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.

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…

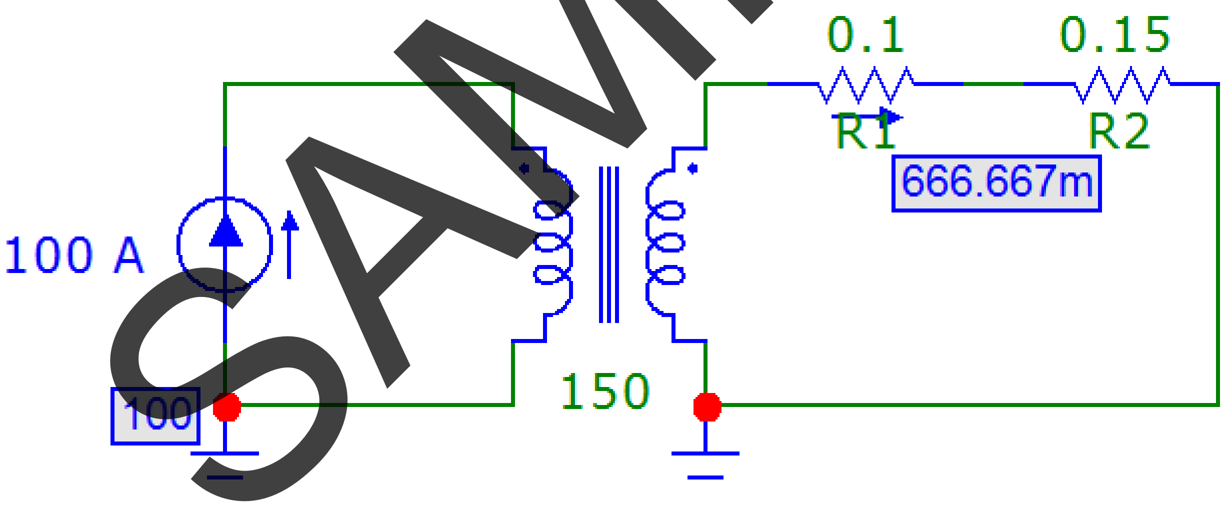

Figure 3 *Simulation for worked example 1*

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…

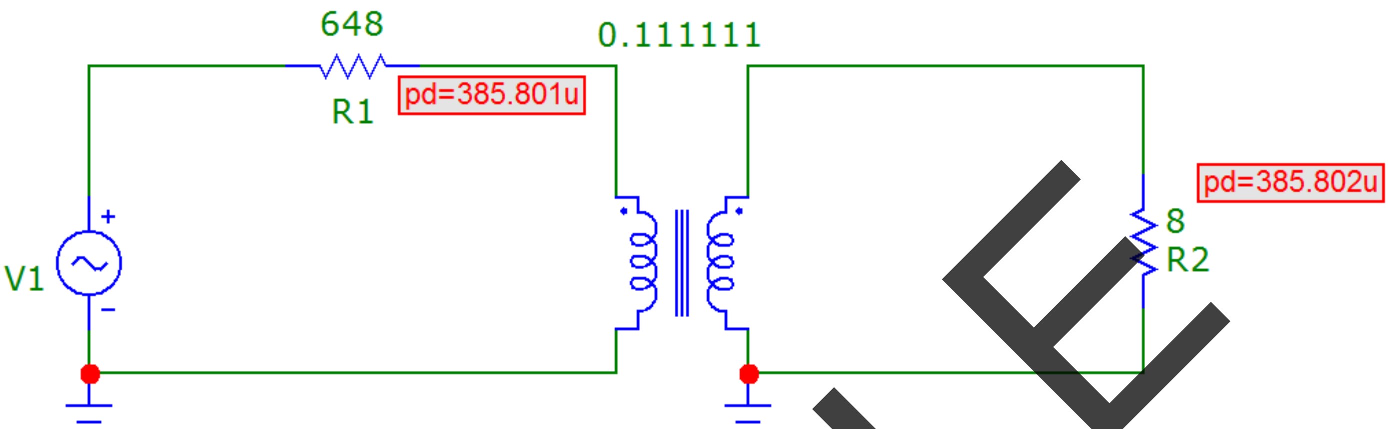

Figure 3 *Simulation for worked example 2*

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;

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

Transformer constructional features

Construction

There are several ways to construct a transformer, some are depicted in subsequent sections of this text. However, the basic principle behind a transformer is that we present a voltage to a metallic winding (basically, a coil, called the 'Primary') and expect to find a higher (step-up), lower (step-down), or the same (isolation) voltage at another metallic winding, known as the Secondary winding (or just 'Secondary').

When an AC voltage is placed across a coil we will see a current flow through it. This fluctuating current causes both an electric field, and a magnetic field, to emanate from the coil, whose combination we call an 'electromagnetic' field. This electromagnetic field will naturally disperse (radiate) in all directions, not equally, but especially through the windings of the coil. If a second coil connected in a closed circuit to a bulb, perhaps, is brought quite close to the first coil then we might see the bulb light up a little.

