Introduction To Electrical Power

Lesson 1 – Basic Theory

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Goal	IMO internal and external sales staff will have a basic introduction into Electrical power
Objectives	• On successful completion you will have learned about the fundamental 'building blocks' of electricity and electrical systems and Units. • Be able to understand basic concepts of power generation and distribultion • Understand SI power system units such as Amps, Volts, Ohms, Hertz, Henrys. • Understand the use of terms- Mega, Kilo, milli, micro, nano, etc
Length	This lesson is intended to take approximately 1.5 hours
Content outline	***1.*** **Getting Started** *(same as general course pattern)* **2. Overview** **a. Course goal** **b. Chapters in this course** **c. What is electricity?** **d. Generating electricity** **e. Basic electrical safety** **f. S.I. units and multipliers**

	3. **What is electricity?** A. **Voltage** B. **Current** C. **Resistance** D. **Series/Parallel** E. **Ohm's Law** F. **Circuit elements** G. **Power** H. **AC and DC** I. **Frequency** J. **Capacitance** K. **Inductance** L. **Reactance** M. **Phase Angles** N. **Impedance** O. **Triangles and Vectors** 4. **Generating electricity** A. **The power station** B. **Transmission** 5. **Electrical safety – Basics** 6. **S.I. Units and Multipliers**
Learning Activities	Delegates will engage in the following activities at the end of this lesson • 2 Quizzes • Test at later date
Evaluation Strategy	Delegates may be deemed to have an appropriate understanding of this course by obtaining at least 80% in the test.

3. What is Electricity?

Electricity is a form of energy that is generated in power stations and distributed in aluminium, copper, or steel wires to consumers properties or plant. When an appliance or other apparatus is connected to the electricity supply, the equipment can operate as designed.

Electricity is composed of tiny particles of matter called Electrons which are present in all materials. In metal wires, these electrons can be made to travel by applying a force such as a battery or a generator, a bit like a pump sending water through pipes.
Electrons always repel each other like two magnets would, so they always have the same density in every part of a circuit. This is very much the same as water flowing in pipes and vessels etc.

Water is a very good analogy when looking at the behaviour of electricity in a circuit, because both behave in similar ways.

Conductors – Materials through which electrons can easily be persuaded to move are classed as *Conductors.*

Insulators – Materials that will not allow movement of electrons regardless of the amount of force applied by a source are known as *Insulators.*

Voltage – this is the measure of electrical pressure that pushes electrons around the electrical circuit. Consider a water tap with a finger firmly placed over its outlet. As the tap is slowly operated, the pressure build up can be felt, even though there is no water flowing. This can be thought of exactly like the voltage of an electric circuit, ie the higher the voltage, the higher the electro-motive force *(E or EMF)* or pressure acting on the electrons to move them around the circuit.

Voltage is measured in ***VOLTS*** *(symbol V),* is sometimes known as *'Potential Difference'* (***pd***). Voltage will appear and can be measured *across* the supply wires of a piece of equipment or component; it does not flow in the wires.
Voltage is measured by a *Voltmeter.*

Current – this is the measure of the flow electrons in a circuit. Using the same water analogy, removing the finger and opening the tap will increase the actual amount of water flowing, from a trickle to a torrent. From a water tap the flow rate would be measured in liters/second, but in an electric circuit the flow of electrons is measured in Amperes or ***AMPS*** *(symbol **I**).*

Like water, conventional electric current will always flow from the highest pressure to a lower pressure, and the higher the voltage the greater the electron flow (current)- but using wires instead of pipes. Because current flows through wires, the device needed for measuring current must be inserted into or around a wire. This instrument is known as an *Ammeter.* Electricity can be delivered in one of two formats; *Alternating Current*-AC or *Direct Current*-DC.

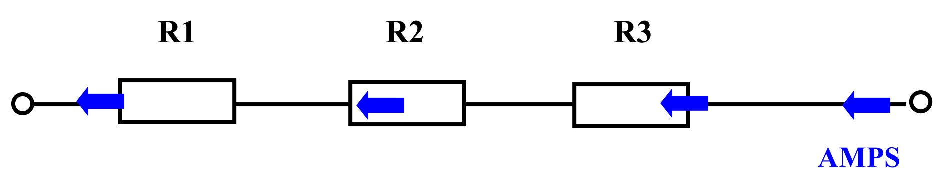
Resistance – Another factor that can influence the flow of water and electric current is called Resistance. In pipes the flow of water will be restricted by the internal diameter of the pipe; i.e., the smaller the bore the less the flow will be, i.e. resistance to flow. In electric circuits, current flow is dependant on the size and characteristics of the material it is required to flow through. Devices known as *Resistors (symbol R)* are used in electrical design and are made of special materials that are give resistance to the flow of current.

