Pearson BTEC Levels 4 Higher Nationals in Engineering (RQF)

Unit 31: Electrical Systems and Fault Finding

Unit Workbook 1

in a series of 4 for this unit

Learning Outcome 1

Electrical Distribution Systems

INTRODUCTION

LO1: Investigate the constructional features and applications of electrical distribution systems

Operating principles:

Three-phase, single-phase distribution methods and connections

Earthing system connections

Transformer constructional features:

Construction, application, characteristics of transformers such as step up/down, isolating, shell and core, windings, connections, efficiency

Electrical circuit symbols and layout diagrams

Fault finding techniques and test equipment:

Input/output, half split

Meters, insulation testers

Typical faults found

Operating principles

Three-phase distribution methods and connections

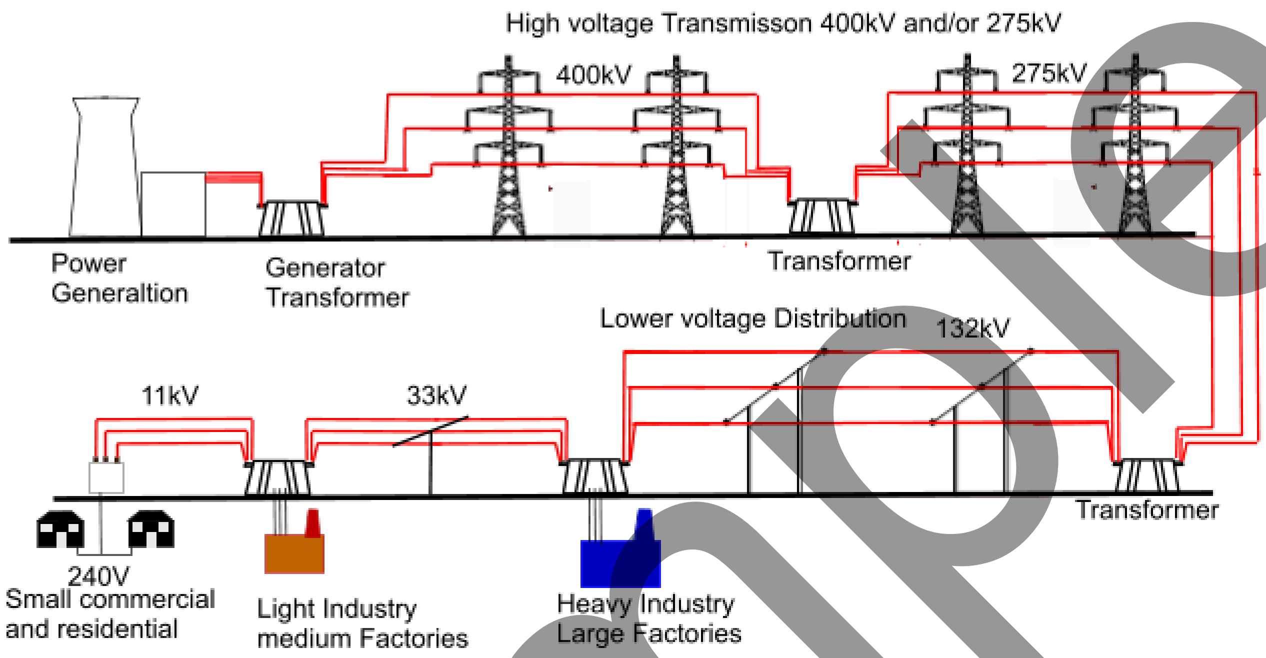

Figure 1 *UK electrical power distribution from source to consumer*

The source of electrical supply is, mainly, at a large power station. The common fuels used can be coal, nuclear, gas or oil. Other sources of supply are renewable in nature; bio-mass, hydro-electric, tidal, wind or solar.

At the power station, the fuel generates energy which turns turbines. These turbines generate 33kV of electricity. The voltage from each turbine is presented to switches, and a transformer. The switches are commonly oil filled (cooling) cylindrical tanks, one tank for each of the three phases. Each tank has an input and an output, and the switch is immersed in the oil beneath. The output from the switch is presented to a step-up transformer, also oil cooled, which transforms the input voltage on its primary to 400kV (sometimes 275kV) at its secondary winding, as per figure 1.

The three 400kV phases are then carried on cables suspended from large pylons. These cables tend to have a steel core surrounded by aluminium and are suspended from the pylon arms by large insulators. Further on, we see more localised distribution, where the 400kV is presented to a step-down transformer which produces 132kV. This 132kV is either presented to heavy industrial factories, or stepped down further, via another transformer, to 33kV. This 33kV is presented to light industrial factories or stepped down further to 11kV. The 11kV can be presented to light commercial industry, or to local sub-stations. The sub-stations convert the 11kV, via a transformer, to 230/240 volts between each phase and neutral (assuming a star/wye arrangement for the three phases (see figure 2 and figure 3).

