Pearson BTEC Level 5 Higher Nationals in Engineering (RQF)

Unit 63: Industrial Services

Unit Workbook 1

in a series of 4 for this unit

Learning Outcome 1

Electrical Power and Lighting

CONTENTS

INTRODUCTION

Apply the operating principles of electrical power and lighting Systems

Electrical power:

Construction, starting and speed control of polyphase induction motors.

Three-phase transformers: construction, clock number and group, parallel operation.

Electrical distribution: power system topologies, efficiency, power factor causes and correction, effect on cost of supplies, circuit protection.

Lighting systems:

Lighting fundamentals: SI units, energy efficient circuit design and layout.

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.

ELECTRICAL POWER

Polyphase Induction Motors

Essentials

The induction motor's presence is very much taken for granted. It drives such things as; electric pumps, industrial fans, compressors, conveyor belts, cranes and many other devices. Many of these devices are run at constant speed but, add some clever power electronics, and we have control of very large *variable* speed devices.

The torque (turning force, rotational strength) of an induction motor is produced by the interaction of alternating electromagnetic fields. The term 'induction' motor comes from the fact that the motor 'induces' its power from such electromagnetic fields. One major attraction of the induction motor is the fact that it does not need 'sliding' mechanical or electrical contacts, thus avoiding much of the maintenance that DC motors require.

The old saying is true: if it moves or gets hot, suspect it as the cause of the problem. Perhaps you have had, or still have, a PC/laptop with a hard drive (rotating disk containing masses of data, read by a mechanical arm)? Sometimes it can take such a computer to boot-up and stabilise maybe 10 minutes or more. A solid-state drive (SSD) on the other hand, can boot up in a few seconds. Why? – no moving parts, data is contained in silicon rather than a delicate high-speed moving disk. A chin lasts longer than a knee, a transistor last longer than a valve, a probe orbiting the earth will last longer than one orbiting the Sun, jackets last longer than socks, gums last longer than teeth, and, finally, women tend to last longer than men. Basically, friction causes wear, and so does heat. We want certain motors to be highly reliable, and hence reduce the amount of hot and moving parts within them.

An induction motor is supplied with AC current, and there can be multiple phases of AC, but usually just three. Due to the absence of many moving parts, the induction motor tends to be much cheaper and reliable than its DC counterpart.

Operation

So, how does an induction motor actually operate? Well, essentially, it needs a ***rotating*** magnetic field. Let's take a look at a typical induction motor in Figure 1. The rotor is always trying to keep up with the rotating magnetic field (generated by the stator) but is continuously dragged along behind it (a bit like a cyclist trying to gain an advantage by pedalling close behind a bus).

The stator is key, because it generates the 'flux' (the driving force, if you like). You know all about magnetic flux from your earlier studies on transformers. More recently perhaps, you have charged your phone wirelessly, taking advantage of such flux. Since things that rotate tend to be circular (the rotor), the stator surrounds this circular rotor, hence it provides a *radial* pattern of magnetic flux to it (a bit like viewing how your bike tyres see, and drive, the centre of the wheel, via the spokes). Of course, we have an air gap between the stator and rotor (stator is stationery, rotor rotates). The stator's job is to produce electromagnetic fields, and because these fields are close to the circular rotor, we have interaction.