Electrical resistance is measured in ***OHMS*** *(symbol* **Ω**) *The* greater the resistance or ohmic value of the resistor, the less current will flow through it. To pass more current through the resistor, either its ohmic value has to be reduced or the voltage across it has to be increased, because voltage, current and resistance are all inter-related, if any one in a circuit is changed it causes one or both of the others to change also. Electrical resistance is measured with an Ohm meter, always with power removed from the equipment.

Series and Parallel Connections

If we put two or more resistors in a circuit so that current flows first through one, then through the second, etc, this is called a ***SERIES*** connection.
The total resistance R_T in the circuit will be a simple addition of each resistor value, see Figure 1a below.

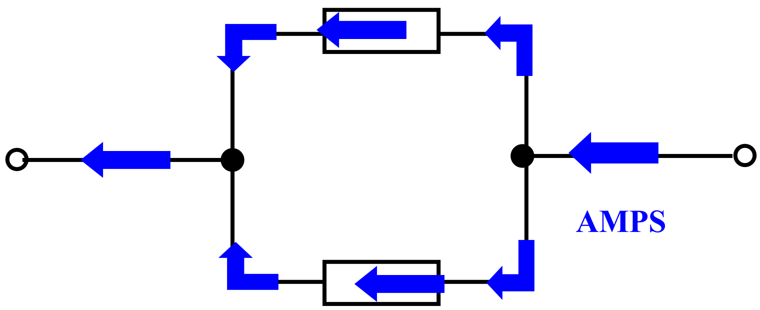
Figure 1a



Total Resistance in a SERIES circuit RT = R1 + R2 + R3 etc

If we connect two or more resistors into a circuit in such a way that the current has to flow through each or all at the same time, ie the resistors both provide a simultaneous current path and have to share the total current flowing, this is called a ***PARALLEL*** connection. The total resistance R_T will not be a simple addition but the addition of the reciprocal of each individual value, see Figure 1b on the next page.

Figure 1b



R2

Total Resistance in a PARALLEL circuit $\frac{1}{R_T} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$ **etc**

Ohm's Law – The relationship between ***Volts, Amps,*** and ***Resistance*** in a DC circuit is given by the law:

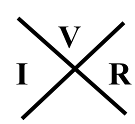
$$I = \frac{V}{R}$$

When **I** = Current in Amps
V = Voltage
R = Resistance in Ohms

For convenience, we can transpose the equation to give **V** or **R**, thus:-

$$V = I \times R \quad \text{and} \quad R = \frac{V}{I}$$

A useful method of remembering these formulas are:-



Circuit Elements

No current can flow until a path has been made between the terminals of a power source, and when such a path is made, it can be called a *circuit.* A circuit will always have the following elements:

- A voltage source or supply (battery, generator, etc)
- Equipment that is to receive current to make it do work, called the 'load'

- Usually some form of switch to turn the current on and off
- Wires or conductors to join all the elements of the circuit together

Any electric power source can be considered as a generator plus a resistor. When the source is not connected to a load – ***Open Circuit***, no current can flow and no volts will be dropped across the source's internal resistance $R_{INT,}$ therefore the output or terminal voltage will be at rated or maximum.

When a load is added and a switch in the circuit is closed, current will flow from the source. The amount of current that flows will be dependent on the resistance of the load. The higher the current that flows the more the voltage at the source terminals will drop. This is because some of the source voltage is used up just pushing the current out through the source's own internal resistance ($R_{INT)}$ and some voltage will be dropped across the load. See Figures 2a below and 2b on the next page.

When a circuit goes faulty, and current takes a shorter (lower resistance) path back to the source – by passing the load, a very large current flows that may damage the circuit. This is known as a ***Short Circuit.***

When a battery goes 'flat', ie the internal resistance has become so large due to chemical activity within it, that most of the available voltage is dropped across it, leaving little to push the current around the circuit.

