Pearson BTEC Level 5 Higher Nationals in Engineering (RQF)

Unit: 43 Further Electrical Machines and Drives

Unit Workbook 1

in a series of 4 for this unit

Learning Outcome 1

Operation and Characteristics of Electrical Machines

Contents

INTRODUCTION

Operation and Characteristics of Electrical Machines.

The aim of this course is to carry out further study into electrical machines and drives, beyond that which was studied in Unit 21 - Electrical Machines.

Electrical machines represent by far the most common form of energy conversion device employed today across a multitude of industrial and domestic applications. Electrical machines are used to convert alternating current from one voltage to another in the case of an AC transformer, which can be designed to step-up or step-down voltages.

Other electrical machines are used to convert mechanical energy into electrical energy in the form of an electricity generator or conversely electricity can be converted into mechanical energy in the case of an electric motor. In each case electrical machines utilise long established electromagnetic and mechanical principles which form the basis of electrical machine theory.

Many electrical machines encountered within the industrial environment are electrical motors and these are further classified as DC (Direct Current) and AC (Alternating Current) machines.

Areas to be studied will include:

Principles of Operation of Transformers, their characteristics, and their industrial applications.

Principles of Operation of DC machines, their characteristics, and their industrial applications.

Operation of three-phase Induction Machines and their Characteristics.

Principles of Operation of Synchronous Machines and their Characteristics.

Introduction to Special Machines.

Simulation using Scilab (open source) or similar commercially available software.

GUIDANCE

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures.

Purpose	Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.
Theory	Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.
Example	The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself.

Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.

Question

Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.

Challenge

You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.

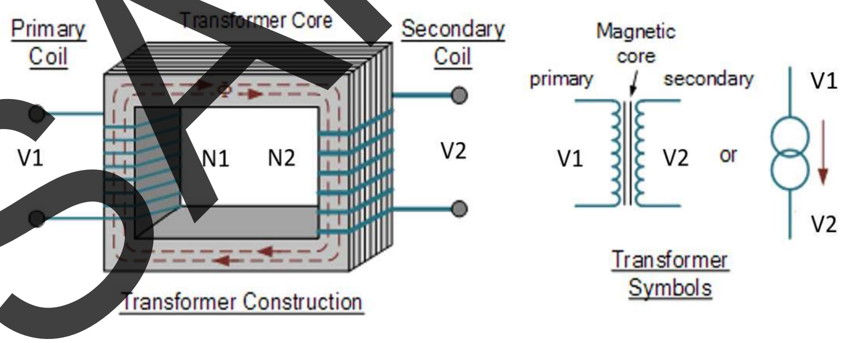
Video

Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

Transformers - Operation & Characteristics.

A transformer is a device which employs the principle of mutual induction to change the values of alternating voltages and currents. The ease with which a transformer can increase or decrease an alternating voltage has led to its longstanding and widespread deployment for AC transmission and distribution of electricity.

The transformer is notably a static device and therefore energy losses are typically low with accompanying high levels of efficiency. Further benefits include rigid construction, stable operation, and long life. Transformers can range in size from the miniature units used in electronic applications to the larger high-cost transformers used in power stations and other large industrial applications.



Basic single-phase transformer construction

The basic construction of a single-phase transformer is shown above and consists of two electrical circuits linked by a common ferromagnetic core. The first circuit is connected to an ac supply and is termed the primary winding or primary coil, the other is known as the secondary winding or coil, which may be connected to a load. The voltages are denoted as V1 and V2 respectively with the associated number of turns for each winding being labelled as N1 and N2. The symbol Φ shown on the ferromagnetic transformer core represents the magnetic flux set up in the core. Typical symbols used to represent the transformer itself are also shown above.

Transformer Principle of operation.

When the secondary coil is not connected to any load and is on open circuit, like that shown above and an alternating voltage V_1 is applied to the primary winding, a small current called the no load current I_o flows. This current sets up an alternating magnetic flux within the core.

This alternating flux links with both primary and secondary coils and induces an emf within each of them of E_1 and E_2 respectively through mutual induction.

For an electrical transformer, the induced emf E in a coil of N turns can be represented by the following formula:

$$E = N\ (d\emptyset)/dt \text{ volts}$$

where $(d\emptyset)/dt$ is the rate of change of magnetic flux.

The concept of the ideal transformer is introduced at this point.

We consider the ideal transformer as that condition where the rate of change of flux as described is the same for both the primary and secondary sections of the transformer and which allows us to write:

$$E1/(N1\ ) = E2/N2$$

which basically means that the induced emf per number of turns is constant.
Assuming no losses then $E_1 = V_1$ and $E_2 = V_2$
from which we can say that:

$$V1/N1 = V2/N2 \quad \text{or} \quad V1/V2 = N1/N2 \qquad (1)$$

The above expressions represent very important parameters in the study and specification of electrical transformers.

V1/ V2 is termed the ***voltage ratio*** and N1/N2 is the ***turns ratio*** or the ***transformation ratio.***

If for example N2 is less than N1, then V2 is less than V1 and the device can be described as a step-down transformer. Conversely, if N2 is greater than N1 then V2 is greater than V1 and we have a step-up transformer.
In the case where a load is connected to the secondary windings of the transformer, a current I_2 flows.

Furthermore, in an ideal transformer, losses are neglected, and the transformer is taken as being 100% efficient such that:

The input power = output power and $V_1 I_1 = V_2 I_2$.

i.e., in an ideal transformer, the **primary and secondary volt-amperes are equal**

and

$$V1/V2 = I2/I1 \qquad (2)$$

Then by combining equations (1) and (2) we get:

$$V1/V2 = N1/N2 = I2/I1 \qquad (3)$$

The rating of a transformer is a very important specification, and it is stated in terms of the volt-amperes that it can transform without overheating. Referring to our earlier diagram, the transformer rating can be expressed as:

$V_1 I_1$ or $V_2 I_2$ where I_2 represents the full load secondary current.