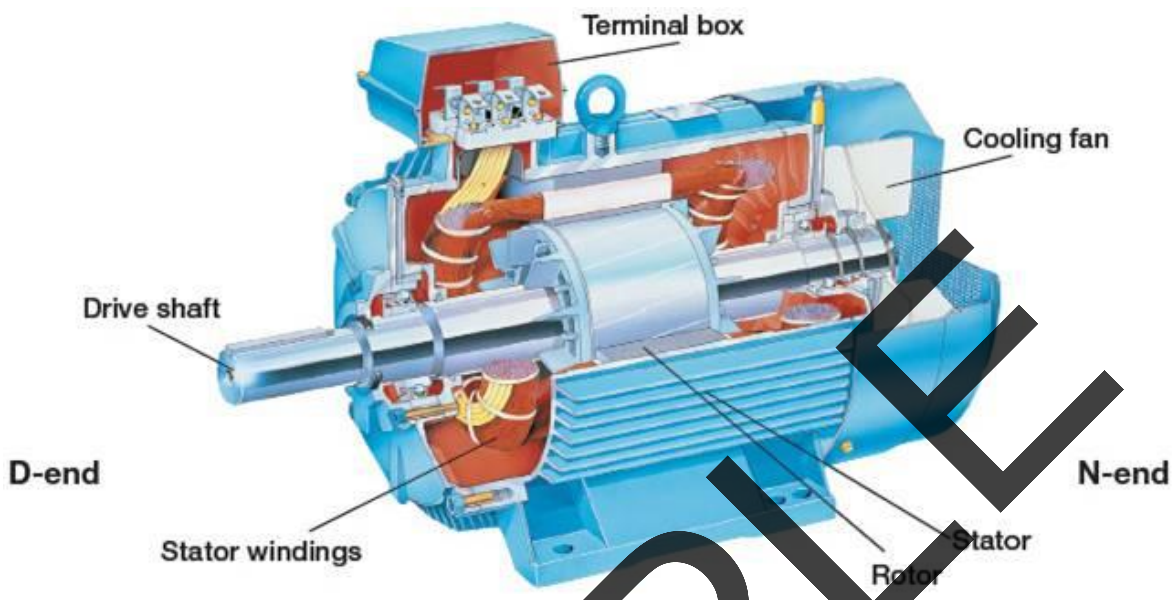

Figure 1: *A typical induction motor*

The interaction of electromagnetic fields with coils of wire is the primary thought we need to consider with induction motors. A good analogy is; you have your bike upside-down and are testing a wheel. You spin the wheel with your hand, and it rotates. However, the wheel will never spin faster than your hand moved. The speed of the wheel always lags behind the speed of your hand (friction prevents this). Another analogy; you know that if you put the accelerator pedal down by one inch in your sports car on a dry road it will go 100 mph, but you try it on a wet road one day, and it takes quite a bit longer to achieve that speed. In this scenario you are the stator and the movement of the car is the rotor (some slippage is involved).

The key to providing more torque, more power, is to provide more current to the stator coils, thus providing flux and power to the rotor windings, via the invisible magnetic fields. Remember, flux is the magic ingredient which provided invisible power from the stator to the rotor.

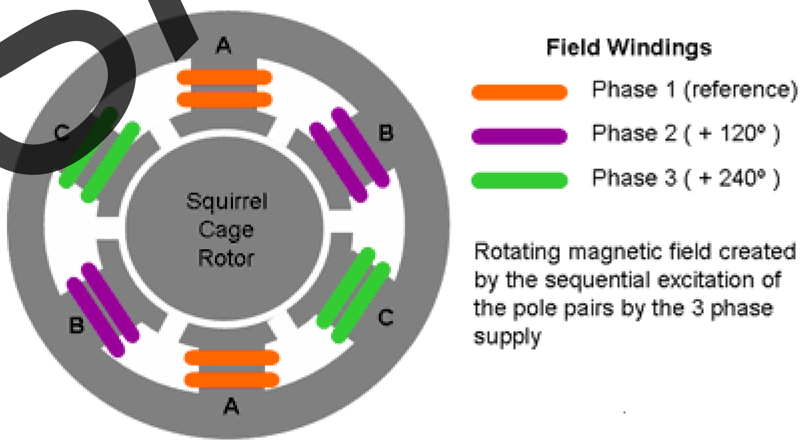

Figure 2: *Stator windings and squirrel cage rotor*

Vector Group

Both primary and secondary windings may be arranged in either a star (wye) or delta (mesh) configuration, as shown in figure 8.

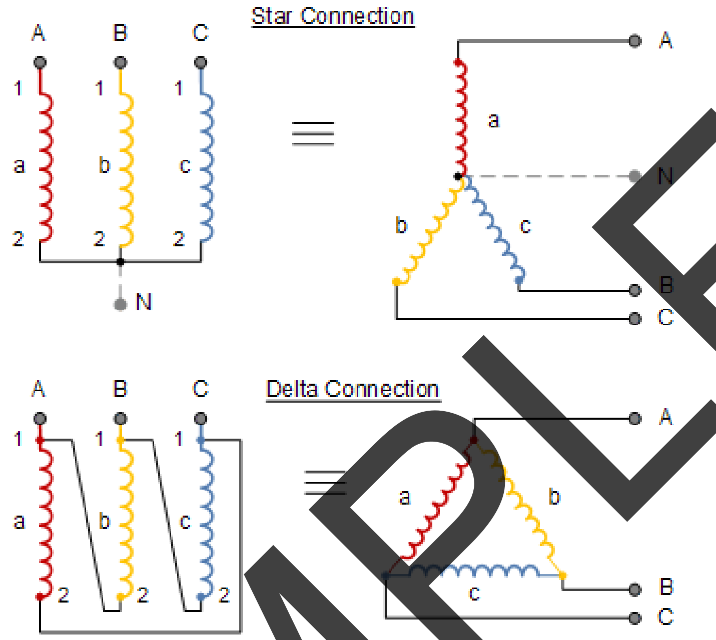

Figure 8: *Transformer star and delta connections*

The four main permutations of primary and secondary winding arrangements are shown in Figure 9.

