformers will be unequal.
- consequently, the transformer with the higher secondary voltage will supply current to the secondary windings of the other, thus causing a waste of energy.

If the regulation curves of all transformers do not correspond throughout the range of load currents and power factors -

- the load will not be divided in proportion to their ratings
- the transformer with the better regulation will take more than its share of the load and consequently overheat, while the other will take less and remain relatively cool.

7. POLARITY OF TRANSFORMERS

The term polarity when used with reference to the parallel operation of electrical machinery is understood to refer to a certain relationship existing between the direction of the voltages in two or more units.

In the case of the primary and secondary windings of a transformer, two terminals are said to have the same polarity if at the same instant in time the two terminals have the same voltage polarity, that is, both positive or both negative.

There are two methods used to mark the polarity of the terminals of a transformer -

- ____
- ____

Figure 6 shows a transformer with the polarity of its terminals marked using the lettering system and figure 7 shows a transformer with the polarity of its terminals marked using the dot method.

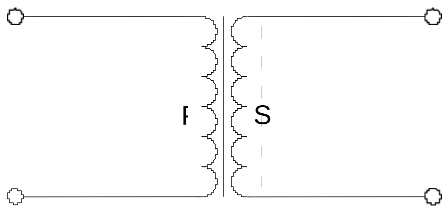


Figure 6

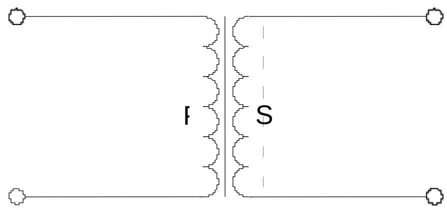


Figure 7

When the primary and secondary induced terminal voltages are in the same direction at every instant the transformer is said to have - ______________________________ polarity.

Alternately, if the induced terminal voltages are in opposite directions, the transformer is said to have -______________________________polarity.

Polarity marks indicate the direction of current into the primary and out of the secondary at the same instant.

8. POLARITY TESTS FOR TRANSFORMERS

Two single phase transformers may be paralleled by joining together similarly marked terminals, as shown in figure 8.

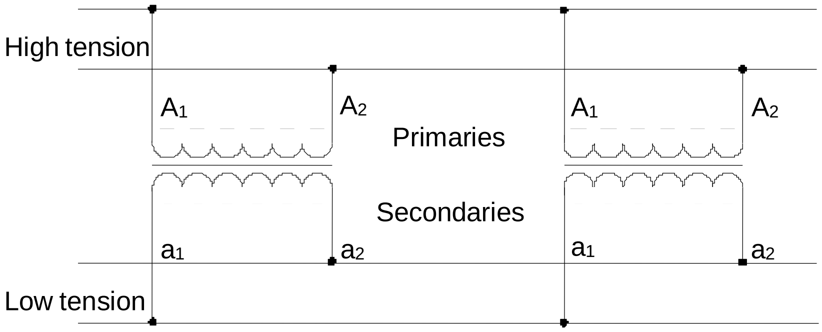


Figure 8

If there is any doubt in regard to the internal connections of the transformers they must be tested for polarity. The following is a simple method of testing.

One pair of adjacent primary and secondary terminals are joined, as in figure 4, and an alternating voltage is applied to one winding while a voltmeter is connected across the other pair of terminals.

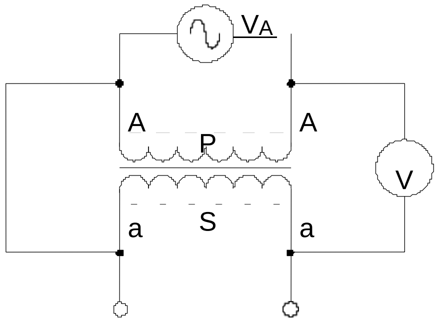


Figure 9

As shown in figure 9 the voltmeter reading will depend on the respective polarities of the two terminals A_2 and a_2. There are two possibilities –

- if the voltage indicated by the voltmeter is less than the supply voltage the transformer is said to have -

  ______________________________ - which means that the primary and

  secondary induced voltages are in the same direction and the two terminals A_2 and a_2 have the same polarity.

- if the voltage indicated by the voltmeter is greater than the supply voltage the transformer is said to have -

  ____________________________ - which means that the primary and secondary induced voltages are in opposite directions and the two terminals A_2 and a_2 have opposite polarity.

Example: 4

For the transformers shown in figures 10 and 11, determine whether they have additive or subtractive polarity and correctly label the secondary terminals.

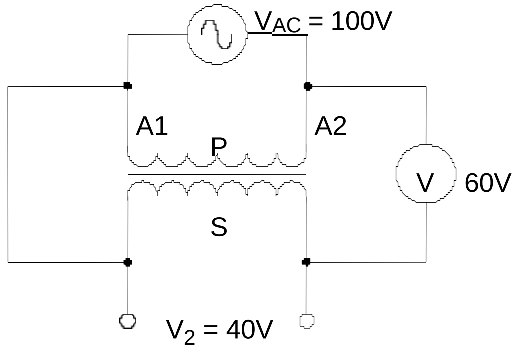


Figure 10

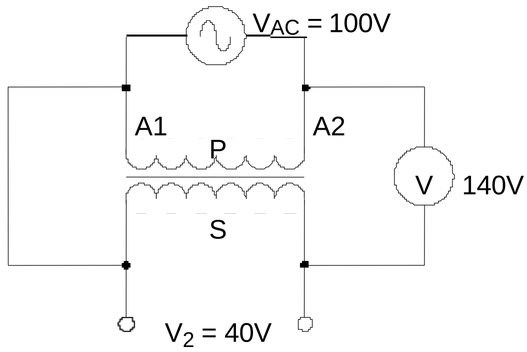


Figure 11

________________________________ ________________________________

As a final check, to ensure the transformers are being correctly paralleled the following test should be carried out. Connect the two transformers as shown in figure 12, with a voltmeter connected between the two open ends of the secondaries.

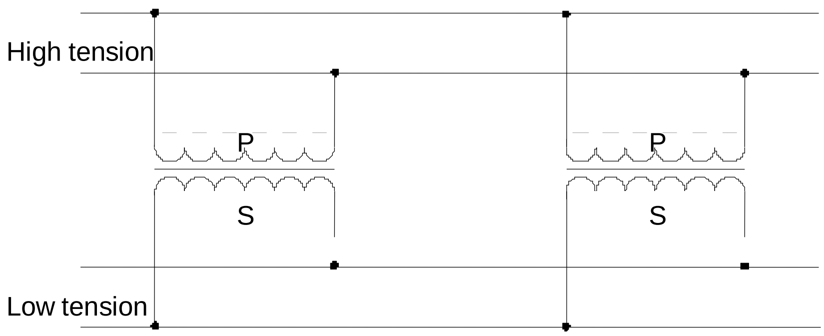


Figure 12

If these terminals have similar polarity the voltmeter will indicate______________. If this is the case, the voltmeter is disconnected and the transformer secondaries can be connected as shown in figure 13.

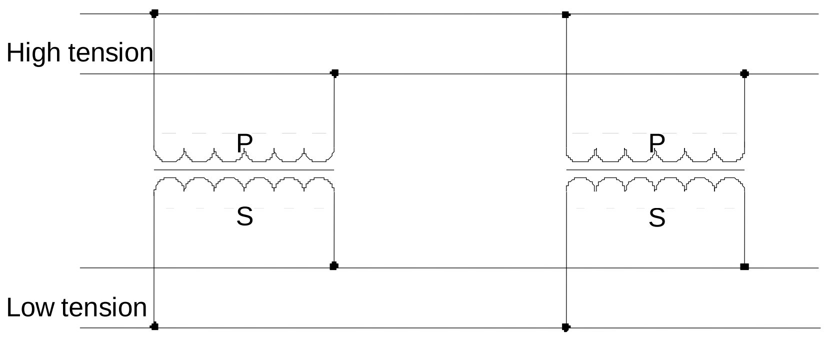


Figure 13

If the terminals are of opposite polarity the voltmeter will indicate ____________________. If this is the case, connect the transformers as shown in figure 14.

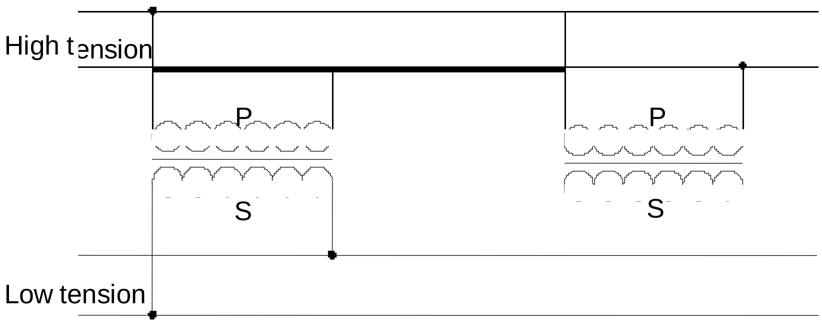


Figure 14

9. PARALLEL OPERATION OF TRANSFORMERS IN STAR AND DELTA

In a star system there is a phase angle of 30° between phase and line voltages, but there is no phase difference between phase and line volts in delta systems, so that if two transformer banks are to operate in parallel on both primary and secondary sides certain combinations only of delta and star are permissible.

There are ten possible combinations of connections but in only six of these are the phase relationships the same for the two banks while the remaining four will not work in parallel. The combinations are shown in table 6.

