Pearson BTEC Level 4 Higher Nationals in Engineering (RQF)

Unit 21: Electrical Machines

Unit Workbook 1

in a series of 3 for this unit

Learning Outcome 1

Transformers

Contents

INTRODUCTION

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

Transformer Principles

A ***transformer*** can transfer energy by means of electromagnetic induction. A typical transformer will have a primary winding and a secondary winding, both around a common iron core, as shown in figure 1.

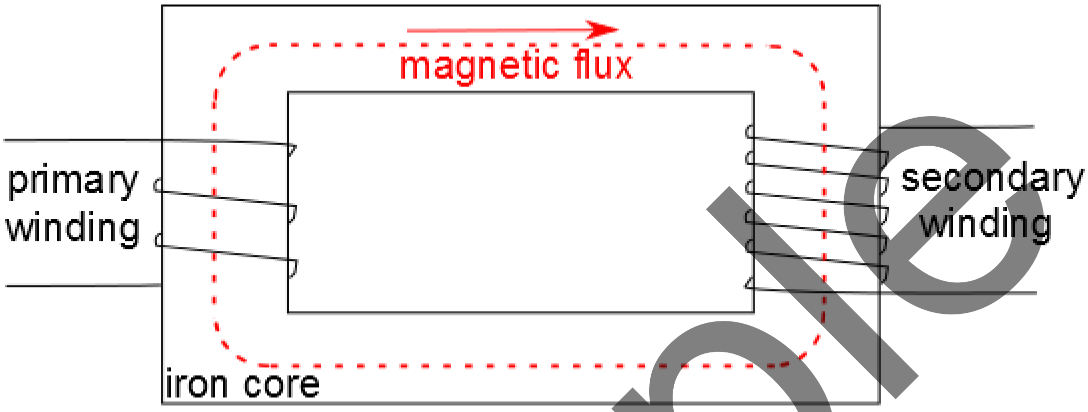

Figure 1 *Basic transformer principle*

When an AC current is applied to the primary winding this generates magnetic flux within the iron core, which links and cuts the windings on the secondary. This concept of magnetic flux linkage produces a voltage on the secondary.

Video 1 **This short video introduces you to basic transformer principles**

Video 2 ***Check out types of transformer windings in this short video***

A simplified equivalent circuit for a transformer is shown in figure 2.

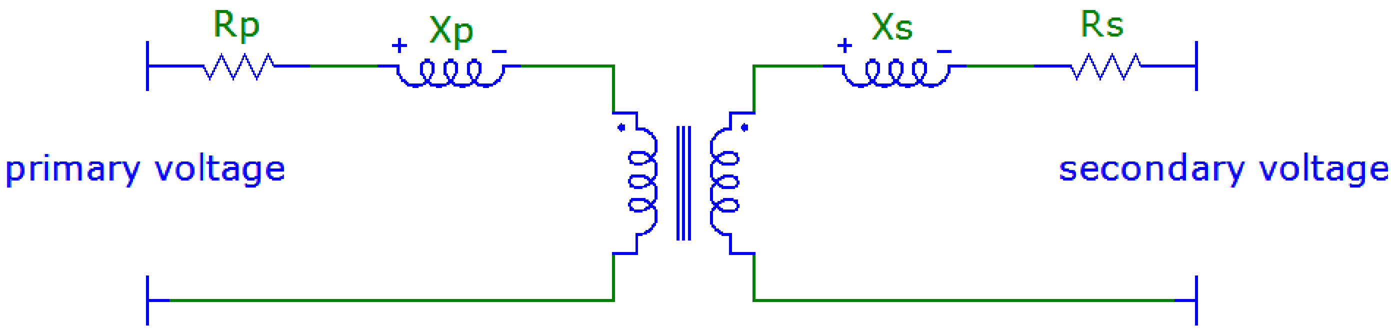

Figure 2 *Basic transformer equivalent circuit*

Here the resistance and reactance of the primary and secondary windings are accounted for.