Example:

An ideal transformer has an input of 240 V and supplies a 10 V, 100 W lamp.
Calculate the transformer turns ratio and the current taken from the supply.

Solution:

$V_1 =$ 240 V and $V_2 =$ 10 V, $I_2 = P/V2 =$ 100 /10 = 10 Amps.

The turns ratio = $N1/N2 = V1/V2 =$ 240 / 10 = 24

So, given that:

$$V1/V2 = I2/I1$$

then

$$I_1 = I_2\,(V2/V1) = 10\,(10/240)$$

Hence the current taken from the supply $I_1 =$ 10 / 24 = **0.416 A**

Transformer load conditions.

Here we examine two important conditions that help us to analyse the behaviour of a typical transformer.

Given that we are dealing with phasor quantities, it is wise to represent transformer load conditions using phasor diagrams.

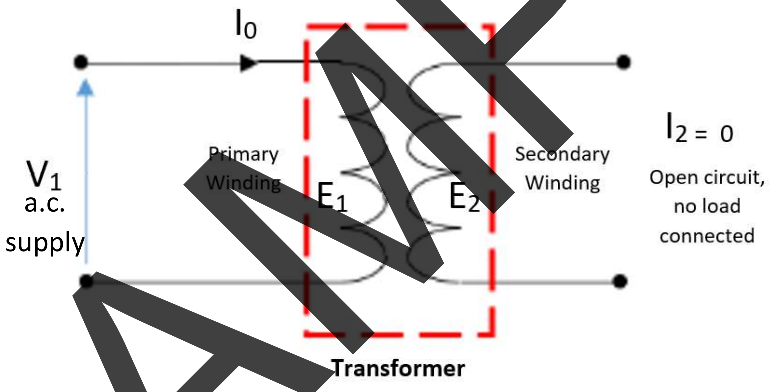
To recap, a phasor diagram in electrical engineering is used to show the phase relationships between two or more sine waves having the same frequency. The length of each phasor is directly related to the amplitude of the wave it represents, and the angle between the phasors is the same as the angle of phase difference between the sine waves.

The two conditions we will look at here are the transformer **no load** and **load conditions.**

Transformer no-load phasor diagram.

The no load phasor diagram helps us to determine the losses in the transformer core which equate to the no load current.

Given that the output side of the transformer is open circuited then for an actual transformer there will be no output power and so the input power only consists of transformer core losses and copper losses.



The core losses relate to the losses that occur in the magnetic core due to the transformer's magnetic field, and are the sum of the hysteresis and eddy current losses.

Copper loss is a resistive loss and relates to the I^2R losses and is due to the resistance encountered by the internal windings of the transformer.

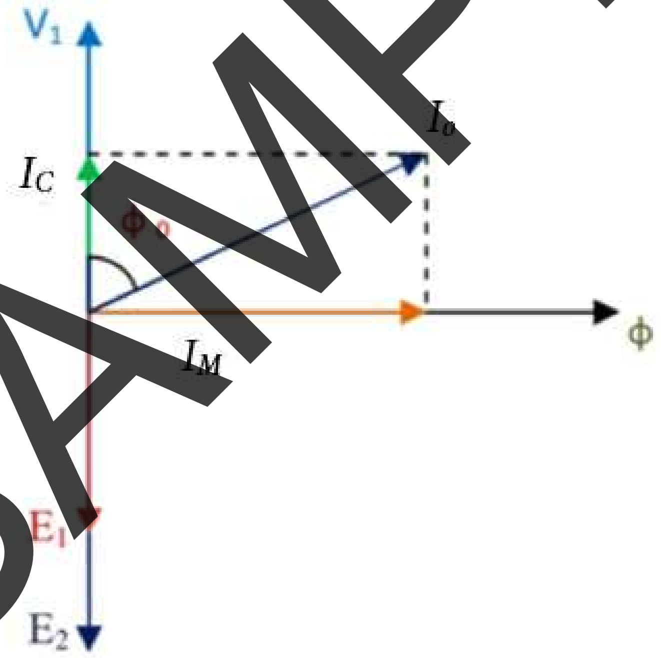
The magnetic flux Φ within the transformer core is common to both the primary and secondary windings Due to this commonality, we can take this as the **reference phasor** (i.e., the x axis) on the phasor diagram. For the no load condition, the primary winding draws a small no load current I_o.
Neglecting losses, the primary winding acts as a pure inductor and as such the primary winding behaves as a pure inductor and lags the applied voltage V_1 by 90°. **E_2** is the secondary induced e.m.f.

When the transformer windings have zero impedance, then the induced voltage within the main winding **E₁** is equivalent **to** the applied voltage V_1. But Lenz's law states that the main winding **E₁** is equivalent & acts in reverse to the primary voltage V_1.

If we assume in the case of an ideal transformer no losses; then the no load current I_o produces the magnetic flux and would be drawn in phase with the flux. However, for a practical transformer, losses will occur, and note that I_o will consist of **two** components:

I. A magnetising current I_M in phase with the flux Φ**.** It produces flux in the core and does not consume any power.
II. The core loss component I_C is in phase with the applied voltage V_1 which accounts for the iron losses and a small amount of primary copper losses (ref. hysteresis and eddy current losses).

The no load phasor diagram for a practical transformer can therefore be represented as follows:



From the above phasor diagram and using simple trigonometry,

the no load current $I_o = \sqrt{(I^2_M + I^2_C)}$ and so

$$I_M = I_o \sin \Phi_o$$