Voltage source

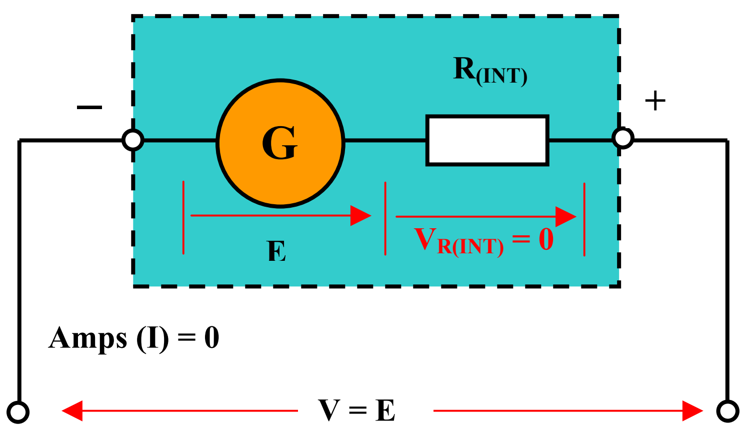
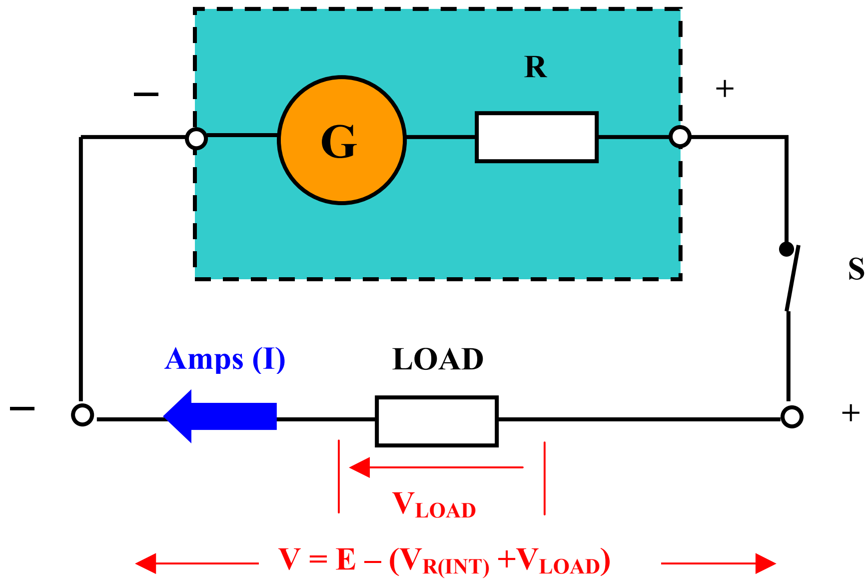


Figure 2a

Figure 2b **Voltage source**

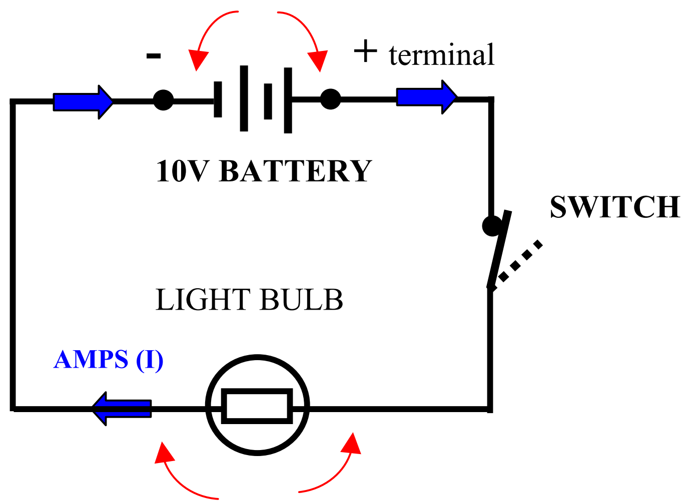


Power – The rate in which a load connected to a circuit uses energy is called power and is measured in the units of ***WATTS*** *(symbol W)* The heat that is generated by a current of 1 Amp flowing for 1 second through a resistance of 1 Ohm is equivalent to *1 Joule*. The Joule is the basic unit of work or energy. One Watt is the rate of work equivalent to 1 Joule for one second, or using the afore mentioned terms, **1 Volt** at **1 Amp** is equal to **1 Watt**.

In figure 3 on the next page we can see that the power in the circuit will be **Volts x Amps**. To calculate the current that is flowing in the circuit when the switch is closed and the lamplights, we must first know the resistance of the lamp.

Assuming the resistance of the lamp is 100Ω, then the current flowing will be I = V/R. This would mean **I = 10/100 = 0.1 Amps**, and **Power** would be **10 x 0.1 = 1Watt**. Another simple formula for calculating power is: $\textbf{Amps}^2 \textbf{ x R}$, so for the same values above, $\mathbf{0.1^{2} \times 100 = 1}$**Watt.** See Figure 3 on the next page.

Full 10 Volts appears across battery terminals until switch is closed



When the switch is closed some of the battery voltage is 'dropped' across across the light bulb due to the current trying to 'squeeze, through the resistance. This current will cause the lamp to become very hot as the voltage pressure from the battery pushes current current through it's resistance.