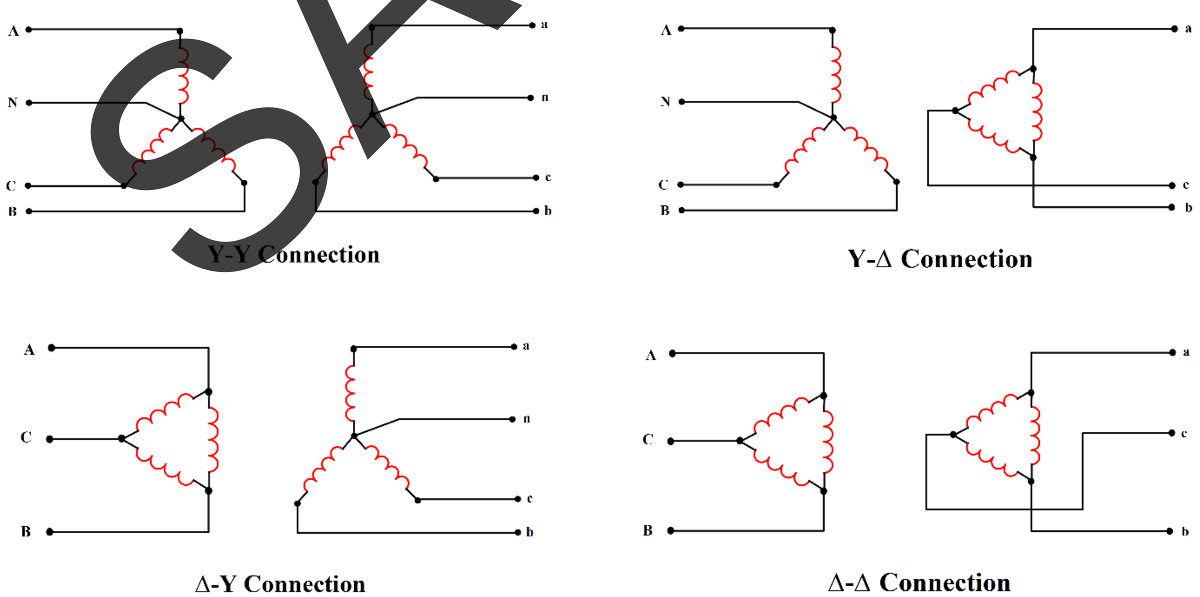

Figure 9: *The four main primary-secondary arrangements*

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The vector group indicates how the transformer connections are arranged and is indicated by a code of two or three letters followed by a 'clock number' (see below). Vector groups are denoted as follows;

- **D or d**
  - Capital D for primary delta, lowercase d for secondary delta
- **Y or y**
  - Capital Y for primary wye (star), lowercase y for secondary wye
- **Z or z**
  - Zig-zag winding (also known as interconnected star)
- **III or iii**
  - Independent windings which need to be connected externally
- **N or n**
  - System neutral is connected to the high voltage side (N) or the low voltage side (n)

The vector group will always start with a capital letter.

Clock number

Using the high voltage winding as a reference, the low voltage winding may be in phase, lagging by 30 degrees, leading by 30 degrees or 180 degrees out of step. A clock analogy is commonly used to indicate the phase shift between primary and secondary, as per Figure 10.

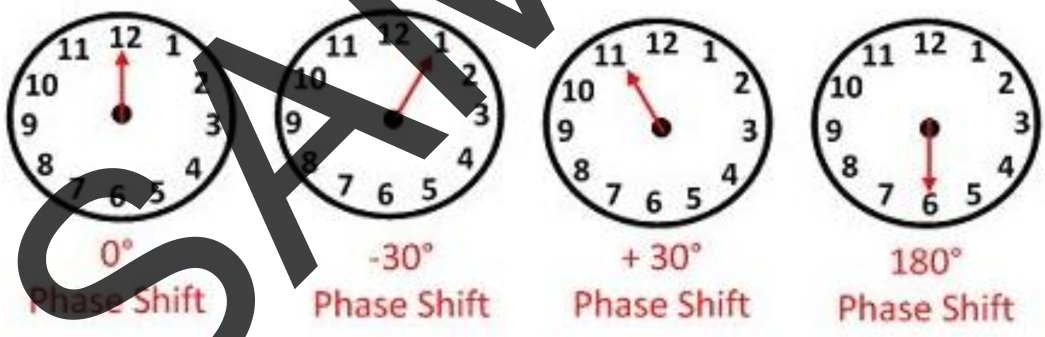


Figure 10: *Phase shift between primary and secondary represented by clock hour hand*