However, it was discovered by early scientific greats that most of the electromagnetic energy from the first (Primary) coil is not being picked up by the second coil (Secondary). They eventually realised that the bulb could be lit brighter if the gap between the primary and secondary was replaced with iron, rather than the original air gap – hooray, the birth of the transformer. Incidentally, it is called a transformer because it will transform one voltage (on the Primary) to another voltage (on the Secondary).

Iron is a great material to use to link the Primary and Secondary. Then it was realised; why put the iron between the coils, when we can wrap both the coils around and iron rod? Further experiments revealed that it was better to use an iron loop, or ring, resulting in even more energy transferred from the primary to secondary. The electromagnetic energy which flows around the ring is known as 'flux'. The more flux that links with individual windings the more voltage we have. The initial experiments continued, and finally it was realised that if the secondary had more turns (windings) than the primary then the secondary voltage would be higher than the primary voltage – and vice-versa. This is the basic principle behind every transformer ever made.

A transformer is a clever discovery/idea, or perhaps a clever idea/discovery, who knows which way round, but the principle of conservation of energy for any system dictates that if you put some energy into it you will get less out; some examples…

- A coal-fired power station produces (output) far less energy than it burns (input)
- A bulb produces far less light (output) than the electricity (input) given to it.
- You pedal hard on a bike (input), but friction and wind resistance slow your progress (output)
- If you had a perfect laptop it would never get hot

And so, transformers are not perfect, but we can make them 90+ % perfect with clever construction. It is all about collecting all of that flux we spoke about and allowing it to flow around the core.

Some transformers use alternative materials, other than iron, for the core. Perhaps you can investigate these?

Step-down means apply a voltage on the primary, depending on the number of turns you give the coil, and expect a lower voltage on the secondary, obviously with less turns on that secondary. Less turns on the coil equals less voltage.

Isolating Transformers

These are useful, used to isolate a circuit from the potential high energy of a previous circuit, voltage or current. Such transformers can be used to isolate a human operator from a dangerous 'live' supply. An isolation transformer will present the same primary voltage to the secondary but will limit the secondary current for safety reasons. Be aware that 10mA is enough to kill a human being.

Shell Type Transformers

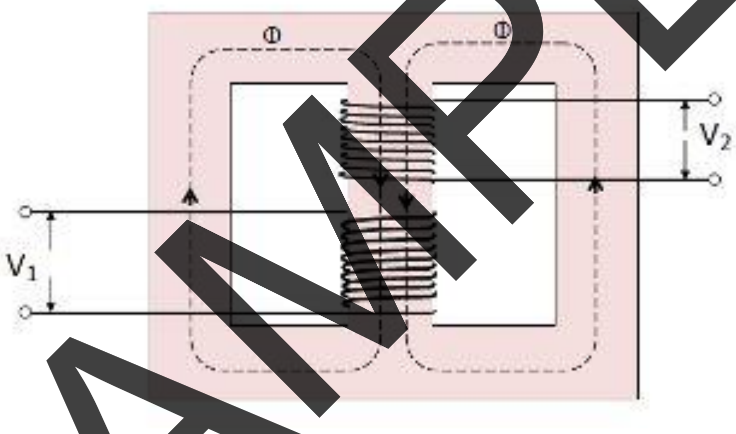

Figure 4 *Shell type transformer*

As can be seen in figure 4, a shell type transformer has both the primary and secondary windings on the central section of a 'figure of eight' topology. Here are some aspects of the shell type transformer…

- Excellent high-voltage performance
- Good short circuit recovery characteristics
- High mechanical strength
- Dielectric strength
- Good control of flux leakage

The transformer is constructed from laminated steel sheets (see figure 5) which are insulated from each other, usually with paper or resin. The laminations are necessary to prevent minimise circulating currents inside the core which can cause overheating. Such circulating currents are known as 'eddy currents'.

Windings

Transformer windings can be made from copper or aluminium. Aluminium is lighter and less expensive than copper and so is used in large power transformers. However, since aluminium conducts less well than copper, more aluminium cross-sectional area is needed to carry the same current as with copper.