Transformer Theory

The key equations for transformers derive from the *ideal case*. In an ideal transformer there will be no losses due to resistance of wires or heat or any flux leakage. In that case we have a fairly simple situation to analyse. We can then say that the power in equals the power out…

$$Primary\ Power,\ V_p I_p = Secondary\ Power,\ P_s I_s$$

$$\therefore \quad V_p I_p = V_s I_s$$

Another obvious fact is that the more windings which we place on the secondary then the more flux will link with these secondary windings. This then means that the turns ratio N_s/N_p is equal to the ratio of the secondary to primary voltages V_s/V_p. So, we may now also write…

$$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$

Combining these last two expressions we may now write a very useful expression for ideal transformers…

$$\boldsymbol{\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}}$$

Let's take a look at some worked examples on transformers…

Worked Example 1

A current transformer has two turns on the primary and three hundred turns on the secondary. The resistance of the secondary winding is 0.1Ω and this winding is connected to an ammeter with a resistance of 0.15Ω. If the primary current is 100A determine the reading on the ammeter.

The important equation we need here is…

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

We can transpose this equation to find an expression for secondary current…

$$I_s = I_p \times \frac{N_p}{N_s} = 100 \times \frac{2}{300} = 667\ mA$$

The information about secondary resistance and the ammeter resistance does not affect the secondary current. However, if we were to add these two quantities together (0.1 + 0.15 = 0.25) we would have the total secondary resistance and would therefore just use Ohm's Law to determine the secondary voltage. The secondary voltage would then be $V_s = i_s R_s = 0.667 \times 0.25 = 167\ mV$.

These results are confirmed with the following MicroCap simulation…

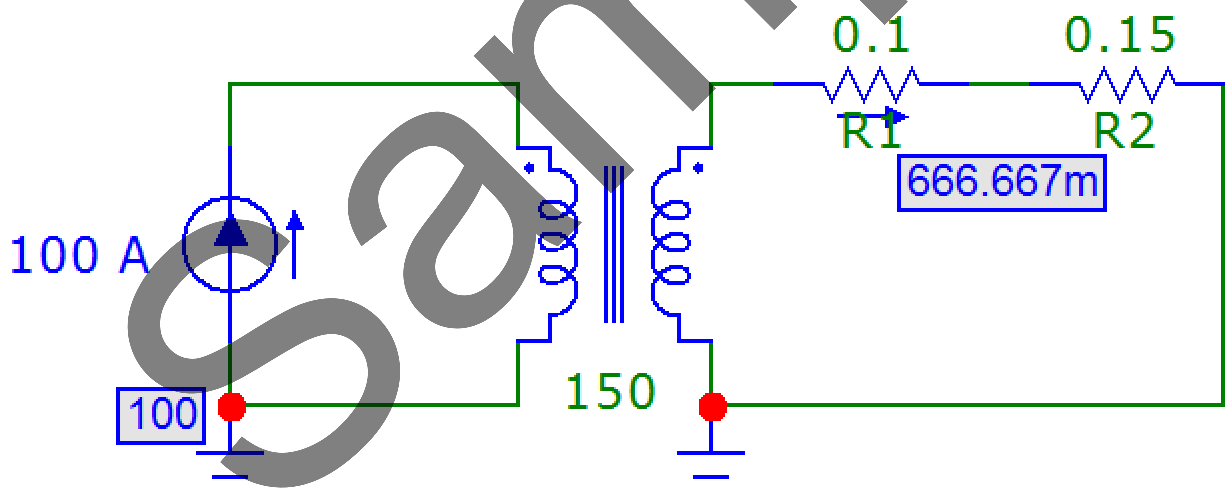

Figure 3 *Simulation for worked example 1*

Worked Example 2

An audio amplifier output stage has an equivalent output resistance of 648Ω. It is desired to match this output stage to a loudspeaker of resistance 8Ω. Calculate the optimum turns ratio of the transformer.