Numbers are given to the phase shift, as follows;

0 No phase shift (same as 12 o'clock)

1 30 degrees lag

6 180 degrees shift (antiphase)

11 30 degrees lead

Figure 11 shows a typical information plate on a large transformer. The relevant information, ringed in red for this particular example plate, indicates **Dyn11**, which translates as …

D Primary configured as Delta (Mesh)

Y Secondary configured as Wye (Star)

n System neutral is connected to the low voltage side

11 Phase leads by 30 degrees

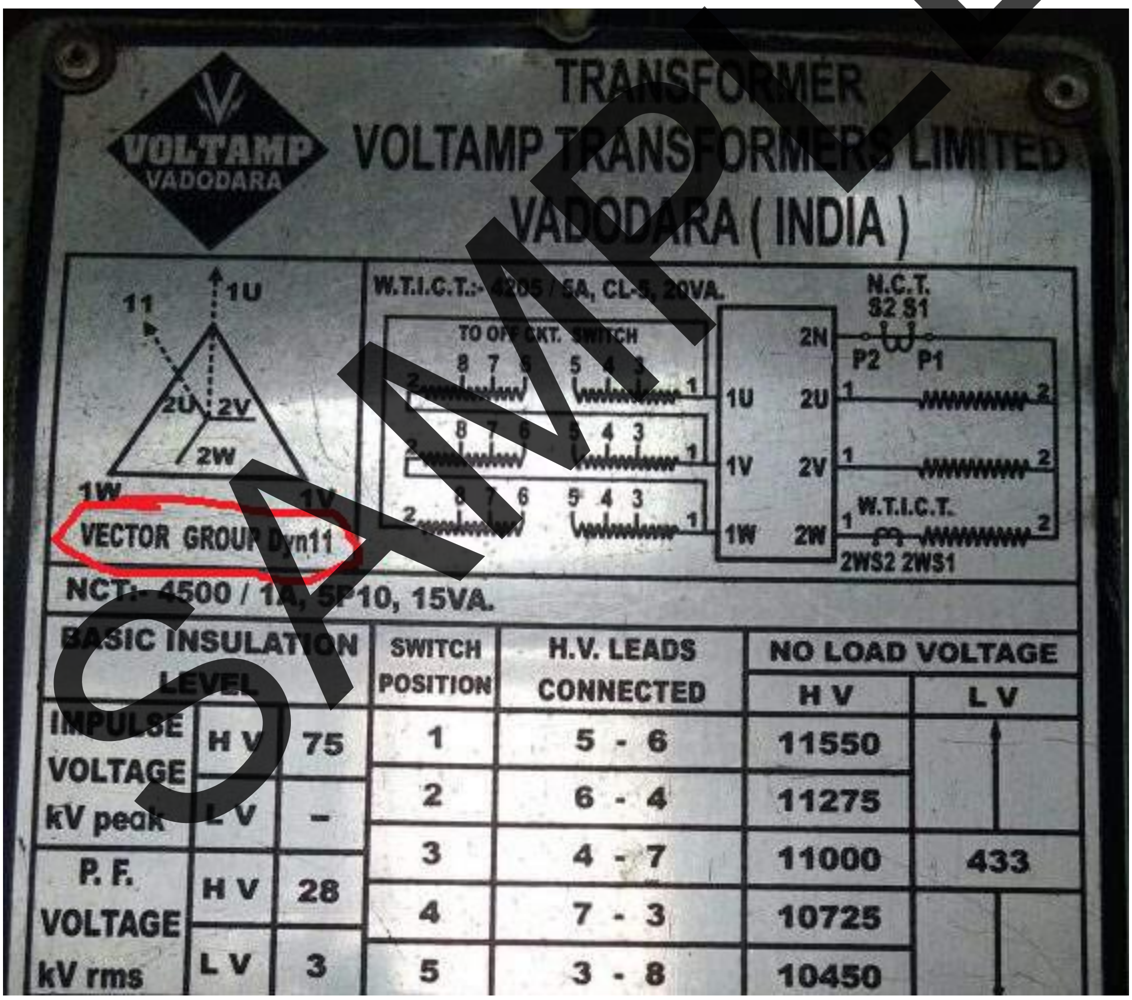


Figure 11: *An example information plate on a three-phase transformer*

Electrical Circuit Symbols

There are hundreds of official IEC (International Electrotechnical Commission) electrical symbols. Here we will highlight a number of symbols used for various types of transformer.