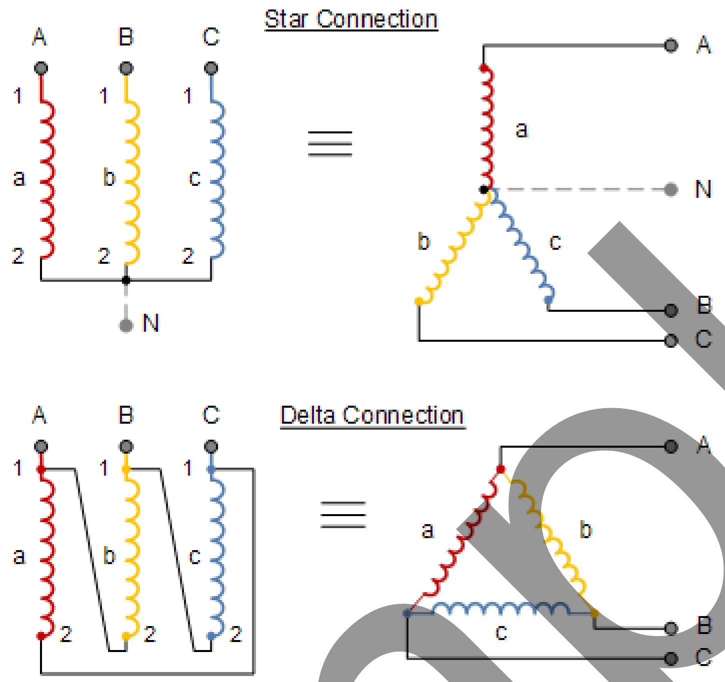

Figure 2 *Star and Delta connections for a three-phase system*

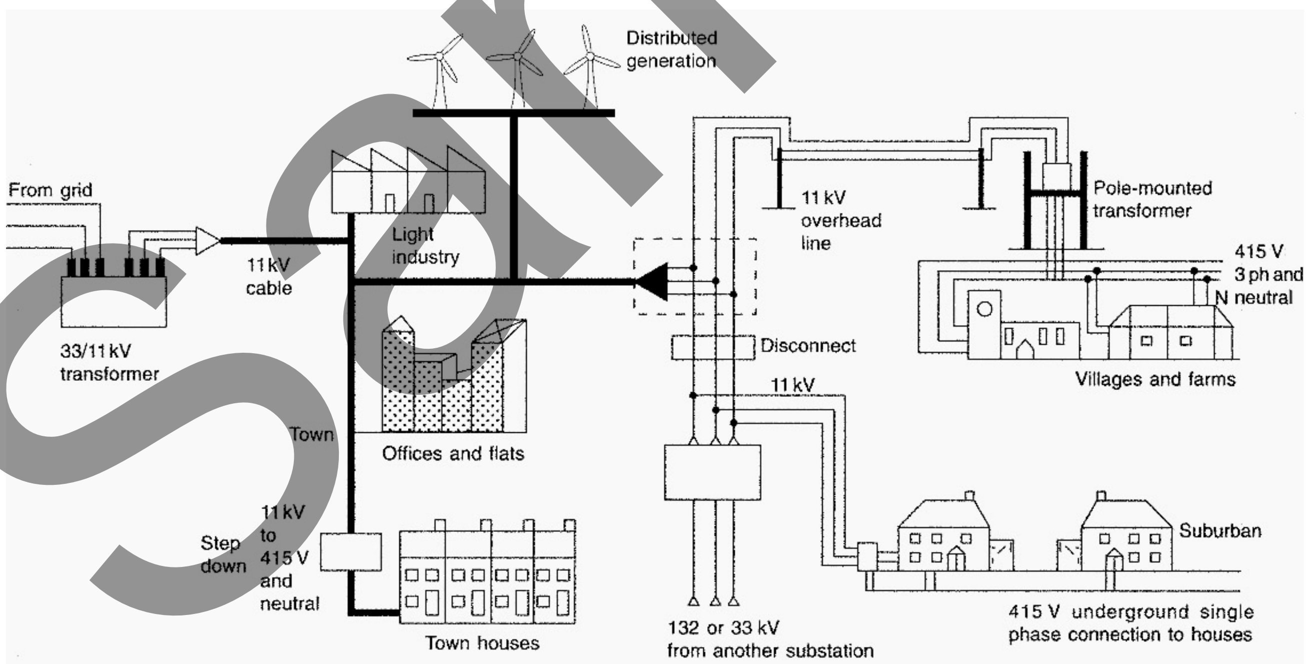

Figure 3 *A closer view of the localised end of the electricity distribution network*

An example of a three-phase transformer is shown in figure 4.