Let's start our analysis here with the basic ideal transformer expression…

$$\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$$

From this we can write…

$$\frac{N_s}{N_p} = \frac{V_s}{V_p} \quad \therefore \quad V_p = V_s \times \frac{N_p}{N_s}$$

… and also…

$$\frac{N_s}{N_p} = \frac{I_p}{I_s} \quad \therefore \quad I_p = I_s \times \frac{N_s}{N_p}$$

We may now combine these expressions to give…

$$R_p = \frac{V_p}{I_p} = \frac{V_s \times \frac{N_p}{N_s}}{I_s \times \frac{N_s}{N_p}} = \frac{V_s}{I_s} \times \frac{{N_p}^2}{{N_s}^2} = R_s\left(\frac{{N_p}^2}{{N_s}^2}\right)$$

So our key expression is…

$$\boldsymbol{\frac{R_p}{R_s} = \frac{{N_p}^2}{{N_s}^2}}$$

The optimum turns ratio of the transformer is the one whereby we match the output resistance of the amplifier to the resistance of the loudspeaker. Since there is no direct electrical connection between the amplifier output and the loudspeaker it is the job of the designer to find the optimum turns ratio of the transformer. Let's put the numbers in…

$$\boldsymbol{\frac{R_p}{R_s} = \frac{{N_p}^2}{{N_s}^2} = \frac{648}{8} = 81}$$

So, we need…

$$\frac{{N_p}^2}{{N_s}^2} = 81 \quad \therefore \quad \frac{N_p}{N_s} = 9$$

We have our answer. The optimal transformer to match the amplifier to the loudspeaker in this example has nine times the number of turns on the primary as it does on the secondary (i.e. a turns ratio of 9:1). These results are confirmed in the MicroCap simulation below…

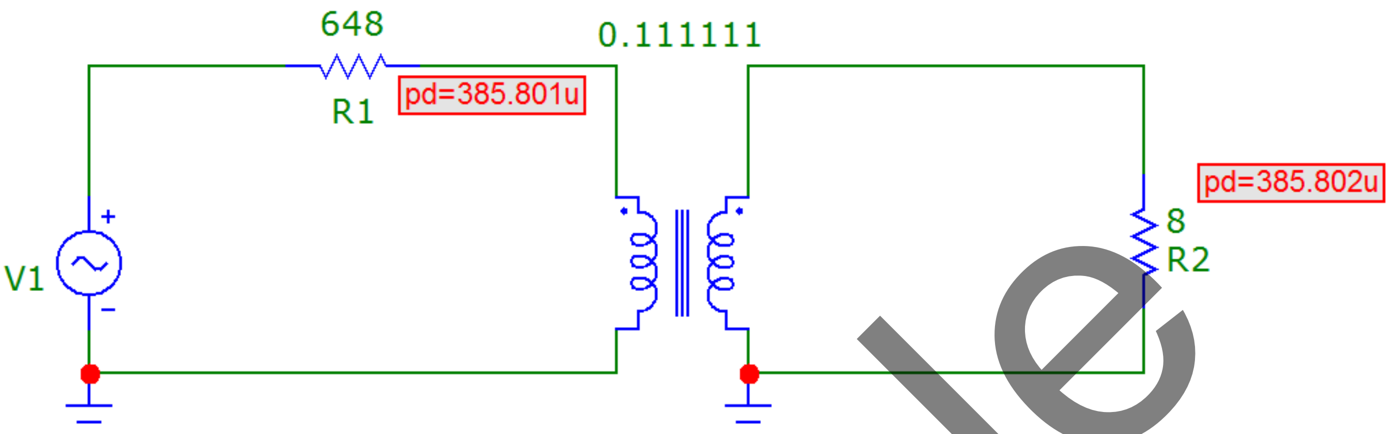

Figure 3 *Simulation for worked example 2*

Here, R1 represents the amplifier and R2 the speaker. Notice that since we have matched the amplifier and speaker with an optimal turns ratio transformer then we are invoking the maximum power transfer theorem (see workbook 1). This means that maximum power from the amplifier is developed in the 8 Ohm load. The simulation clearly shows that 385µW is developed in the amplifier and the load. The figure in green represents a turns ratio of 1:9, which is 0.111111. Try the simulation yourself, but ensure that you use an ***ideal*** transformer.

Worked Example 3

A transformer is rated 200kVA at full load. At full load the copper loss is 1.2kW and the iron loss is 1.8kW. Determine the full load efficiency of the transformer, given that the power factor is 0.75.

The ***Efficiency*** (η) of a transformer is given by;

$$\eta = \frac{output\ power}{input\ power} = \frac{input\ power - losses}{input\ power} = 1 - \frac{losses}{input\ power}$$