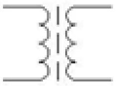
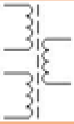
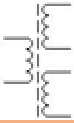
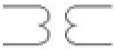
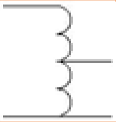
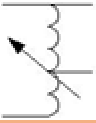
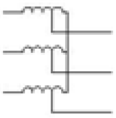
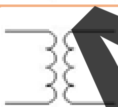
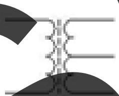
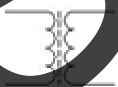
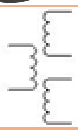
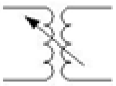
SYMBOL	DESCRIPTION
	Transformer
	Transformer Dual
	Transformer Dual (flipped)
	Potential Transformer
	Single phase auto
	1 Phase Autotransformer
	3 Phase Autotransformer Star Connected
	Power Transformer 1 with 2 Windings
	Power Transformer 2 with 2 Windings
	Power Transformer with 2 Windings and Screen
	Power Transformer with 3 Windings
	Adjustable Power Transformer with 2 Windings

Table 1 *IEC symbols for a transformer*

Electrical Layout Diagrams

An example of the inclusion of a transformer in an electrical layout diagram is shown in figure 22.

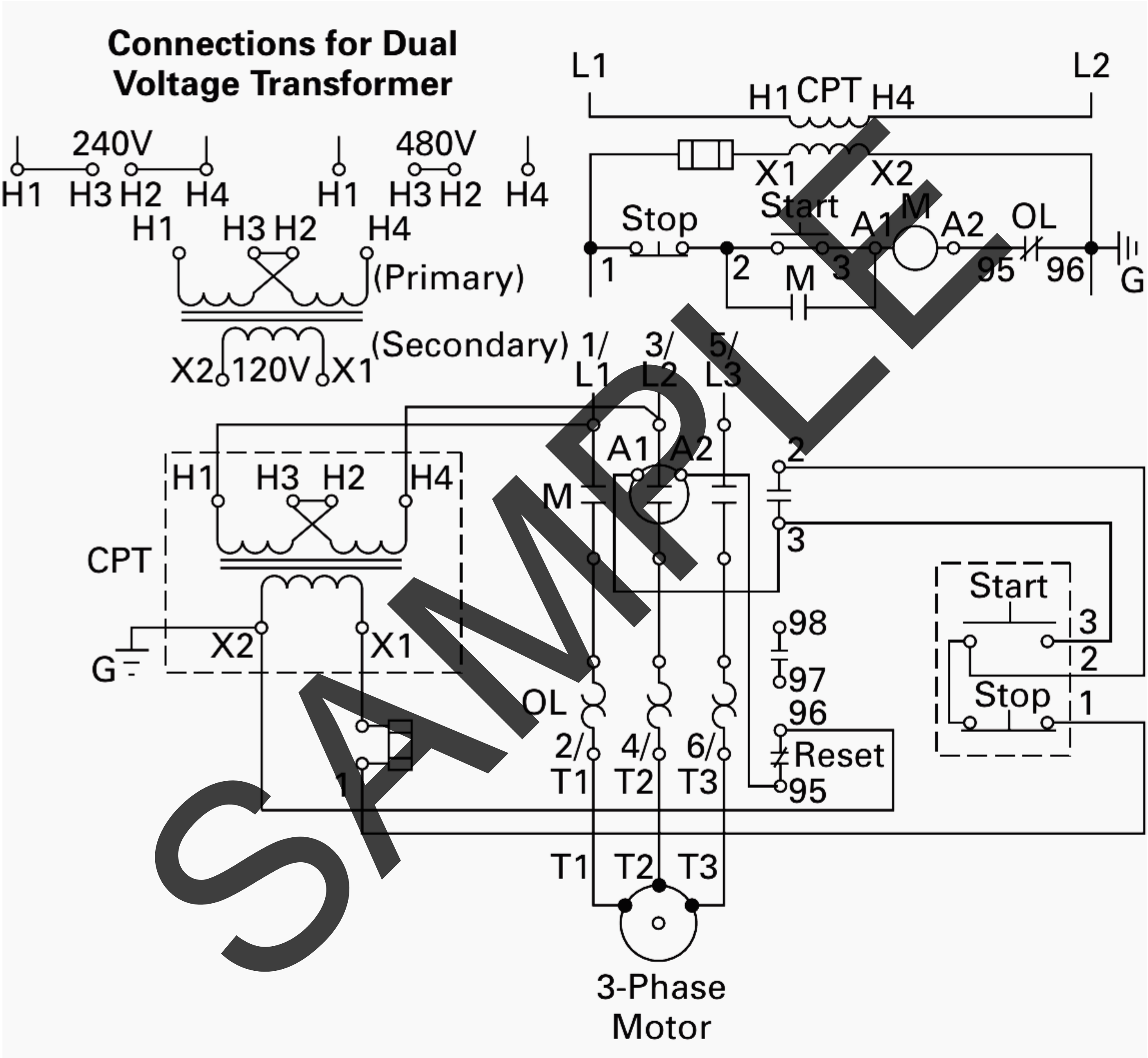


Figure 22 *A wiring diagram which includes a transformer symbol*

Fault finding techniques and test equipment

Input/Output

This technique involves applying a suitable input voltage and testing the output, discovering a fault, then systematically measuring again by working back stage-by-stage towards the input until the faulty stage, cable or component is identified.

Half Split

This method involves considering the whole distribution system as a series of blocks. A block could be considered to be either a transformer, cable, connector, fuse, sub-station, MCB etc. It is then required to test at the midway point of the blocks (roughly halfway through the system. If the measurement is healthy then the fault lies to the right of the system, so the blocks to the right are then tested at their midway point, etc. until the faulty block is identified.

Meters

A clamp meter is used to measure the current flowing in a cable. A typical clamp meter is shown in figure 23.

Figure 23 *A clamp meter used for measuring current in a cable*

An analogue test meter will display current, voltage or resistance on an analogue display, as shown in figure 24.

Sodium