Figure 4 *A three-phase transformer*

Single-phase distribution methods and connections

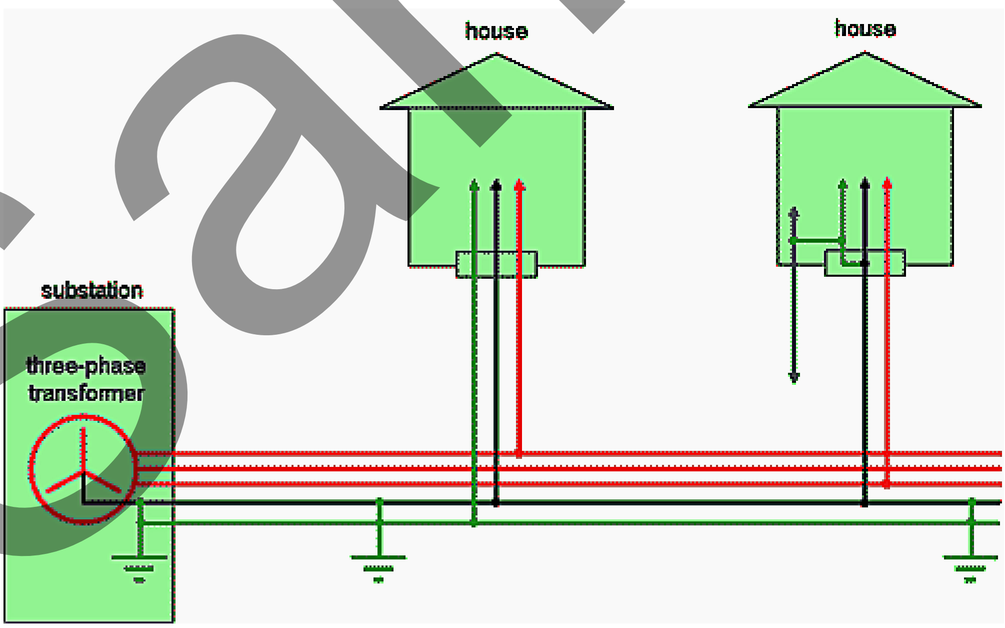

Figure 5 *Distribution of alternate phases to residential dwellings*

A residential dwelling normally has its electrical distribution arrangement in the form a Ring Circuit, as shown in figure 6.

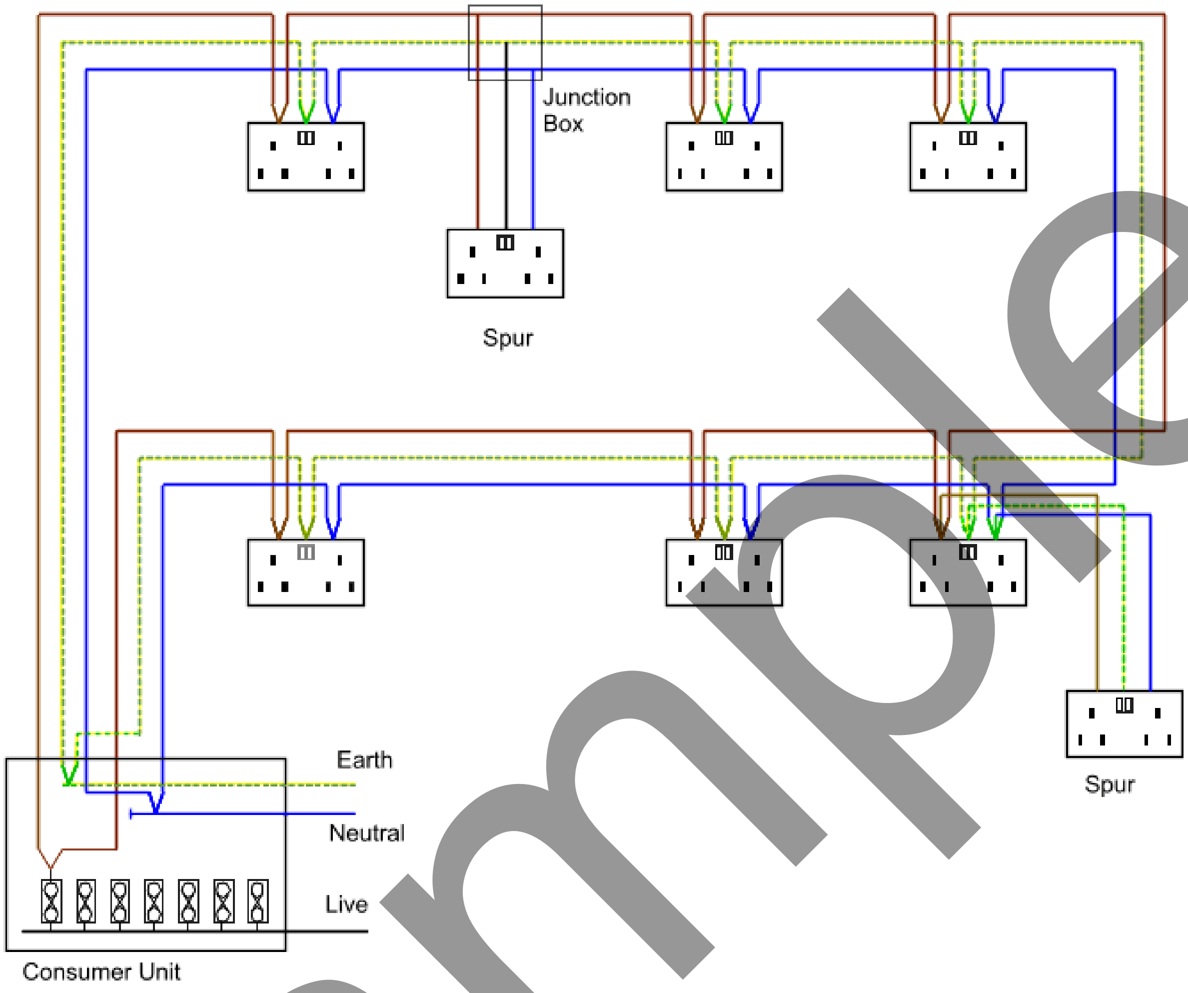

Figure 6 *A residential ring circuit*

The consumer unit (MCB) is protected by a 32A fuse, and the 230V supply is routed around the dwelling as shown.

Earthing system connections

Earthing systems can be classified by three schemes;

- TT System (earthed neutral)
- TN System (exposed conductors connected to neutral)
- IT System (impedance-earthed neutral)

TT System

Here the neutral is connected to earth at its source. All other exposed metallic parts are connected to a separate earth rod, which could possibly be connected to the source neutral. This arrangement is shown in figure 7.