***The Power produced will be V* x *I* Watts**

Figure 3

Types of Electricity

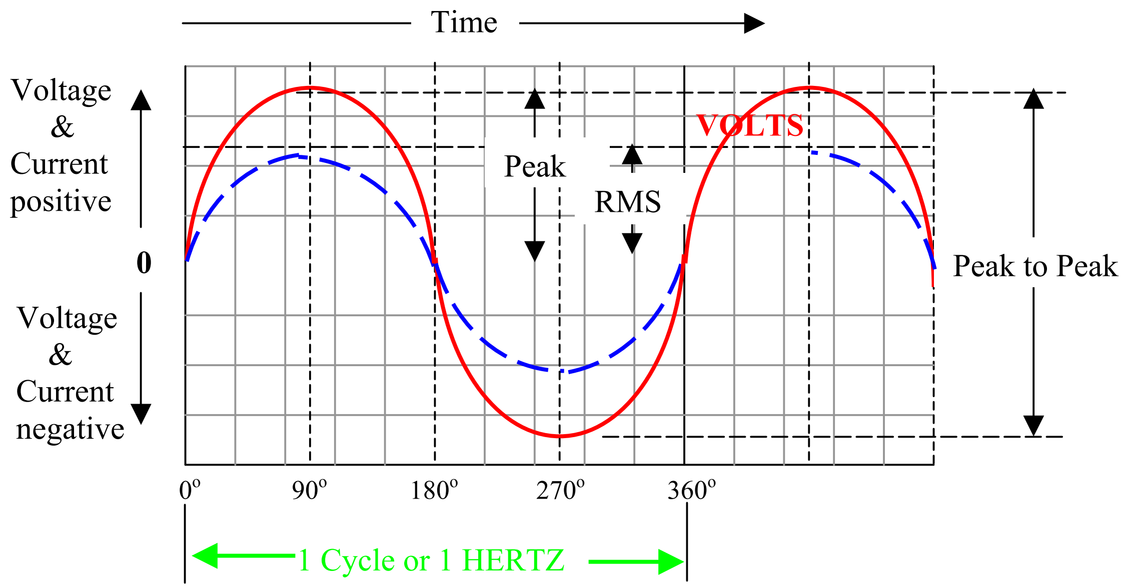
There are **two** kinds of electrical energy each defined by the behaviour of the current flowing from the source.

DC –Direct Current; this is the type of current that would flow from a battery for example. The current can and would only ever flow in one direction, and the voltage that pushes the current around the circuit would have constant value and fixed polarity, so the battery or DC generator will always have one positive terminal and one negative.

AC –Alternating Current; like the type that is available from the wall sockets in your home or office. AC current and voltage change direction with time, and are created by AC generators called *Oscillators* or *Alternators*. In a car's electrical system, the fan belt drives an alternator, which generates AC current. The AC current is then converted (rectified) to DC current to keep the battery charged, and supply all the car's electricity.

There are many forms of AC but all are related to the fundamental 'Sin Wave' shape. The RMS value (Root Mean Square) of an AC current or voltage is the DC equivalent which would provide the same power (Watts) to a circuit containing resistance, and is always quoted for AC unless otherwise stated. The RMS value of current or voltage can be stated as **0.707 x Peak**. Typical sin waves for AC voltage and current are shown in Figure 4 below.

Figure 4



RESISTIVE circuit – Current and Voltage are 'in phase' (reach their peaks at same time)

The RED sin wave shown in Figure 4 represents the voltage in a resistive circuit, ie the voltage is applied across a resistor or some device having only resistance – for example a filament light bulb. It can be seen that with time, the voltage rises to a maximum positive peak value, then falls away back to zero before rising to a maximum negative peak value and back to zero. The BLUE sin wave is typical of the current waveform in a purely resistive circuit whereby they both reach their respective peaks at the same point in time or angle. We say that the current is 'in phase' with the voltage.

Frequency - AC voltage will always repeat this pattern, its polarity changing sequentially with time and angle. Because the current is being 'driven' by the voltage, it will constantly reverse direction in the circuit, first flowing into the load then flowing out of it.

When the voltage has completed the 0 → +ve → 0 → -ve → 0 in 360º it is said to have completed **one cycle**. The same is true for the current flowing in an AC circuit. Frequency is measured in cycles per second and its unit is ***HERTZ,*** *(symbol **Hz**)*. In the UK and Europe the frequency of the mains AC power supply to industry, commerce and domestic users is 50Hz, ie the voltage and current complete 50 cycles in one second with each cycle taking 1/50 Second or 20 milliseconds.