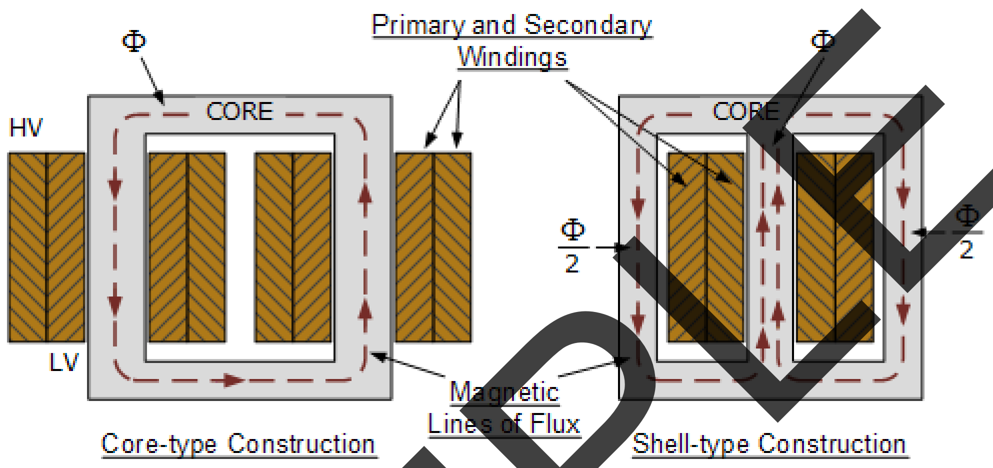

Figure 7 *Transformer windings on cores*

In the core type transformer, half of a winding is wrapped around each limb of the core, thereby increasing flux linkage and the efficiency of the transformer.

For the shell type of transformer, the windings are both on the central limb, which reduces flux loss when compared to the core type.

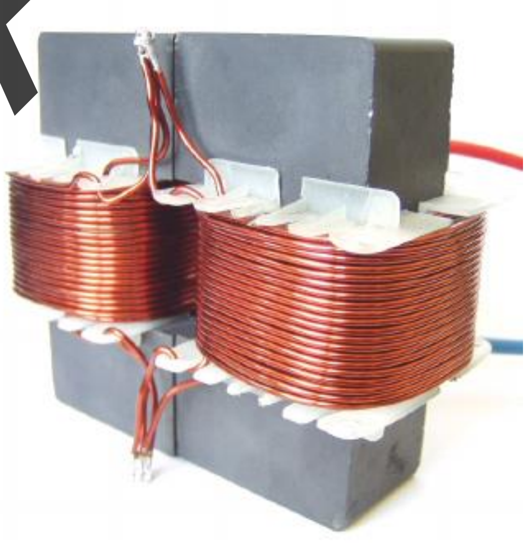

Figure 8 *Core type transformer windings*

A transformer secondary way also have multiple connections, as shown in figure 11.

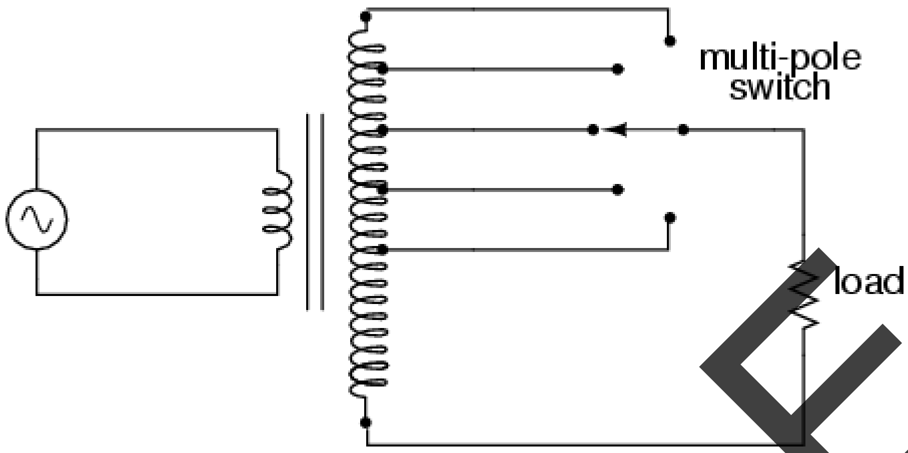

Figure 11 T*ransformer with multiple secondary connections*

It is also occasionally useful to construct a transformer which has just one winding. Such an arrangement is shown in figure 12, known as a step-up 'autotransformer'.

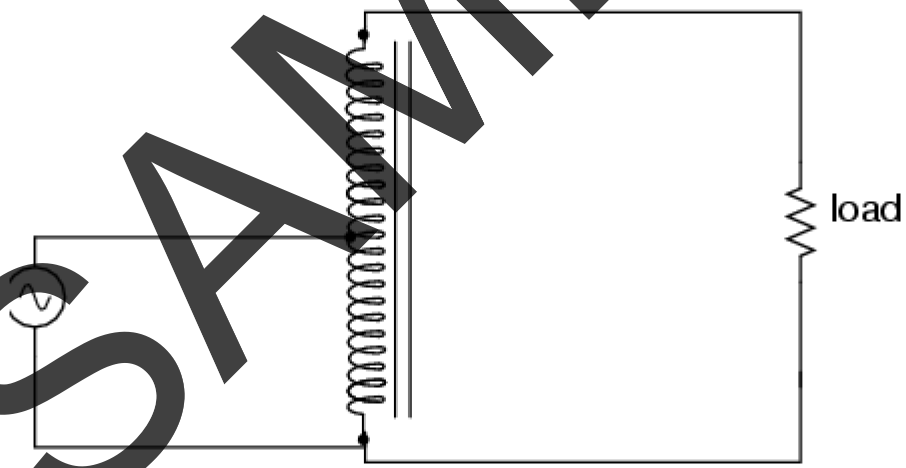

Figure 12 *A step-up autotransformer*