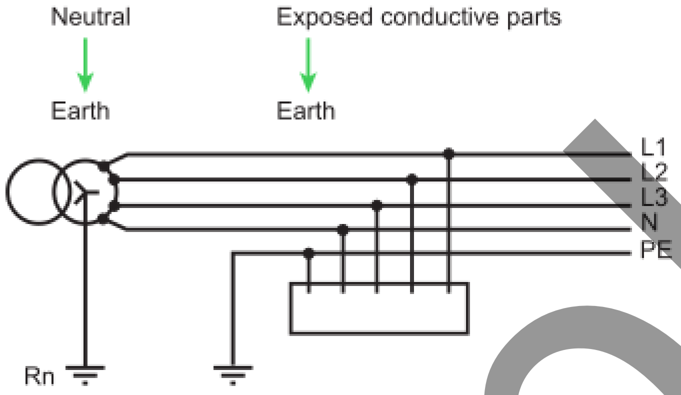

Figure 7 *The TT earthing scheme*

TN-C System

In this arrangement the neutral is used as a protective conductor, known as a PEN (Protective Earth and Neutral). The system is not allowed for portable devices, nor when the conductors have a cross-sectional area of less than 10mm^2. An equipotential environment is necessary here, so the system needs regularly distributed earth electrodes. The arrangement is shown in figure 8.

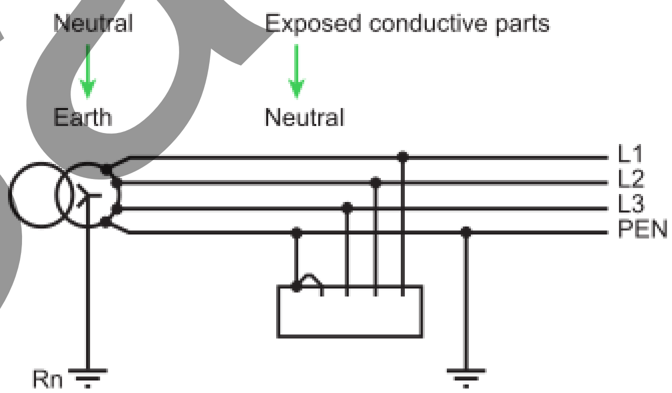

Figure 8 *The TN-C earthing scheme*

TN-S System

For portable equipment, and systems with wires less than 10mm^2 in cross sectional area, this system is ***mandatory***. The protective conductor and neutral are separated, with five wires used in the scheme, as shown in figure 9.

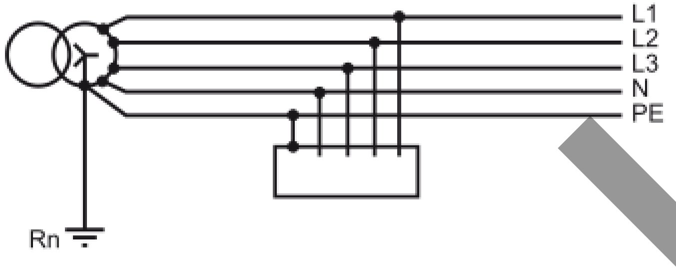

Figure 9 *The TN-S earthing scheme*

TN-C-S System

This system can be used in conjunction with the TN-S system, hence the name, within the same installation. However, it is ***vital*** that the TN-C scheme is not used downstream of the TN-S system, as per figure 10.

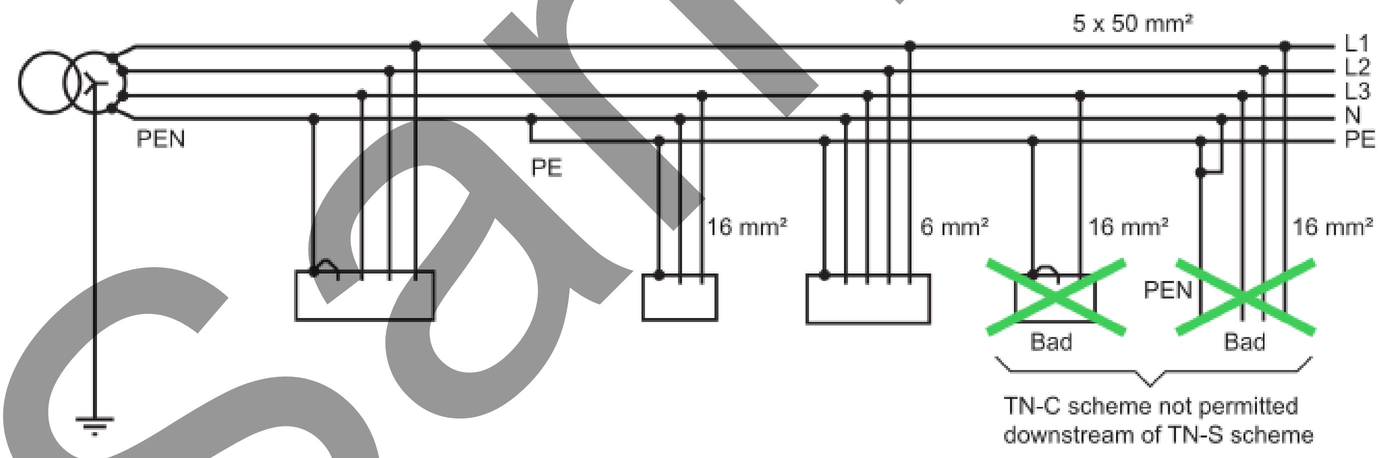

Figure 10 *The TN-C-S earthing scheme*

IT System

This scheme dictates that no connection is made between the source neutral and earth (see figure 11). Conductive parts which are exposed are connected to an earth electrode. Since, in practice, ALL conductors have a finite leakage impedance to earth, plus a capacitive reactance path to earth, the combination of these two leakages must be considered (see figure 12).