Table 6

	Primaries		Secondaries		OK to Parallel
	Transformer 1	Transformer 2	Transformer 1	Transformer 2	
1	Δ	Δ	Δ	Δ	Yes
2	⅄	⅄	⅄	⅄	Yes
3	Δ	⅄	Δ	⅄	Yes
4	⅄	Δ	⅄	Δ	Yes
5	⅄	⅄	Δ	Δ	Yes
6	⅄	Δ	Δ	⅄	Yes
7	Δ	Δ	Δ	⅄	No
8	⅄	Δ	Δ	Δ	No
9	⅄	⅄	Δ	⅄	No
10	Δ	⅄	⅄	⅄	No

Example: 5

Determine if the following combinations of transformers may be paralleled. Write 'yes' or 'no' in the OK to parallel column.

Transformer 1	Transformer 2	OK to Parallel
Dy1	Dy1	
Dy1	Dy11	
Yy0	Dd0	
Dy11	Yd11	
Yy6	Dy1	
Yy0	Dd6	
Dy1	Yd1	

Table 7

10. POLARITY TEST - THREE PHASE TRANSFORMER

Three phase transformers may be paralleled by joining together correspondingly placed terminals.

If there is any doubt about the internal connections of the transformers, then their polarities may be tested by connecting the primaries to the supply and joining one pair of secondary terminals.

The other two pairs of secondary terminals are joined with voltmeters as shown in figure 15.

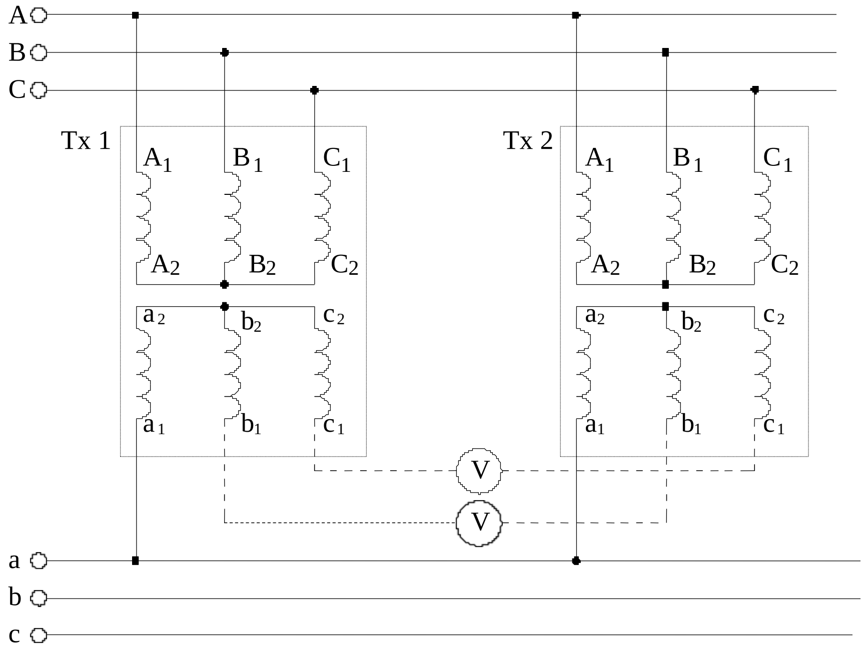


Figure 15

If the terminals are of -

- the correct polarity,__________________voltage will be indicated.
- reversed polarity,__________________the phase voltage will be shown.

Assuming that two transformers belong to vector groups capable of being paralleled, a test as in figure 15 may not give zero voltmeter readings for either or both of two reasons -

- reversed polarity
- reversed phase sequence.

If this is the case, the internal connections of the transformers need to be examined.

In figure 16 the transformers are alike in all respects except for the reversal of each secondary phase winding in transformer 2 and it is clear that no arrangement of external connections will enable the transformers to be paralleled.

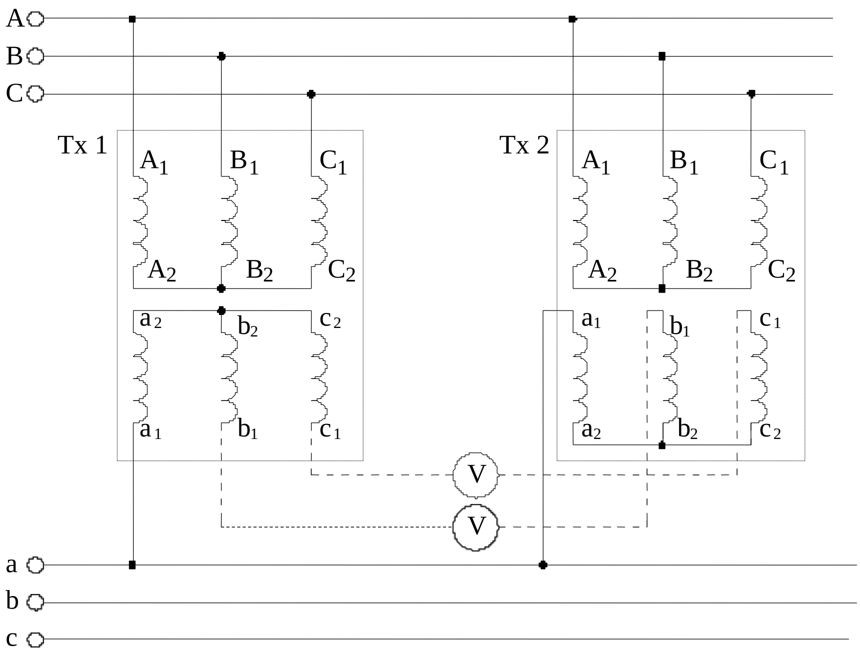


Figure 16

The two sets of secondary voltages will be displaced from each other by 180º and can be made to coincide only by reversing the internal connections of the primary or secondary phase windings of either transformer.

In figure 17 transformer 2 has a pair of secondary leads crossed internally.

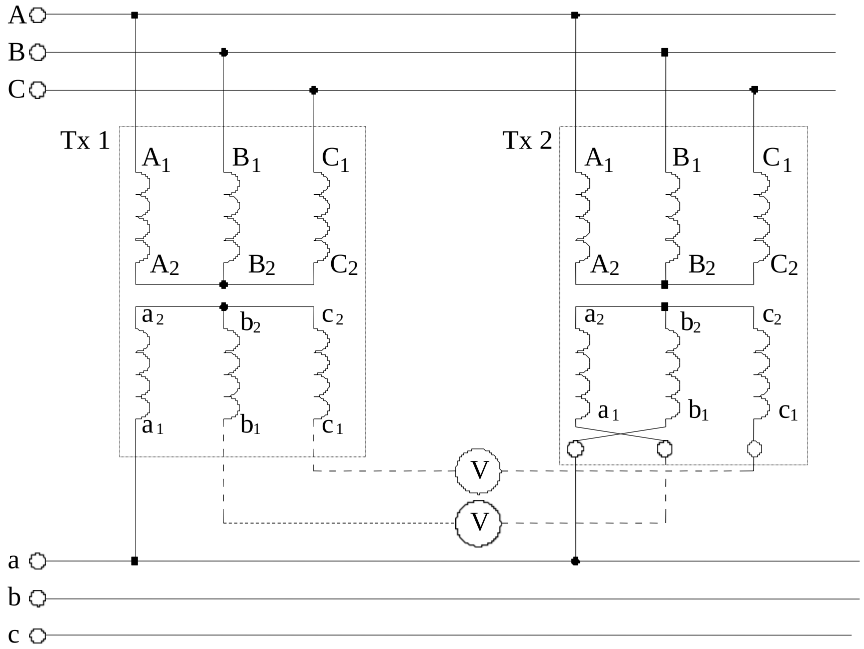


Figure 17

In this case it is necessary to cross the leads to terminals a_1 and b_1 or A_1 and B_1 of transformer 2 either internally or externally before the secondary voltages can coincide in phase sequence.

11. HARMONICS

In order to fulfil the requirements of economical design it is essential to use high values of flux densities in the cores of power transformers. Consequently the iron is worked beyond the knee of the B-H curve. This means that to produce a sinusoidal flux wave, the magnetising current wave must be "peaky" and contains harmonics. See figure 18.

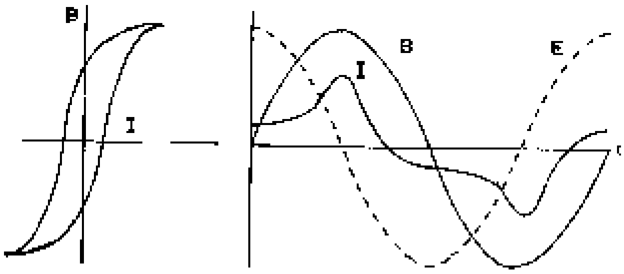


Figure 18

Note - the higher the flux density the greater are the amplitudes of the harmonics.

If for any reason the third harmonic current is unable to flow in either the primary or the secondary circuits then the sinusoidal wave current will produce a flat-topped flux wave, and this will induce a peaky emf wave in the secondary winding and a third and other harmonic voltages in the output.

Therefore it is possible to have harmonic distortion of transformer voltages and/or currents.

The effect of three-phase connections on the third harmonic can be explained as follows.