Capacitance – The second most common component in an electric circuit is a device known as the *Capacitor (symbol **C**).* Capacitance is measured in ***FARADS*** *(symbol **F**) or more realistically the much smaller **MICRO FARADS** (symbol **µF**).* Reduced to its basic essentials the Capacitor (or Condenser as it used to be called) consists of two plates of metal foil separated by a dielectric (insulator). The effect of a capacitor in a DC circuit is essentially to store electric charge or electrons, and can be used to 'smooth' out a rough waveform, or slow down a fast rising voltage. A capacitor will not pass DC current.

In an AC circuit, the uses are very different, because the higher the frequency the more current the capacitor will pass. It is used in ac circuits to 'advance' current waveforms 90º ahead of the voltage, and as filtering devices. Capacitance is inversely proportional to the spacing between its two plates. A Capacitor with a pd of **1 Volt** after passing **1 Amp** for **1 Second** would have a capacitance of **1 Farad.**

In Figures 5a below and 5b on the next page, we can see that the way we add up the total capacitance of the circuit is exactly the opposite way around from a circuit having resistors.

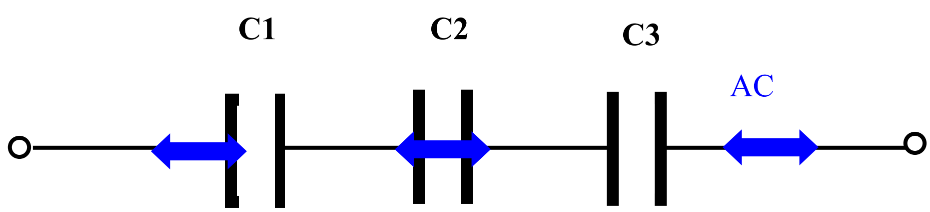
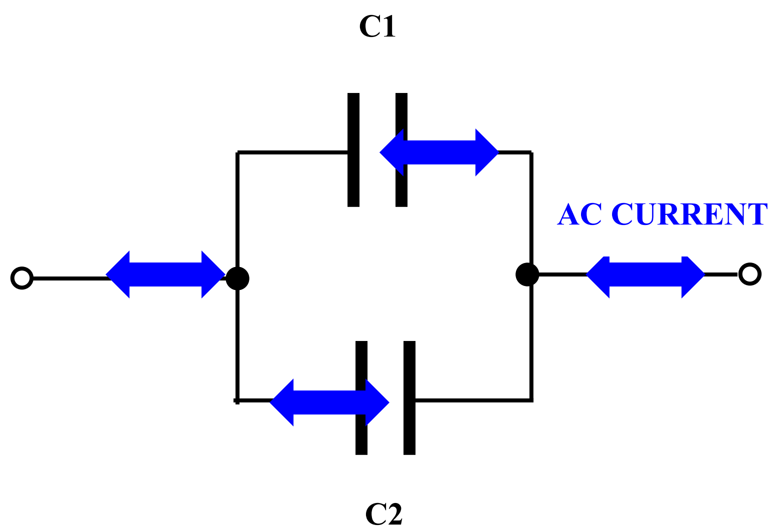


Figure 5a

Figure 5b

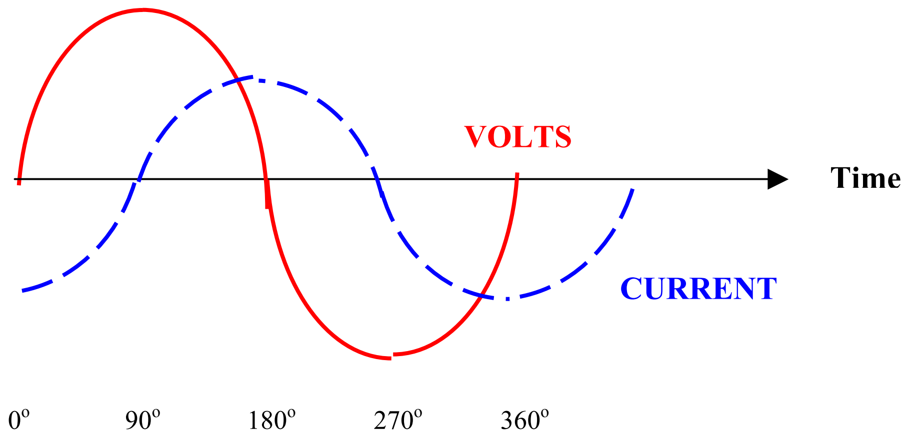


Inductance – Inductors are most commonly in the form of a wound coil of copper wire and work by utilizing the effects of electro-magnetism. When a dc current flows through an inductor, a magnetic field is created with a north pole at one end of the coil and a south at the other. If while the current is flowing, a steel rod were placed into the coil, the strong electro magnet would either snatch the coil and pull it through, or repel it and prevent it from entering, depending upon which end of the coil it is entered.
The more turns and/or the larger the current (together known as ***Ampere- turns****),* the stronger the magnetic field ***(Flux)***.