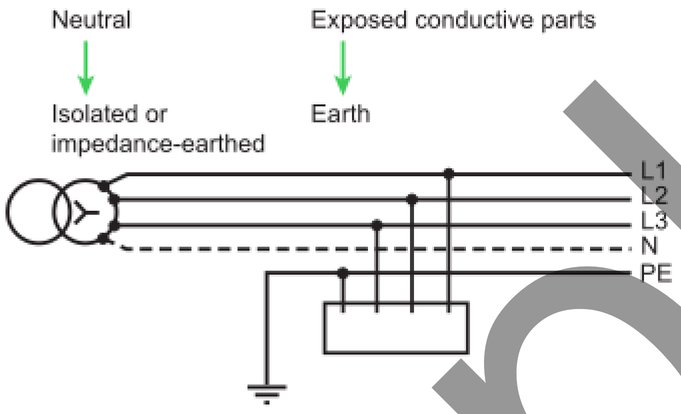

Figure 11 *The IT earthing scheme*

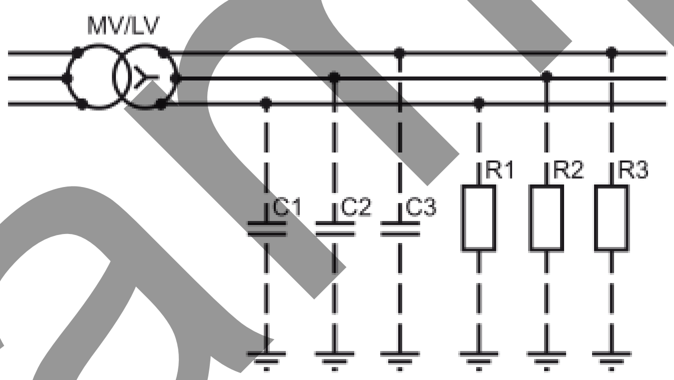

Figure 12 *The IT scheme leakage impedance*

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?

Also, if we had perfect transformers, why then do those big electricity companies cool them in oil? Because they cannot be perfect, of course, and therefore produce a lot of heat. Heat is the enemy of a transformer and can destroy it. Everything produces heat, even thoughts, which brings us on nicely to burn some cerebral energy in considering some applications of transformers.

Applications

- Power station distribution systems, as we have learned
- TV's
- Radios
- Kitchen white goods
- Gardening tools
- Inverters (converting DC to AC, for example when camping)
- Military equipment and satellites
- Electric cars
- Robotics
- Heavy industry
- Manufacturing
- Computers
- Nanoelectronics (molecular-scale circuits)
- Space travel and colonisation
- Simulation tools, of course: MicroCap and TINA TI are amongst the best used at UniCourse

Step Up Transformers

Well, if you read the section on 'Construction' you will know what these are already. It is so amazing to know basic principles, because you can then apply them in your engineering career – Read it again.

Step-up means apply a voltage on the primary, depending on the number of turns you give the coil, and expect a higher voltage on the secondary, obviously with more turns on that secondary. More turns on the coil equals more voltage.

Step Down Transformers

Well, if you read the section on 'Construction' you will know what these are already. It is so amazing to know basic principles, because you can then apply them in your engineering career – Read it again.

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

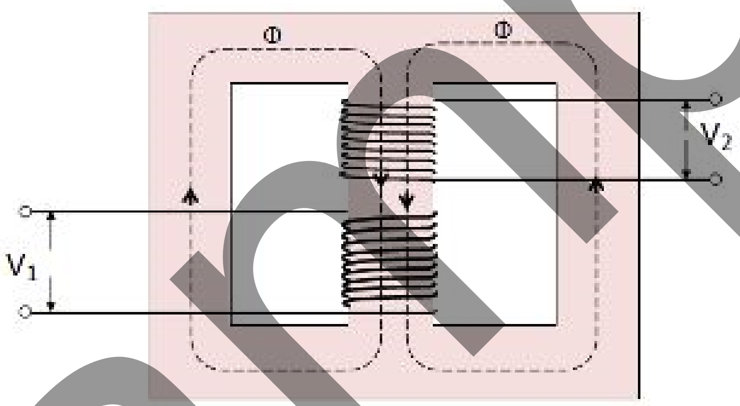

Figure 13 *Shell type transformer*

As can be seen in figure 13, 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 14) 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'.