- three-wire star connection -
  - third harmonic voltage may exist between the star-point and the lines, but cannot appear in the line to line voltage.
  - if there is no return path to the star point there can be no third harmonic current. If the primary and secondary are both 3-wire star connected there is no path for the third harmonic current and it cannot flow. At least two star points must be joined or earthed if the third harmonic is to be able to flow.
- four-wire star connection -
  - as for a three wire system except that the third harmonic currents flow in the phases and the lines and return in the neutral.
- delta connection -
  - no third harmonic voltage can be detected in the phase or in the line.
  - no third harmonic current exists in the lines, but it does so in the phases.
- inter-star or zig-zag -
  - the third harmonic voltages in the two halves of each phase are in opposition and so cancel in both the phase and the line voltages.

12. NAMEPLATE INFORMATION

In accordance with the Australian Standards, transformers shall be provided with a nameplate (rating plate) -

- of weatherproof material
- fitted in a visible position
- showing the appropriate items listed below
- with entries on the plate indelibly marked.

The following information is to be given in all cases

- kind of transformer (transformer, auto-transformer, booster transformer)
- the Standard to which the transformer complies
- manufacturer's name
- manufacturer's serial number
- year of manufacture
- number of phases
- rated power in kVA or MVA
- rated frequency
- rated voltages (in V or kV) and tapping range
- rated current (in A or kA)
- connection symbol (diagram showing winding connections and phase displacement)
- percentage impedance
- type of cooling (for example, ONAN)
- total mass and mass of insulating oil.

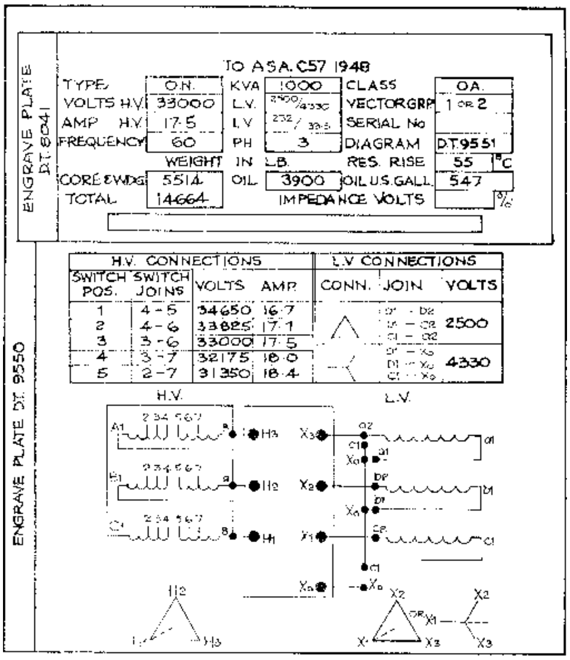


Figure 19 shows an example of a transformer nameplate.

Figure 19

13. HIGH VOLTAGE SAFETY PROCEDURES

The Australian Standard AS/NZS 3000 devotes Section 7.6 to High Voltage Installations. High voltage is defined as any voltage above 1000 V ac or 1500 V dc.

High voltage may be encountered in

- power stations
- transmission systems
- substations
- high rise office blocks or large shopping complexes (on site sub station)
- heavy industrial sites or large factory complexes (on site sub station)
- transformers to supply the above.

High voltage installations have an increased level of electrical hazard, therefore the personnel working on these installations must -

- be safety conscious
- follow correct safe working practices.

The regulation that covers safe working practices on high voltage installations is the Electricity (Workers' Safety) Regulation 1992 under the Electricity Act 1945.

The minimum safe working distances stated by the regulations are as follows:

- up to 650V 500mm
- 650V to 11kV 700mm
- 11 kV to 66kV 1000mm
- 66kV to l32kV 1500mm
- l32kV to 220kV 2500mm
- 220kV to 330kV 3000mm
- above 330kV 4000mm

The safety procedure for working on or near high voltage exposed conductors requires that an employee must be authorised to do so by an access permit. For an access permit to be issued, the following procedure must be followed.

- conductors and/or equipment isolated
- isolation must be locked out and danger tagged
- conductors and/or equipment proved to be de-energised by an approved method
- conductors shorted together and earthed
- identify safe work area by taping (white tape barrier)
- issue access permit.

If this procedure has not been completed the basic safety principle, stated by the Regulation, is that the conductors must be regarded as alive.

To ensure correct isolation switching is carried out to comply with the safety regulation requirements a switching schedule is developed. If the switching is for work to be carried out on the high voltage installation, an access permit must be issued according to the safety regulation. Switching operations can only be carried out by authorised people who must ensure that all safety requirements are filled.

The switching schedule is a step-by-step instruction that formats the sequence of operations. To assist in writing schedules a single line diagram of the whole installation, correctly labelled, is used to determine the operational steps and sequence.

For the purpose of maintaining equipment within a high voltage installation the following steps should be carried out:

- a request must be made for the work to be done which identifies the equipment to be worked on and the nature of the work ie. service, repair or test
- the work should be programmed for a date that suits all concerned, ie. owner, maintenance staff and supply authority (if required)
- a switching schedule is written detailing:
    - all operational functions of the installation
    - continuity of supply if achievable
    - isolation and earthing requirements
    - safety requirements according to the regulation
    - isolation of control and protection equipment and shorting of CTs

The switching schedule covers all the operational steps up to the point of issuing an access permit. Then, on completion of work and cancelling the permit, it covers the operational steps to restore the equipment back into service.

Notes

NAME: **Practical 5**

TRANSFORMER POLARITY & PARALLELING

PURPOSE:

This practical assignment will be used to examine the polarity testing and paralleling of single phase transformers.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Carry out a polarity test on a single phase transformer.
- Parallel two single phase transformers.
- Test transformers for correct polarity immediately prior to paralleling.
- Determine by measure the ability of two paralleled transformers to share load.

EQUIPMENT:

- 1 x variable single phase, 50Hz AC supply
- 3 x 100VA, 42/24V, single phase transformer
- 1 x 100VA load panel
- 2 x digital multimeters
- 1 x AC current clamp
- 1 x switch
- 4mm connection leads

– REMEMBER –
– WORK SAFELY AT ALL TIMES –
Observe correct isolation procedures

PROCEDURE

1. POLARITY TESTING

1. Using the transformer on the left of the three transformers provided, connect the circuit as shown in figure 1.

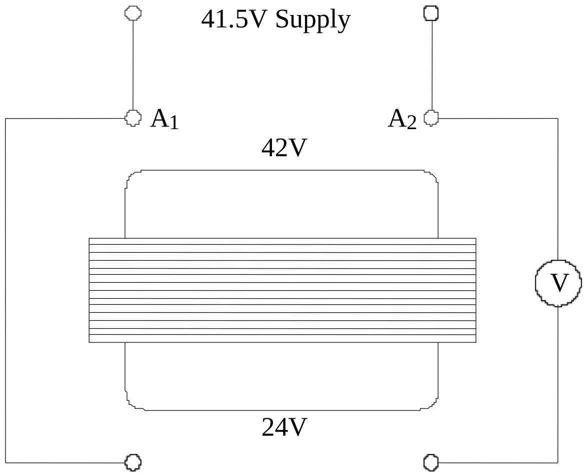


Figure 1

2. Switch on the supply and note the voltmeter reading.

   If the voltmeter reading is equal to $V_1 - V_2$ (approx. 18V), then similar ends of the windings are bridged together.
   If the voltmeter reading is equal to $V_1 + V_2$ (approx. 66V), then dissimilar ends of the windings are bridged together.

3. Based on your results, label the secondary winding connections a_1 and a_2.
4. Repeat the procedure for the other two transformers.
5. When the two transformers have been polarity tested, transfer your terminal markings onto the diagram shown in figure 2.

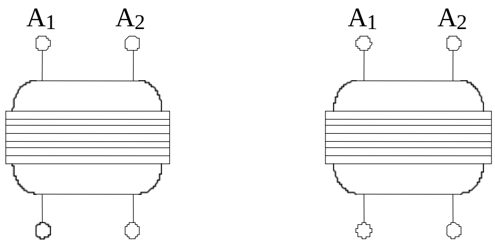


Figure 2

6. **<u>Do not proceed</u>** until the teacher checks your results and completes the progress table.

Progress Table 1

attempt 1	attempt 2	attempt 3
5	2	0

2. PARALLEL OPERATION

1. Connect the two single phase transformers as shown in figure 3.

Take particular care to ensure the transformers are paralleled with the correct polarities.

Note, the voltmeter connected between the secondaries of the two transformers.

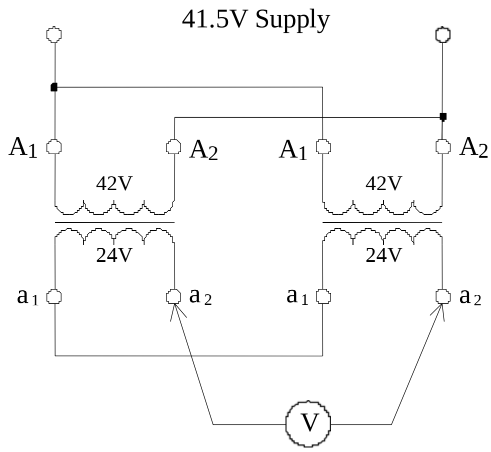


Figure 3

2. Switch on the supply, then record the voltage indicated by the voltmeter connected between the two secondaries.

Voltage between secondaries = _____________

3. Based on the voltmeter reading determine if the transformers are able to be paralleled.

Transformers ok to be paralleled? (YES or NO) = ________

4. If the transformers are not ok to parallel, make the necessary corrections and re-test.
5. **Do not proceed** until the teacher checks your results and completes the progress table.