Its effect in an electric circuit is almost the reciprocal of capacitance and these two components are frequently used in conjunction with each other. Inductors have many uses but primarily, like a Capacitor it stores energy and does not want its electrical state to change quickly. An inductor (sometimes called a coil or choke) will not accept a sudden change of current, and for this reason it is often used to protect other components or parts of a circuit.

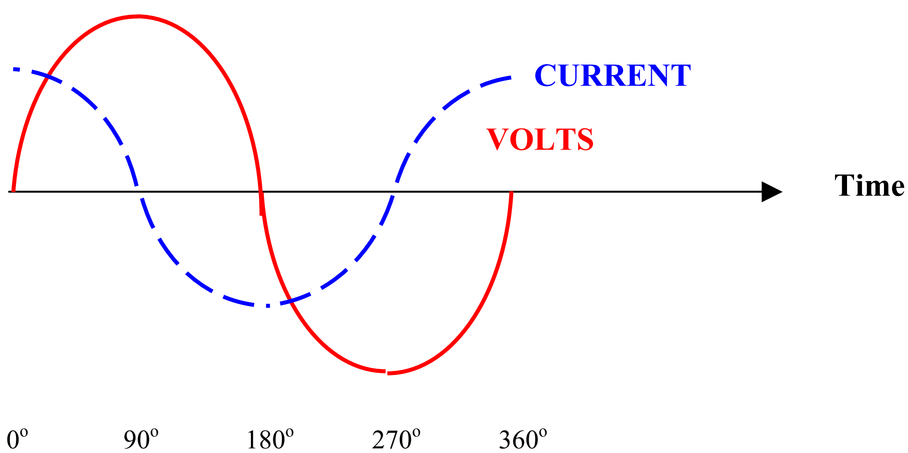
The standard unit of measurement is the ***HENRY*** *(symbol **H**)* but because of convenience it is more usually more appropriate to use ***MILLI HENRYS*** *(symbol **mH**)*. ***LENZ'S LAW*** states that any current change in an inductor produces a '**Back EMF'** (opposite polarity voltage), which tries to oppose that change. Like a Capacitor, current through the inductor, whether rising or falling, does so 'exponentially', and causes the current to lag behind the voltage by 90º.

Figure 6



INDUCTIVE circuit – Current lags (reaches its peak after) voltage by up to 90º

Figure 7



CAPACITIVE circuit – Current leads (reaches its peak before) voltage by up to 90º

Reactance – In an ac circuit only, a capacitor or an inductor will have another property known as ***REACTANCE*** *(symbol **X**)*. The reactance of a circuit, like resistance, is also measured in ***OHMS*** *(symbol **Ω**)*, and is caused by the frequency of the current passing through it. When we consider an inductor or a capacitor in an AC circuit, we can determine it's reactance by the following equations:-

Inductor, ***Inductive Reactance*** X_L **= 2πFL (Ohms Ω)**

Capacitor, ***Capacitive Reactance*** $X_C = \frac{1}{2\pi FC}$ **(Ohms Ω)**

Where:-
π = 3.142 (mathematical constant)**, F = Frequency in Hz, L = Inductance in H or mH, C = Capacitance in F or μF**

Phase Angle – The phase angle of a circuit is an important consideration because it is used to determine power in ac circuit.

We can represent the actual magnitude of any electrical quantity by using *'Vectors'* drawn on a *'Vector Diagram'*. Vectors represent quantities drawn like arrows having both magnitude (length) and direction (phase angle). Vector diagrams clearly show the relationship between voltage, current and time. In the following examples we shall draw the red voltage vector as the reference object, and show it in the horizontal plane. Because sin waves are always moving quantities and can be drawn accurately from a point at the locus of a circle, we must accept that all the vectors are travelling at the same speed in an anticlockwise direction. The time of one revolution is equal to the period time of the sine wave. The velocity of the vector, per second, is known as the *angular velocity (symbol* ***ω*** *[****Omega****]).* $\omega = 2 \times \pi \times F$

For example, if we look at Figures 6 and 7 again, we can draw their vector diagrams as shown in Figures 8, 9, and 10 below.