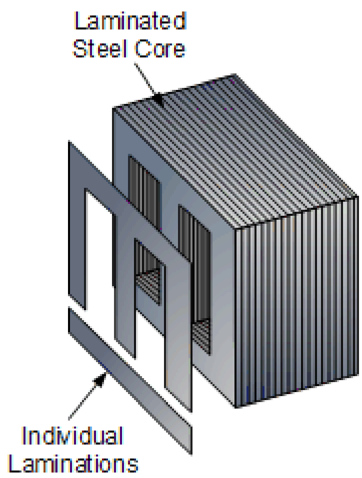

Figure 14 T*ransformer laminations*

Core Type Transformers

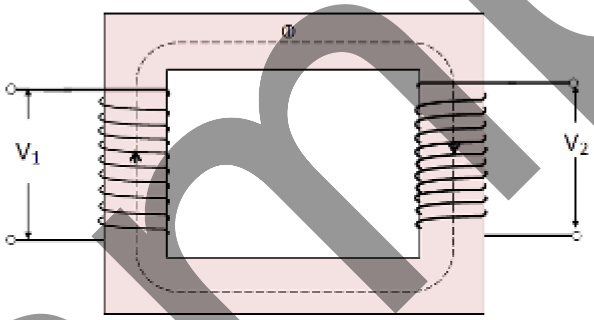

Figure 15 *Core type transformer*

Since this arrangement has a circular type of core (see figure 15) it is simpler and cheaper to manufacture. Again, a laminated structure is adopted to minimise eddy current losses. Here are some aspects of the core type transformer…

- Less mechanical strength than shell type
- Increased separation of windings means more loss of magnetic flux
- More of the surface is exposed to air so this type stays cooler than the shell type
- Used in low voltage applications
- Requires less copper to form the windings than the shell type

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.

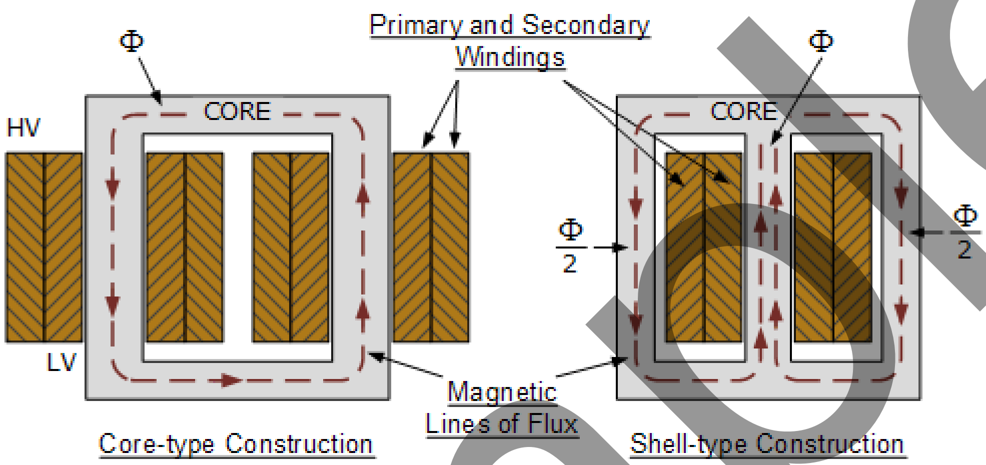

Figure 16 *Transformer windings on cores*

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.

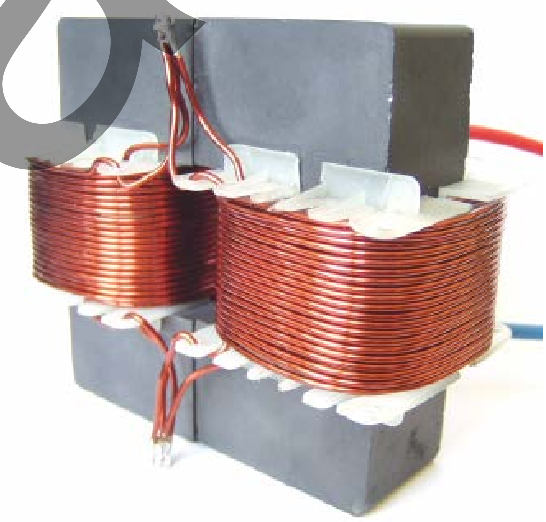

Figure 17 *Core type transformer windings*

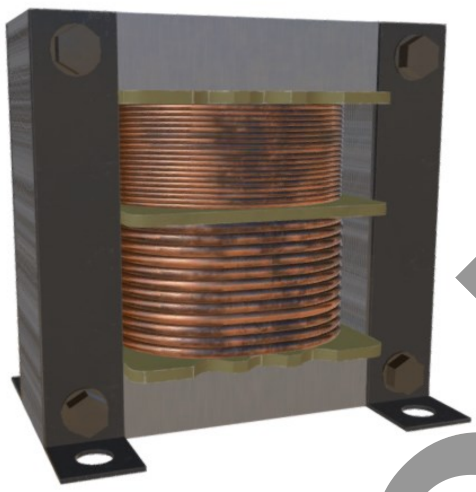

Figure 18 *Shell type transformer windings*

Connections

Transformers may be configured and connected in many ways. Figure 19 shows a transformer with two primaries and three secondaries. Primaries may be connected or one left unused; the same applies to the secondaries.