Progress Table 2

attempt 1	attempt 2	attempt 3
5	2	0

6. Switch off the supply, remove the voltmeter and replace with a connecting lead.
7. Connect the load to the paralleled transformers as shown in figure 4.

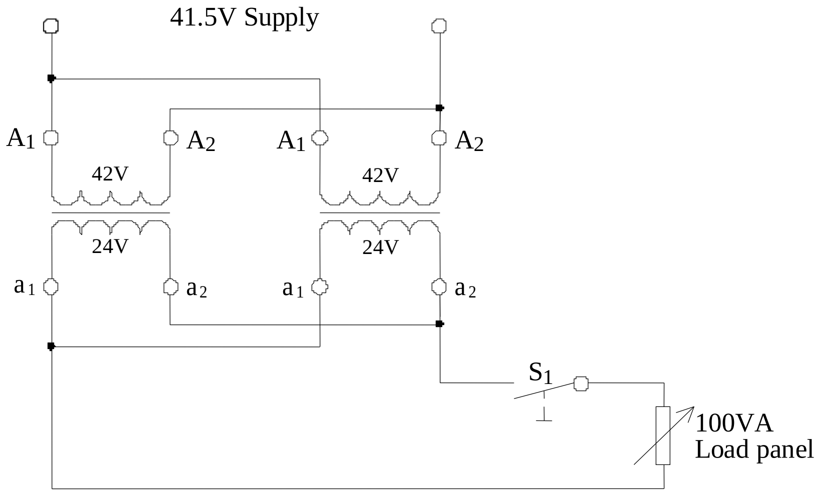


Figure 4

8. Switch on the supply, close switch S_1, then adjust the load panel for a load current of 4A. Measure the primary currents. Record the values in table 1.

Table 1

Supply Current amperes	Primary Current Tx. 1 amperes	Primary Current Tx. 2 amperes

9. Measure the transformer secondary currents and record in table 2.

Table 2

Load Current amperes	Secondary Current Tx. 1 amperes	Secondary Current Tx. 2 amperes
4A		

10. Disconnect the load by opening switch S_1, then, measure the secondary current of both transformers and record in table 3.

Table 3

Secondary Current Tx. 1 amperes	Secondary Current Tx. 2 amperes

11. **Do not proceed** until the teacher checks your results and completes the progress table.

12. Switch off the supply, then disconnect the circuit.

13. Please return all equipment to its proper place, safely and carefully.

Progress Table 3

attempt 1	attempt 2	attempt 3
5	2	0

3. OBSERVATIONS:

1. Why is it necessary to carry out polarity testing before connecting two or more transformers in parallel?

2. Is it necessary to measure the secondary voltage before being able to carry out a polarity test on an unmarked transformer? Why is it necessary to know the values of the primary and secondary voltages?

3. Did the two transformers used share the load equally? If not, which transformer took the greatest share of load?

4. If two parallel transformers do not share the load equally, what does this indicate about the transformer with the smaller portion of load?

5. Was there any circulating current between the paralleled transformers?

6. What effect would circulating current have on the load capacity of paralleled transformers?

Notes

Tutorial 5 **NAME:**

TRANSFORMER POLARITY & PARALLELING

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter on your answer sheet.

1. Transformers are paralleled when -
   a) a greater output voltage is required
   b) the load becomes too large for one transformer
   c) transformer regulation must be minimised
   d) the effect of the vector groups must be reduced

2. A transformer designated Dy11 would have a -
   a) star primary, delta secondary and 0º phase shift
   b) star primary, delta secondary and 30º phase shift
   c) delta primary, star secondary and 30º phase shift
   d) delta primary, delta secondary and 0º phase shift

3. Load sharing by parallel transformers of equal rating is dependent upon the respective transformer -
   a) line voltage
   b) vector group
   c) impedance
   d) voltage regulation

4. When conducting a final additive/subtractive polarity test for paralleling two single phase transformers, the voltmeter is connected across -
   a) each transformer primary winding
   b) each transformer secondary winding
   c) the two transformer secondaries in series
   d) the two transformer primaries in parallel

5. Which of the following combinations of three phase transformers may be paralleled
   a) star/star and star/delta
   b) delta/star and star/star
   c) delta/delta and star/delta
   d) delta/star and star/delta

6. As long as certain other characteristics are identical, a 3-phase star/delta transformer can be connected in parallel with a second transformer which has its primary delta connected and its secondary connected in -
   a) delta
   b) star
   c) inter-star
   d) zig-zag

7. Three phase transformers that are to be paralleled -
   a) must come from an alternate vector group
   b) can come from any vector group
   c) are not affected by their vector group
   d) must come from the same vector group
8. Transformer polarity marks indicate the direction of current -
   a) into the primary and out of the secondary
   b) out of the primary and into the secondary
   c) into the primary and into the secondary
   d) out of the primary and out of the secondary

   at the same instant
9. When the primary and secondary terminal voltages are in the same direction at every instant, the transformer is said to have -
   a) additive polarity
   b) negative polarity
   c) subtractive polarity
   d) positive polarity
10. Which of the following combinations of three phase transformers may be paralleled
    a) Dy1 and Dy11
    b) Dy11 and Yd1
    c) Yy0 and Dd6
    d) Dy1 and Yd1

SECTION B

Blank spaces in the following statements represent omissions. Write the appropriate information on your answer sheet.

When two transformers of equal rating are paralleled, the transformer with the _____(1)_____impedance will take the greater share of load.

If two transformers of equal rating and impedance are paralleled, the transformers will share the load______(2)_____.

Transformers are connected in parallel to provide additional______(3)_____.

Transformers are paralleled when the load becomes______(4)_____for one transformer.

Identical single phase transformers that are to be paralleled must have the same _____(5)_____,_____(6)_____and______(7)_____.

The two methods used to mark the polarity of the terminals of a transformer are _____(8)_____and_______(9)_____.

When the primary and secondary terminal voltages of a transformer are in the same direction at every instant, the transformer is said to have______(10)_____polarity.

When the primary and secondary terminal voltages of a transformer are in opposite directions at every instant, the transformer is said to have______(11)_____polarity.

Three phase transformers that are to be paralleled must have identical______(12)_____, _____(13)_____,______(14)_____,______(15)_____and______(16)_____.

SECTION C

1. Three single phase 5:1 transformers have their primaries connected in star to a 415V supply. The delta connected secondaries supply three 6Ω star connected elements. Determine -

   a) primary phase voltage (240V)
   b) secondary phase and line voltages (48V, 48V)
   c) load phase current (4.62A)
   d) secondary line current (4.62A)
   e) secondary phase current (2.67A)
   f) primary phase and line current. (0.53A, 0.53A)

2. A three phase 415V inductive load is to be supplied by a three phase delta/star step down transformer. If the primary line voltage is 1000V, determine the required transformer ratio. (4.17:1)

3. A three phase 11kV/415V star-star transformer supplies a load consisting of three delta connected heating elements. If the secondary line current is 173A determine the -

   a) transformation ratio (26.46:1)
   b) load phase current (100A)

c) load phase voltage (415V)

d) resistance of each heating element (4.15Ω)

e) transformer primary line current. (6.54A)

4. Two transformers of equal rating are to be paralleled to supply a load of 3MVA. If transformer A has an impedance of 5% and transformer B an impedance of 4.5%, determine how the transformers will share the load. (Tx A = 1.42MVA and Tx B = 1.58MVA)

5. Two 33kV/5kV, 15MVA transformers are to be paralleled. Show by calculation if they will operate satisfactorily to supply a 25MVA load. The transformer impedances are $\%Z_A$ = 6% and $\%Z_B$ = 3.5%. (Tx A = 9.2MVA and Tx B = 15.8MVA, not satisfactory Tx B overloaded)

SECTION D

1. What would be the expected voltmeter readings in the circuit of figure 1, if the transformers were -

a) correctly paralleled

b) incorrectly paralleled.

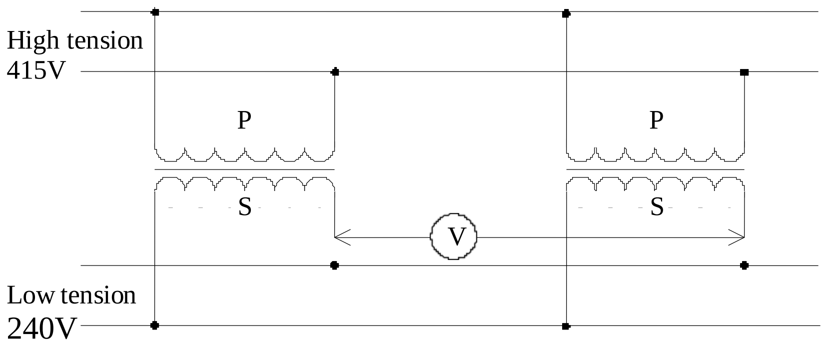


Figure 1

2. What would be the expected voltmeter readings in the circuit of figure 2, if the transformers were -

a) correctly paralleled

b) incorrectly paralleled.

3.