These work by exciting metallic sodium vapour and mercury under high pressure. Since these devices operate at high temperatures (around 1300°C), the arc tube cannot be manufactured from glass, but is instead commonly made from aluminium oxide. Sodium lamps can have efficacies of around 150 lm/W and emit an orange-white light which appears yellow on most surfaces which it illuminates. A high-pressure sodium lamp is shown in figure 30.

Figure 30 *A 400 W high pressure sodium lamp*

Fluorescent Lighting

Fluorescent lamps emit light by producing ultraviolet energy which interacts with a phosphor coating on the inside of the glass envelope. A tiny amount of mercury is placed inside the envelope, along with an inert gas. Once the lamp is turned on, the mercury begins to vaporise. This vapour, along with the inert gas, is ionised by electrical current flow through the tube, producing ultraviolet energy, which excites the phosphor coating on the inside of the tube.

A typical fluorescent lamp can have an efficacy of around 75 lm/W. A common type of fluorescent light is shown in figure 31.

Figure 31 *A fluorescent lamp*

Halogen Lighting

Halogen lamps, commonly referred to as tungsten-halogen lamps, are manufactured with a tungsten filament surrounded by a quartz envelope. The envelope is filled with either iodine or bromine, which allow the tungsten filament to be operated at high temperature, thus improving its efficacy up to around 15 lm/W. Chemical reactions ensure that evaporated particles of tungsten are re-deposited back onto the filament's surface. A tungsten-halogen lamp is shown in figure 32.

Figure 32 *A tungsten-halogen lamp*

LED Lighting

LED lights can have efficacies of around 200 lm/W and are becoming increasingly popular, especially since they can have a lifetime of around ten times that of an incandescent lamp. Another advantage of these lights is that they do not require any warm-up time.

LEDs work on the principle of a semiconductor p-n junction being forward-biased by an applied voltage. The resulting current causes photons to be emitted by the LED, hence light is radiated.

It is common to see an array of LEDs in a single LED lamp, depending upon the application. Also, LEDs work on direct current (DC), rather than alternating current (AC) as used in other types of lighting. For this reason, many LED lamps contain circuitry to convert an AC supply to a suitable DC source. Such circuitry may contain a transformer, rectifier and smoothing capacitors. A typical LED lamp is shown in figure 33.