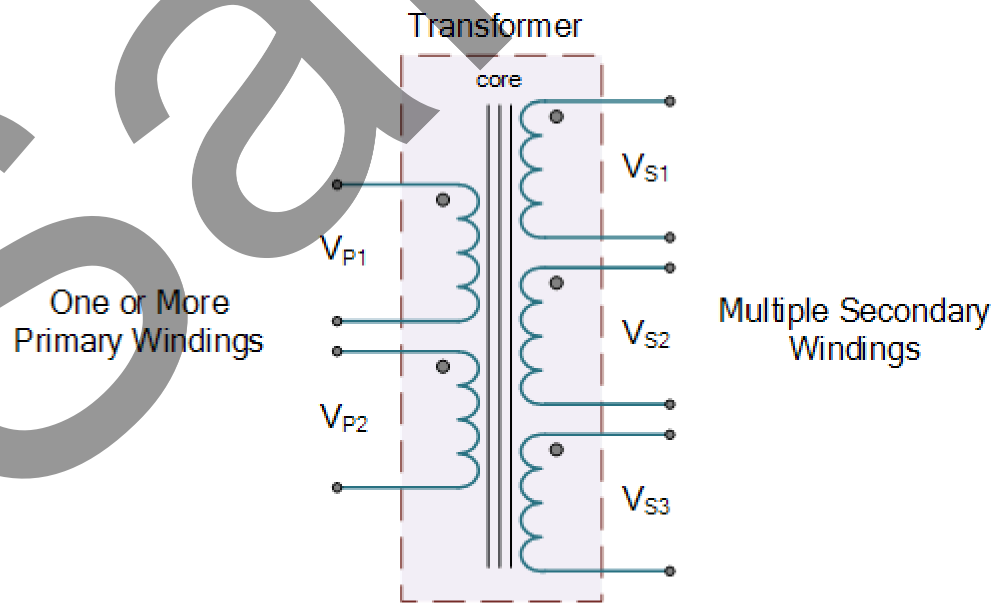

Figure 19 *Transformer with multiple windings*

A transformer secondary way also have multiple connections, as shown in figure 20.

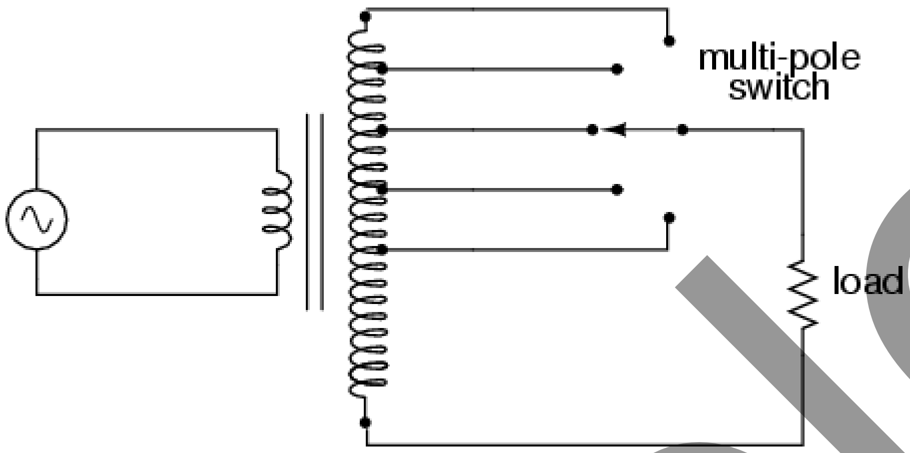

Figure 20 T*ransformer with multiple secondary connections*

It is also occasionally useful to construct a transformer which has just one winding. Such an arrangement is shown in figure 21, known as a step-up 'autotransformer'.

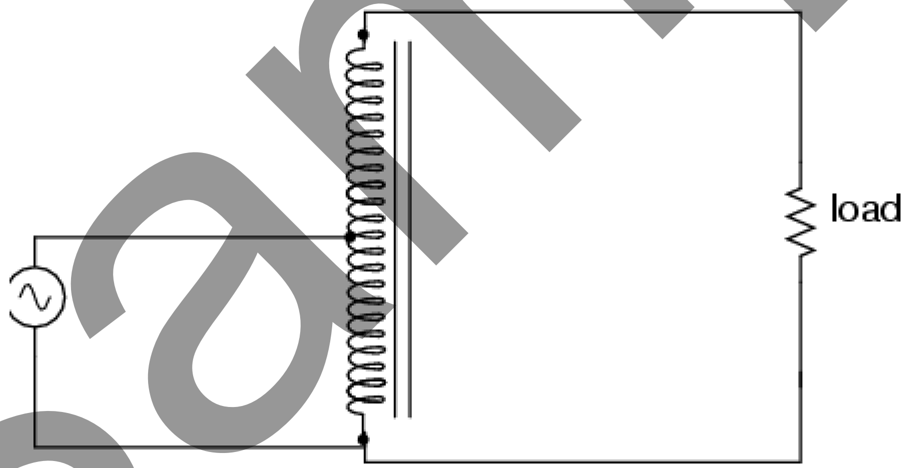

Figure 21 *A step-up autotransformer*

Transformer Efficiency

An ideal transformer will have no losses, and therefore be 100% efficient. In practice, this is not possible. Losses arise due to;

- Energy dissipated in the resistance of the windings, known as 'load losses' or 'winding losses'
- Magnetic core losses (primarily eddy currents)

Large power transformers can achieve an efficiency in excess of 99%. Small transformers, perhaps used to power a television or computer, may have efficiencies less than 85%.

Winding losses increase with the square of the current flowing ($p = I^2R$ remember). When the load is light on the transformer it is the magnetic losses which dominate. However, once the load becomes heavier, the current increases and the winding losses rapidly dominate and can contribute up to 90% of the overall losses at full load.

Other forms of loss are;

- Stray losses: Some magnetic flux will escape the core and cause nearby objects to heat up
- Hysteresis losses: Each reversal of the AC current waveform causes the magnetic field to also reverse, causing losses in the core material.
- Mechanical losses: The alternating magnetic field causes forces between each turn of a winding, the core itself, and nearby metal, causing energy-consuming vibrations.
- Magnetostriction: The alternating magnetic flux causes the core to expand and contract slightly. This causes heat, which will reduce efficiency.