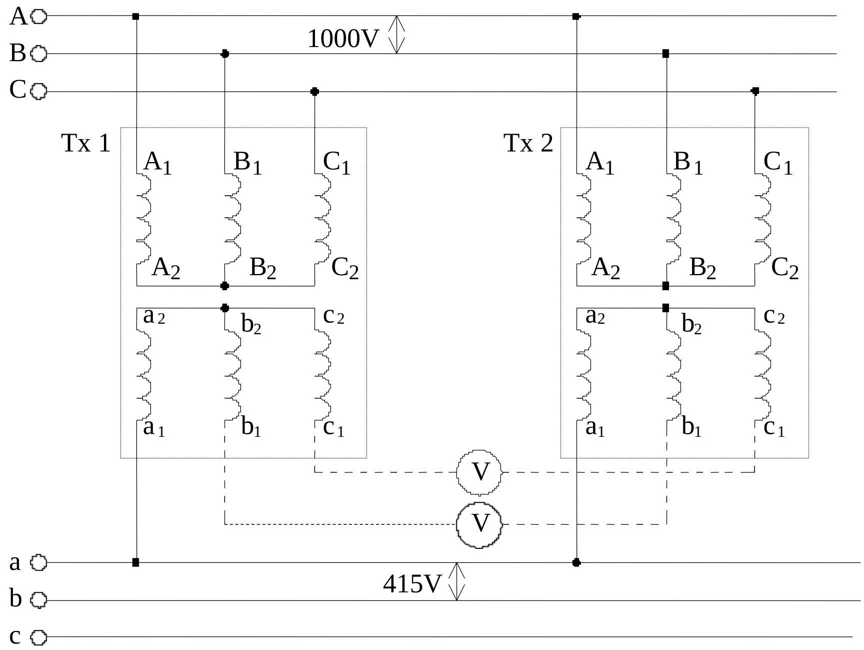


Figure 2

Section 6

INSTRUMENT & AUTO-TRANSFORMERS

PURPOSE:

In this section you will learn about the construction, operation and application of instrument and auto-transformers.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- Identify potential, current and auto-transformers from their winding diagrams.
- List the advantages and disadvantages of the auto-transformer.
- Describe the construction of potential, current and auto-transformers.
- Calculate voltages and currents associated with auto-transformers.
- State the ratings of potential and current transformers.
- List the precautions to be taken with the connection and disconnection of instrument transformers.
- State applications for potential, current and auto-transformers.
- Test a transformer to determine its suitability for connection to the supply.

REFERENCES:

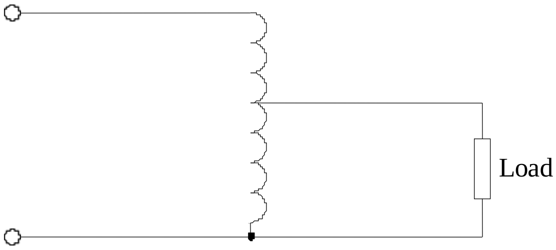
- Hampson, J. & Hanssen, S. *Electrical Trade Principles*, 2nd Edition, Section 7
- Jenneson, J.R. *Electrical Principles for the Electrical Trade*, 5th Edition, Pages 349 - 352

1. AUTO-TRANSFORMERS

An auto-transformer is one which has a part of the winding common to both primary and secondary circuits. In general, the two coils of a transformer are connected together only by the magnetic field, but in an auto-transformer, as well as the magnetic coupling, there is an electrical connection.

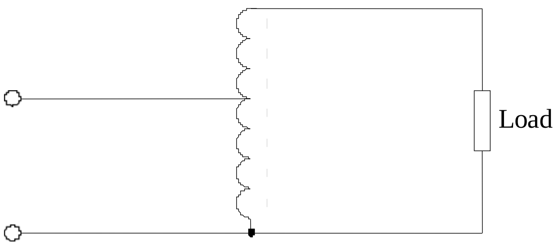
The winding of an auto-transformer is provided with one or more taps, from which the secondary voltage is obtained, in the case of a step down auto-transformer, or across which the primary voltage is applied if the auto-transformer is of the step up type.

Figure 1 shows the connections for a step down auto-transformer and figure 2 those of a step up auto-transformer.



Step down auto-transformer

Figure 1



Step up auto-transformer

Figure 2

As is the case with the double wound transformer, if losses are neglected the transformation ratio of the auto-transformer is equal to the turns ratio, and also equal to the current ratio -

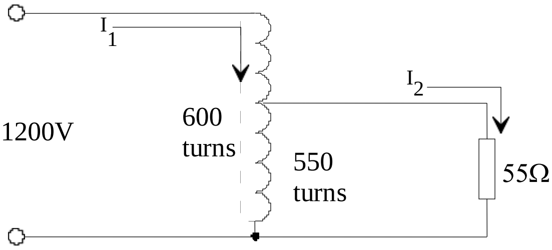
Since the direction of current in the secondary of a transformer is opposite to that of the primary current, it follows that in an auto-transformer the part of the winding common to the primary and secondary carries the difference of the two currents.

This condition permits the common part of the winding to be of much smaller cross section than the other part, which saves copper and reduces size and cost.

Example: 1

For the step down auto-transformer shown in figure 3 determine the -

a) secondary voltage
b) secondary current
c) primary current
d) current in the common section of the winding



Example: 2

Determine the current in the common section of the winding of a 240/220V auto-transformer supplying a 1kW load at unity power factor.

____
____
____
____
____
____
____

Figure 4 shows an example of one type of auto-transformer.

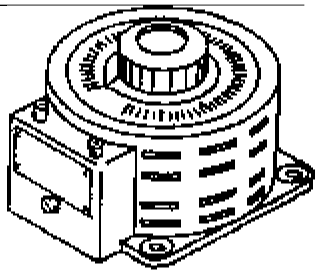


Figure 4

There are three main applications for auto-transformers -

- ____________________ on long transmission lines and
- to reduce voltage for _____________________________
- variable ac supplies -____________________________.

2. ADVANTAGES AND DISADVANTAGES OF AUTO-TRANSFORMERS

By combining the primary and secondary of a transformer into one winding, a saving of material and a reduction in losses can be effected.

As the primary and secondary currents are 180º out of phase, that part of the winding which carries both currents will actually carry their difference. The copper losses will be lower and a smaller iron core can be used for a given output, thus reducing the iron loss.

Therefore, the advantages are -

- ______________________________________
- ______________________________________ ______________________________________
- ______________________________________

Especially where the ratio of transformation is low

Auto-transformers are restricted in their application, since the primary and secondary circuits are electrically connected. Refer to clause 4.14 of AS3000, for details regarding the installation of transformers, including auto-transformers.

3. INSTRUMENT TRANSFORMERS

Instrument transformers are generally used with AC instruments when high voltages or high currents have to be measured.

Instrument transformers are of two types -

- ____
- ____.

4. POTENTIAL TRANSFORMERS

Voltage or potential transformers (PT's) are used in conjunction with -

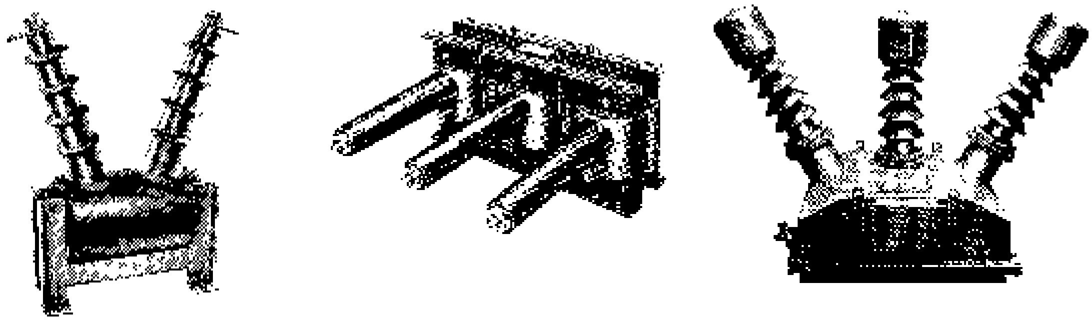
- voltmeters
- protection relays
- the potential coils of wattmeters and kilowatt-hour meters,

and do not differ materially from the constant voltage power transformers already discussed, except that their power rating is low. Since only instruments or relays are connected to their secondaries, such transformers have ratings of 5VA to 200VA.

Potential transformers are very carefully designed to maintain an extremely accurate transformation ratio, which changes very little with load.

The standard secondary voltage of a potential transformer is____________. This arrangement enables high voltage to be kept away from instruments, thus eliminating the danger of electric shock or a breakdown of insulation in meter windings.

Figure 5 shows examples of single and three phase potential transformers.



Single phase, 16kV cast in resin | Three phase 11kV cast in resin | Three Phase, 33kV PT

Figure 5

Figure 6 shows the Australian Standard drawing symbols for the potential transformer.

Complete form | Simplified form

Figure 6

Figure 7 shows the connection of a potential transformer to allow the measurement of the voltage on an 11kV supply line. The primary is connected across the 11kV line, with a 110V voltmeter connected across the transformer secondary. The voltmeter would be scaled to read 0-11kV.

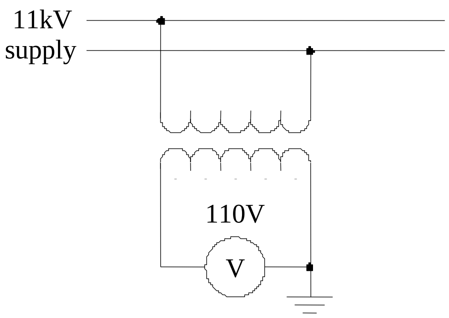


Figure 7

5. CURRENT TRANSFORMERS

Current transformers (CT's) are used -

- when the current to be measured is greater than can be carried safely by a meter connected directly into the circuit
- where an instrument is to be used at some distance from the load circuit
- where it is necessary to isolate the windings of instruments or relays from high voltage circuits.