Figure 8

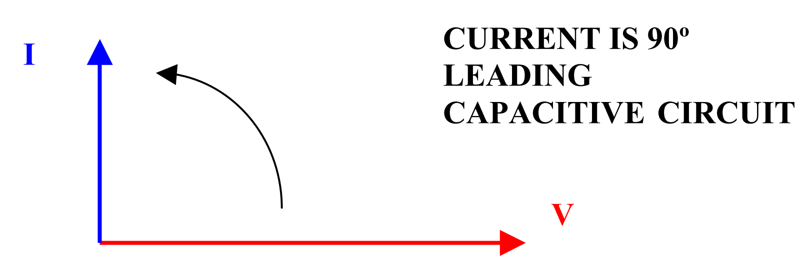


Figure 9

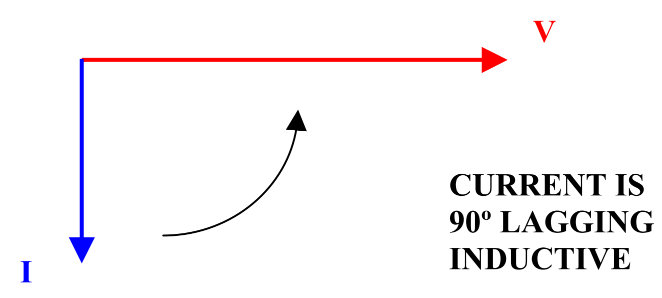
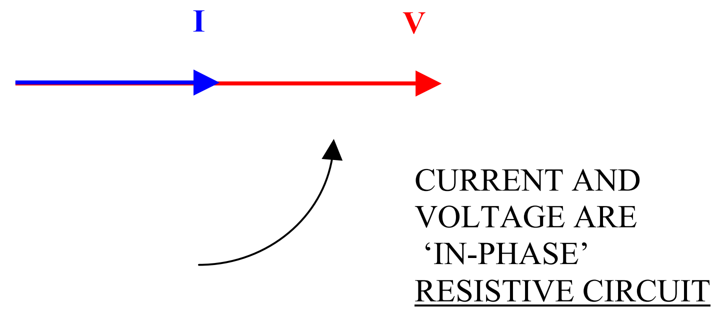


Figure 10



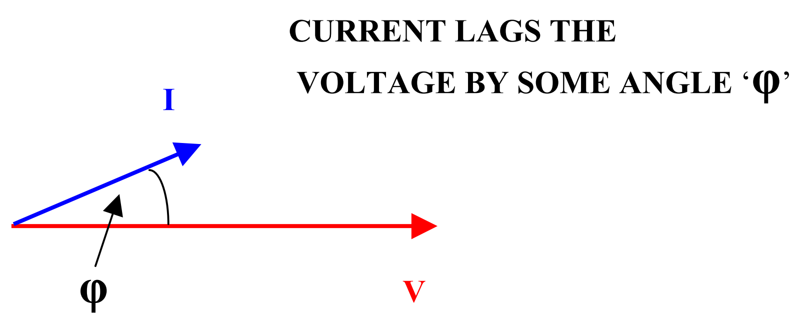
In Figure 8 we can see that the vectors represent the waveforms shown in Figure 7, ie the blue current vector is shorter than the red voltage vector because the voltage is a greater magnitude than the current. Also the current is shown leading the voltage by 90º indicating that the circuit for which this vector diagram represents is a purely capacitive circuit, ie contains only a capacitor.

Exactly the same applies for Figure 9 only this time the current is behind the voltage. This indicates the opposite of the above, meaning that the current in this circuit is flowing only through an inductor.

In practice, both of these are scenarios are rare, and more realistically, a practical circuit would consist of only resistance for example a filament type light bulb, and the vector diagram would look like Figure 10 where there is no angle between voltage and current and both are said to be 'in-phase'.

Even more likely is a circuit containing a mix of R and C, R and L, or R, C and L. Depending upon the actual quantities of each component, and of how each is connected into the circuit (series or parallel) will determine the actual *Phase Angle* **'φ'** (Greek letter Phi). Figure 11 below is more realistic, where the circuit is slightly inductive overall and the current only lags the voltage by a small phase angle.

Figure 11



Impedance – In an AC circuit it is seldom possible to use the straight *Ohm's Law* equation I = V/R described earlier when we talk about resistance to the flow of AC current, because most practical circuits have some inductive properties, ie they have resistance and inductance *(hence Inductive Reactance X_L)*.

Now we must introduce a new term ***IMPEDANCE*** *(symbol **Z**)*. The impedance of a circuit, like resistance and reactance, is also measured in ***OHMS*** ***(****symbol* ***Ω)*** and can be thought of as the sum of all the circuit components acting to restrict the flow of AC current.