The equation used for efficiency is…

$$efficiency, \eta = \frac{output\ power}{input\ power} \times 100\ \%$$

Electrical Layout Diagrams

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

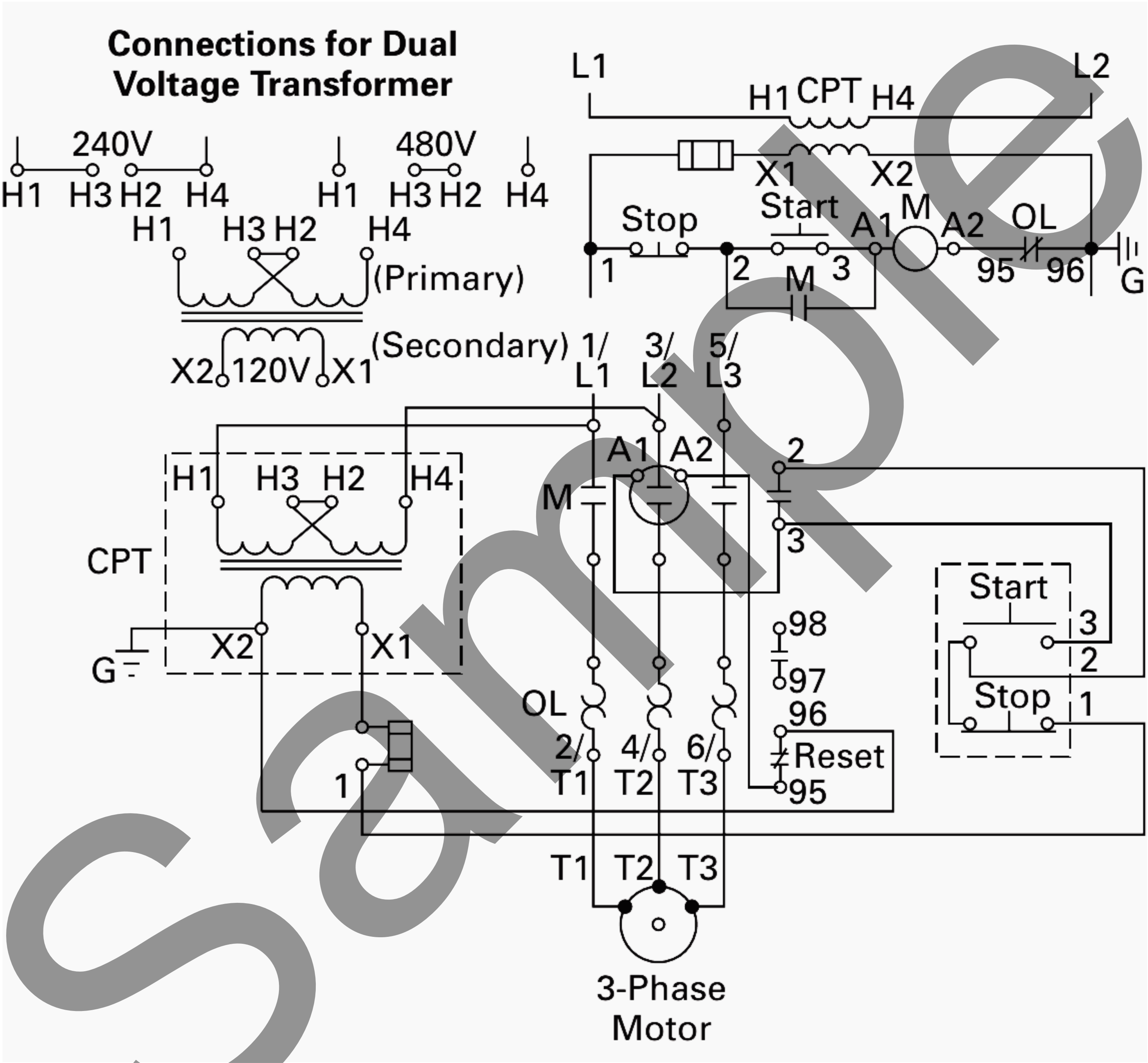

Figure 22 *A wiring diagram which includes a transformer symbol*

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.

Figure 24 *An analogue test meter*

A digital multimeter (DMM) will perform the same basic tasks as an analogue meter, but with higher accuracy and a digital display. Such a DMM is shown in figure 25.

Figure 25 *A digital multimeter (DMM)*

Insulation Testers

An insulation tester, also known as a ‘megohmmeter’, or just ‘megger’ is used to determine the quality of insulation in equipment, wires, windings etc. A megger will introduce a high DC voltage, ranging from 50 to 15,000 volts to the item under test.

Insulation testers measure the leakage current caused by the applied DC voltage, and then determine the insulation resistance (since both voltage and current are known, Ohm’s Law is used to determine the resistance). Since insulation testers produce high voltages, it is imperative that they are only used by qualified personnel. A typical insulation tester is shown in figure 26.

Figure 26 *A modern insulation tester*

Typical Faults

The most common types of fault which occur in electrical distribution systems are known as ‘unsymmetrical’ faults. These cause inequalities in both phase current and phase shift in a three-phase system. These faults are typically caused either by an open-circuit or short-circuit in a phase or phases.