The current transformer has a primary, usually of a few turns only, wound on an iron core and connected in series with the line. When the primary has a high current rating it may consist of a straight conductor passing through the centre of a ring shaped laminated core. The secondary consists of the required number of turns wound on the core.

Figure 8 shows a sectioned view of one type of current transformer.

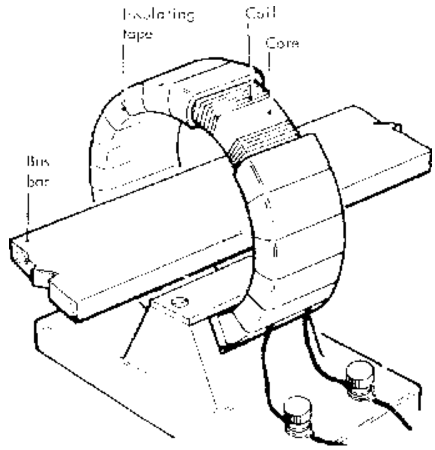


Figure 8

Figure 9 shows two examples of current transformers.

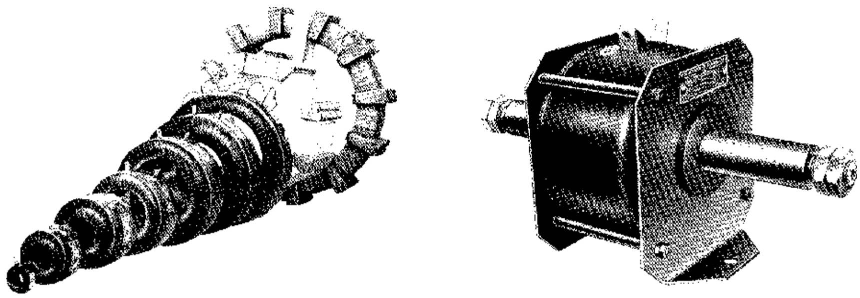


Figure 9

Figure 10 shows the Australian Standard drawing symbols for the current transformer.

Complete form   Simplified form

Figure 10

The current transformer is designed to work with a very low flux density in the core, and the secondary has a low impedance. This arrangement makes it possible to obtain a current in the CT load which is practically proportional to the line current.

The standard values of rated primary currents are - 10, 12.5, 15, 20, 25, 30, 40, 50, 60 and 75A and their decimal multiples or fractions. The preferred values are those underlined.

The standard values of rated secondary currents are 1, 2, 5, but the preferred value is ____________.

Figure 11 shows the connection of a current transformer and an ammeter, which are used to measure the line current taken by a three phase motor. The current transformer is used to step the current down to a value which can be safely measured using an ammeter. In this case the ammeter used would be a 5A ammeter, with the scale calibrated to read 0 - 200A.

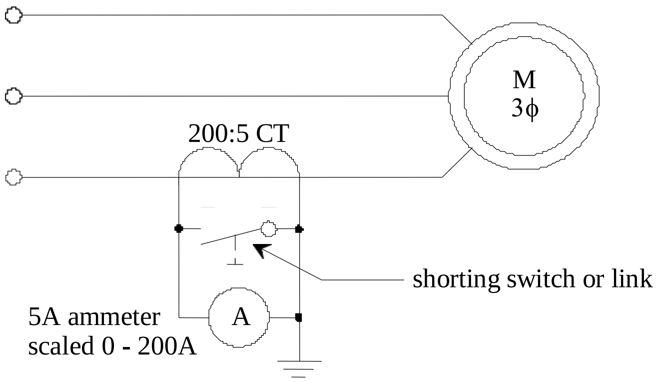


Figure 11

The secondary circuit of a potential transformer may be opened safely and the load removed, but in the case of a current transformer, the secondary circuit must be short circuited before the load is removed. If there were no secondary current to produce a demagnetising effect, the flux would rise above normal value, inducing a voltage in the secondary which may damage the insulation or create a shock hazard. The increased iron losses may also cause such a rise in temperature that the quality of the iron may be altered permanently and the accuracy of the transformation ratio affected.

6. PROTECTION OF INSTRUMENT TRANSFORMERS

Instrument transformers are always given a VA load rating and these ratings should not be exceeded if accuracy is desired.

An excessive current in the secondary circuit of a potential transformer produces an excessive current in the primary circuit. Consequently, a potential transformer can and should be protected by fuses in either the primary or secondary circuit.

The currents in the windings of a current transformer are determined only by the line current and therefore cannot become excessive when a fault occurs in the transformer or ammeter. Consequently, fuses are not required to protect current transformers.

Example: 3

Connect the components shown in figure 12 to allow the load voltage, current and power to be measured.

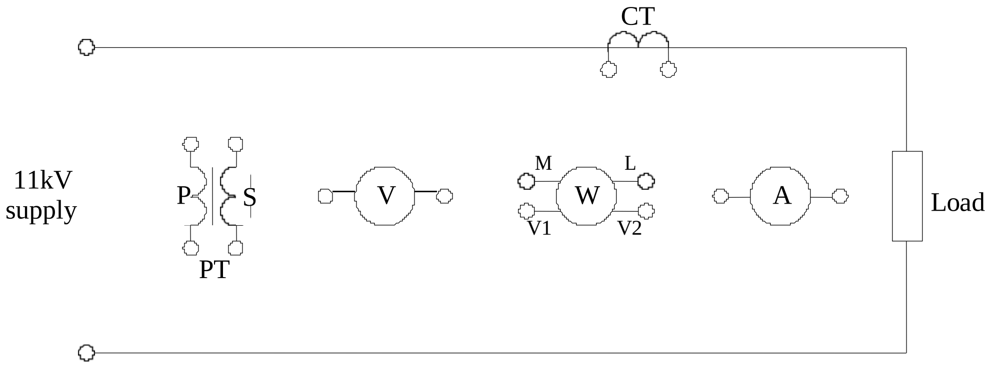


Figure 12

Example: 4

A CT with a ratio of 200/5A is used to measure the current taken by an induction motor. If the motor current is 175A determine the current flowing in the CT secondary.

____

____

Example: 5

A PT with a ratio of 11kV/110V is used to supply the potential coil of a maximum demand indicator. If the line voltage drops to 10450V, determine the voltage supplied to the maximum demand indicator.

____

____

7. TRANSFORMER TESTING

The tests to determine the operating condition of a transformer are laid down by the Australian Standards. One of the tests carried out on a transformer to determine its suitably for connection to the supply is the measurement of the transformers -

- ____________________________________.

When an insulation resistance test is carried out, the insulation resistance is measured between -

- ____ and
- ____.

Theoretically the insulation resistance should be_______________________.

The connections required to measure the insulation resistance between windings are as shown in figure 13.

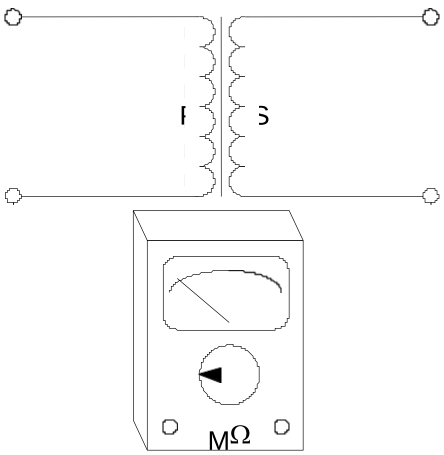
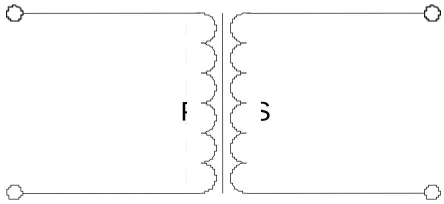


Figure 13

The connections required to measure the insulation resistance between the windings and earth are as shown in figure 14.



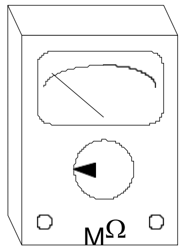


Figure 14

With double wound transformers it is particularly important that no breakdown occurs between primary and secondary windings, as this could lead to a dangerous situation and damaged equipment.

To provide additional protection, some transformers are fitted with an earth shield between the primary and secondary windings.

NOTES:

NAME: **Practical 6**

TRANSFORMER VECTOR GROUPS

PURPOSE:

This practical assignment will be used to examine the phase shift between primary and secondary line voltages of a three phase transformer.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Connect Dd0, Dy11 and Dy1 transformers.
- Use a CRO to measure the phase shift between primary and secondary line voltages of a three phase transformer.
- Identify an angle of lead or lag for transformer primary and secondary line voltages that are out of phase.

EQUIPMENT:

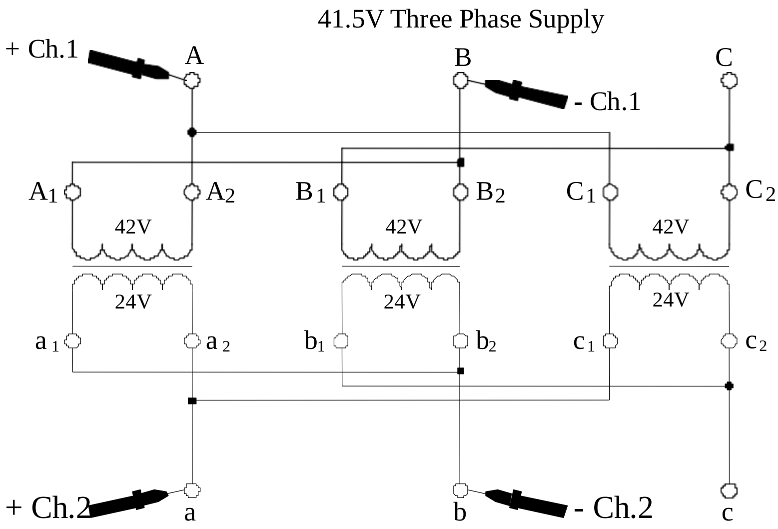
- 1 x 41.5/24V three phase, 50Hz AC supply
- 1 x 300VA, 42/24V three phase transformer
- 1 x BWD powerscope
- 4mm connection leads

– REMEMBER –
– WORK SAFELY AT ALL TIMES –
Observe correct isolation procedures

PROCEDURE

1. Dd0 TRANSFORMER

1. Connect the transformer in a Dd0 configuration as shown in figure 1.



CRO Settings

Ch.1 = 20V/div

Ch.2 = 20V/div

Sweep = 5mS/div

Figure 1

2. Connect the CRO to measure the primary line voltage V_{AB} and the secondary line voltage V_{ab}, that is - +channel 1 to primary line A and -channel 1 to primary line B
+channel 2 to secondary line a, and -channel 2 to secondary line b.
3. Switch the CRO on and centre both beams horizontally.
4. Switch on the supply and neatly sketch the waveforms of the two line voltages, paying particular attention to the phase relationship.

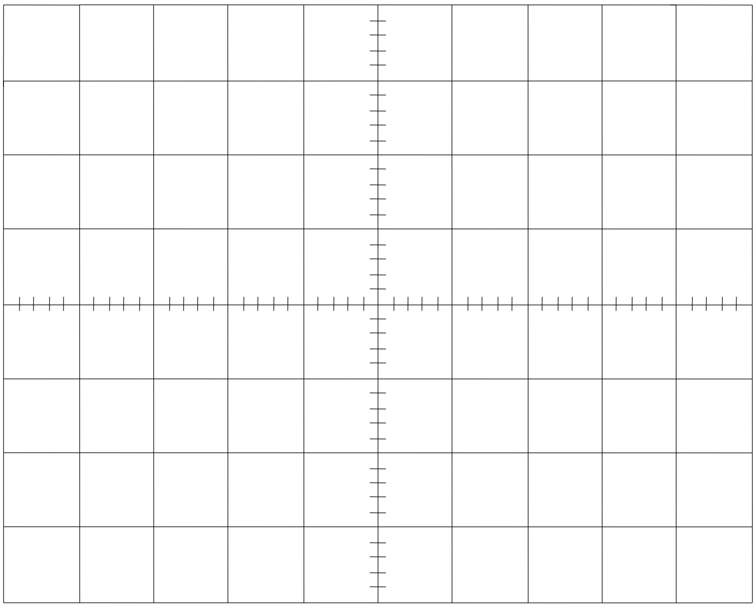


Figure 2

5. Determine the phase relationship between the two line voltages.

   The secondary line voltage is______________phase with the primary line voltage.

6. Measure the periodic time and the time separation between the line voltages.

   Periodic time = ____________

   Time separation = ____________

7. Determine the phase shift between the line voltages.

   Phase shift $= \frac{\text{Time seperation}}{\text{Periodic time}} \times 360 =$

   The phase angle between the primary and secondary line voltages is __________ degrees.

8. **<u>Do not proceed</u>** until the teacher checks your results and completes the progress table.

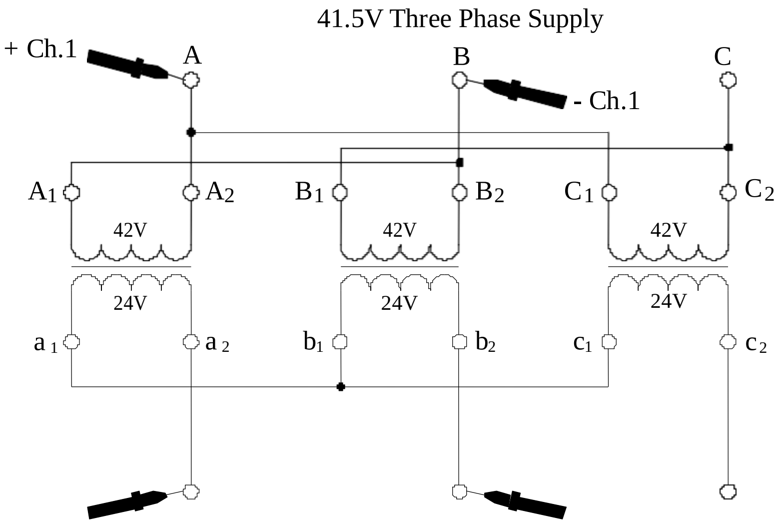
9. Switch off the supply - but do not switch the CRO off.

Progress Table 1

attempt 1	attempt 2	attempt 3
5	2	0

2. D y11 TRANSFORMER

1. Connect the transformer in a Dy11 configuration as shown in figure 3.



CRO Settings

Ch.1 = 20V/div

Ch.2 = 20V/div

Sweep = 5mS/div

+ Ch.2 a b - Ch.2 c

Figure 3

2. Ensure that both CRO beams are centred horizontally.

3. Switch on the supply and neatly sketch the waveforms of the two line voltages, paying particular attention to the phase relationship.

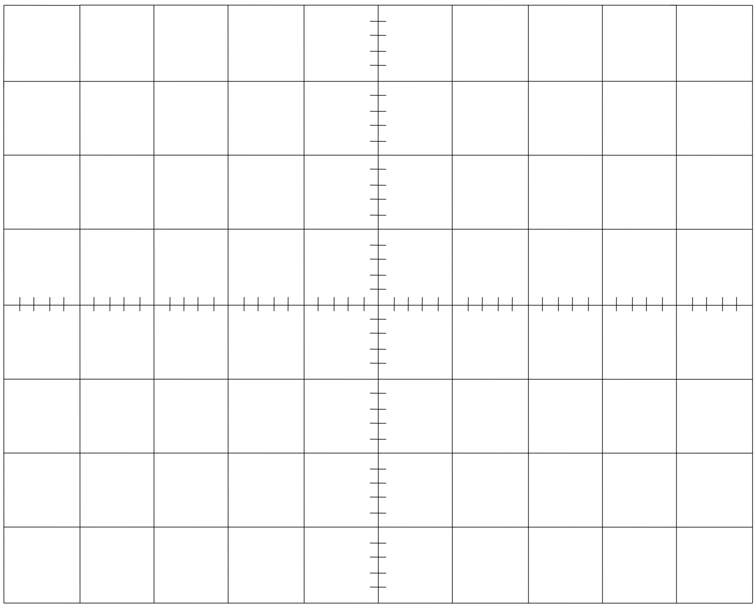


Figure 4

4. Determine the phase relationship between the two line voltages.

The secondary line voltage is________________phase with the primary line voltage.

5. Measure the periodic time and the time separation between the line voltages.

Periodic time = _____________

Time separation = _____________

6. Determine the phase shift between the line voltages.

Phase shift $= \frac{\text{Time seperation}}{\text{Periodic time}} \times 360 =$

The phase angle between the primary and secondary line voltages is ___________ degrees.

The secondary line voltage____________the primary line voltage.

7. **<u>Do not proceed</u>** until the teacher checks your results and completes the progress table.

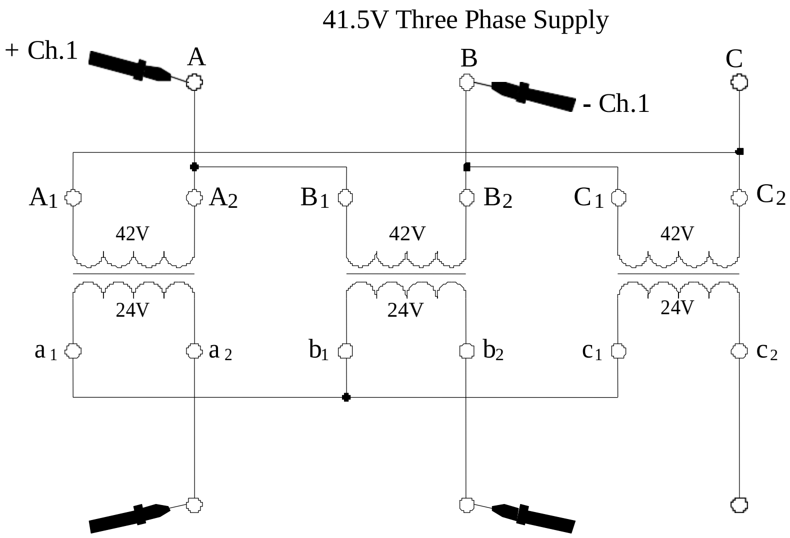
Progress Table 2

attempt 1	attempt 2	attempt 3
5	2	0

8. Switch off the supply.

3. Dy1 transformer

1. Connect the transformer in a Dy1 configuration as shown in figure 5.



CRO Settings

Ch.1 = 20V/div

Ch.2 = 20V/div

Sweep = 5mS/div

+ Ch.2 a b - Ch.2 c

Figure 5

2. Ensure that both CRO beams are centred horizontally.
3. Switch on the supply and neatly sketch the waveforms of the two line voltages, paying particular attention to the phase relationship.

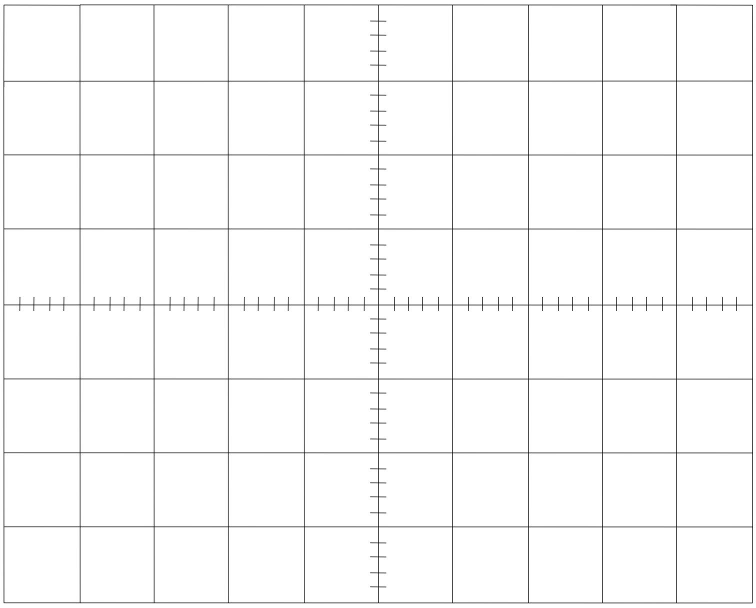


Figure 6

4. Determine the phase relationship between the two line voltages.

   The secondary line voltage is________________phase with the primary line voltage.

5. Measure the periodic time and the time separation between the line voltages.

   Periodic time = _____________

   Time separation = _____________

6. Determine the phase shift between the line voltages.

   Phase shift = $\frac{\text{Time seperation}}{\text{Periodic time}} \times 360$ =

   The phase angle between the primary and secondary line voltages is ___________ degrees.

   The secondary line voltage_____________the primary line voltage.

7. **<u>Do not proceed</u>** until the teacher checks your results and completes the progress table.

Progress Table 3

attempt 1	attempt 2	attempt 3

5	2	0

8. Switch off the supply, then disconnect the circuit.
9. Please return all equipment to its proper place, safely and carefully.

4. OBSERVATIONS:

1. How is a particular vector grouping achieved in a three phase transformer?

____

____

____

2. Based on the results of this practical, what is the phase shift between primary and secondary line voltages of a three phase transformer that is in the '0' vector group?

____

____

____

3. Based on your results, what is the phase shift between primary and secondary line voltages of a three phase transformer that is in the '11' vector group?

____

____

____

4. Based on your results, what is the phase shift between primary and secondary line voltages of a three phase transformer that is in the '1' vector group?

5. What would you have to do, to change a Dy11 transformer to a Dy1 transformer?

6. When must an electrician be aware of the vector grouping of a transformer?

7. What would happen if two transformers from different vector groups were paralleled?

8. A transformer is nominated as Dd6, what does the 6 mean?

NOTES
****

Tutorial 6 **NAME:**

INSTRUMENT & AUTO-TRANSFORMERS

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter on your answer sheet.

1. In an auto transformer the current in the primary is 10 amperes and the current in the secondary is 20 amperes; the current in the common part of the winding is—
   a) 30 amperes.
   b) 20 amperes.
   c) 15 amperes.
   d) 10 amperes.

2. The current in the common section of the winding of an auto transformer, when on load is equal to—
   a) the phasor sum
   b) the phasor difference
   c) the sum.
   d) the difference

   of the primary and secondary currents.

3. When an auto transformer is properly designed, one of the features compared to a double wound transformer of the same rating is -
   a) larger physical size
   b) requires less material to manufacture
   c) has a lower efficiency
   d) has higher losses

4. The rated secondary current of a standard current transformer is -
   a) 0.6A
   b) 5A
   c) 10A
   d) 25A

5. The rated standard secondary voltage of a potential transformer is -
   a) 415V
   b) 240V
   c) 120V
   d) 110V

6. If the instrument is to be removed from the secondary of a current transformer it is necessary to -
   a) short circuit the primary terminals
   b) short circuit the secondary terminals
   c) open circuit the secondary terminals
   d) open circuit the primary terminals
7. A certain current transformer when operating at full rated current has a primary current of 550A, the secondary current would be -
   a) 110A
   b) 10A
   c) 5A
   d) unknown
8. An 11kV potential transformer has a primary voltage of 11kV applied, the secondary voltage would be -
   a) 110V
   b) 5V
   c) 1V
   d) unknown

SECTION B

Blank spaces in the following statements represent omissions. Write the appropriate information on your answer sheet.

Instrument transformers are usually rated in terms of their______(1)_____output.

The secondary of a______(2)_____transformer must always be short circuited before disconnecting its associated meter.

The more common Australian standard secondary current of a current transformer is _____(3)_____amperes.

The primary circuit of instrument type______(4)_____transformers should always be protected by fuses.

When the primary of a current transformer is energised and the secondary is open circuited, a high______(5)_____is produced at the secondary terminals.

Auto transformers are transformers with a______(6)_____winding.

The current in the common part of an auto transformer is the______(7)_____of the primary and secondary currents.

In an auto transformer, the primary current is 5A and the secondary current is 12A. The current in that part of the winding which is common to the primary and secondary is _____(8)_____amperes.

The applications of auto transformers is limited due to the danger of a______(9)_____ between the primary and secondary.

The minimum acceptable insulation resistance for a transformer between windings is _____(10)_____and between windings and earth______(11)_____.

To provide additional protection, some transformers are fitted with an______(12)_____ shield between the primary and secondary windings.

Instrument transformers are of two types,______(13)_____transformers and _____(14)_____transformers.

A variac is an example of the use of an______(15)_____transformer.

The rated standard secondary voltage of a potential transformer is______(16)_____ volts.

SECTION C

1. An auto transformer is used to step down from 300 volts to 200 volts. The complete winding consists of 600 turns and the secondary current is 30 amperes. Determine:
   a) secondary turns (400 turns)
   b) primary current (20A)
   c) current in common portion of winding, neglect all losses (10A).
2. Determine the current at full load, in the common section of the winding of a single phase 440/415V, 5kVA auto transformer. Neglect losses. (0.69A)
3. A 400/32V, 0.5kVA, single phase auto transformer delivers full load at unity power factor. Determine the current in the common section of the winding. Neglect losses. (14.375A)
4. An auto transformer is used to step up from 200 volts to 250 volts. The primary winding consists of 400 turns and the secondary current is 20 amperes. Determine:
   a) secondary turns (500 turns)
   b) primary current (25A)
   c) current in common portion of winding, neglecting all losses (5A).
5. A 500/5A CT has a primary current of 450A, what is the secondary current? (4.5A)
6. A 415/110V potential transformer has a primary applied voltage of 425V, what is the secondary voltage? (112.65V)
7. A 1000/5A CT has a secondary current of 3.5A, what is the primary current? (700A)

8. A three phase, 11kV/415V, delta/star transformer supplies a star connected load consisting of three 15Ω heating elements. Determine -
   a) primary phase voltage (11kV)
   b) secondary phase and line voltages (240V, 415V)
   c) load phase voltage (240V)
   d) load phase current (16A)
   e) secondary line current (16A)
   f) secondary phase current (16A)
   g) transformation ratio (45.83:1)
   h) primary phase and line current. (0.349A, 0.605A)

9. A three phase 11kV/415V star-star transformer supplies a load consisting of three delta connected heating elements. If the secondary line current is 200A determine the -
   a) transformation ratio (26.46:1)
   b) load phase current (115.47A)
   c) load phase voltage (415V)
   d) resistance of each heating element (3.59Ω)
   e) transformer primary line current. (7.56A)

10. Two transformers of equal rating are to be paralleled to supply a load of 2MVA. If transformer A has an impedance of 5% and transformer B an impedance of 4%, determine how the transformers will share the load. (Tx A = 0.889MVA and Tx B = 1.111MVA)

SECTION D

1. Re-draw the symbols shown in figure 1 and connect the ammeter, voltmeter and wattmeter to measure the line current and line voltage of the three phase motor. The instruments are to be connected via instrument transformers. Note, a bar type CT is used.

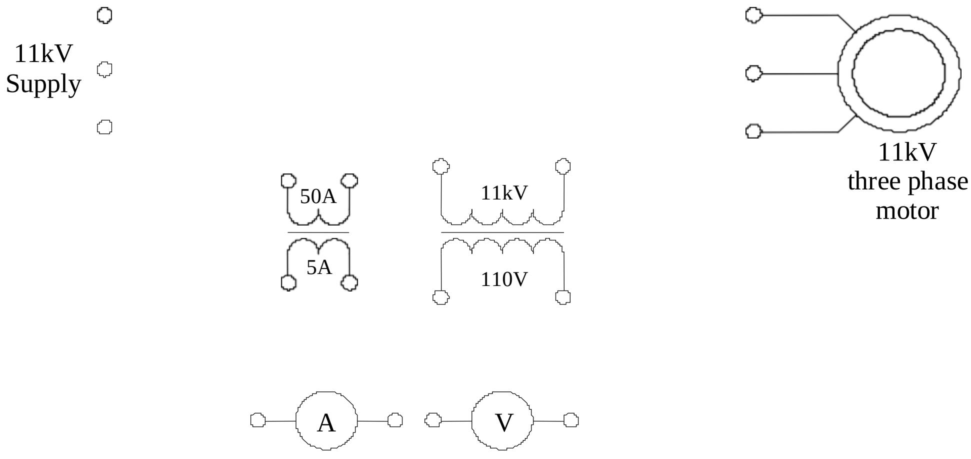


Figure 1