We can now alter the Ohm's Law equation replacing the term 'R' with **'Z'.**

Current flowing in an AC circuit $\mathbf{I} = \mathbf{V/Z}$

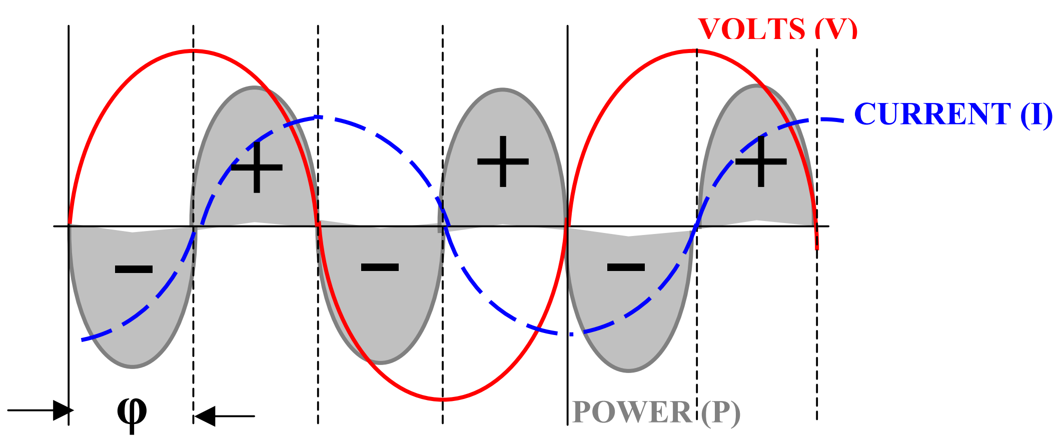
It is possible to calculate the impedance of an AC circuit by using the following equation:-

Impedance $\mathbf{Z} = \sqrt{(\mathbf{R}^2 + X_L^{\ 2})}$

Where:- R = resistance in Ω, and X_L = inductive reactance in Ω

Power in an Inductive Circuit – In a highly inductive circuit of negligible DC resistance ***(R)*** compared to X_L , Current **I** lags the applied voltage by 90º and Figure 12 shows the product of **V** and **I** which is **Power (P).**

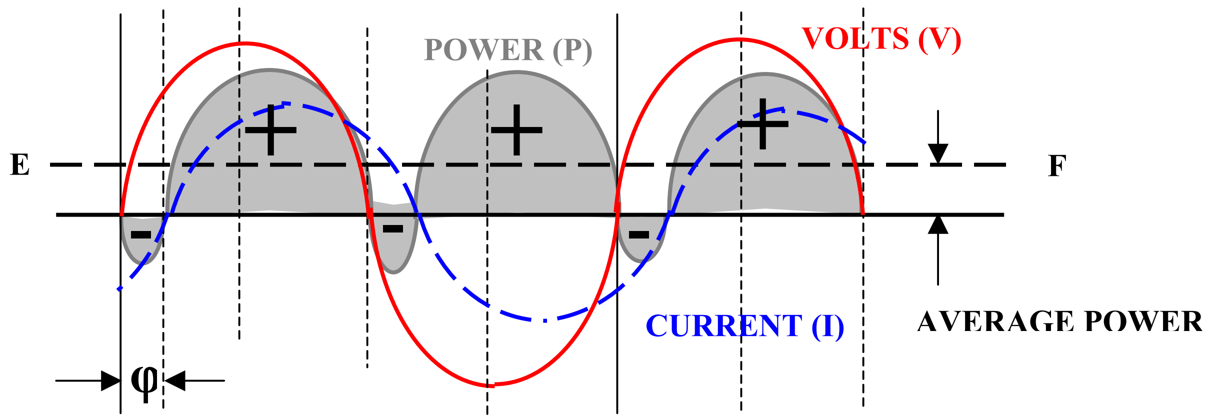
Figure 12



Since the shaded areas marked + and – are equal, the average value of power is zero. This means that no power is absorbed by the inductor (coil) since it is returning energy to

the circuit during the negative period by virtue of the collapse of the magnetic field. The same would be true for a purely capacitive circuit but the field would be electro-static.
If the DC resistance of the circuit is increased the phase angle **φ** gets smaller, resulting in increased power being absorbed in the form of heat.

Figure 13



The graphical display E – F shows that the power absorbed is less than the product **I** x **V** ***(Voltamperes)*** and it must therefore be multiplied by some factor to give the Power **(W).** This is known as the **POWER FACTOR.**

POWER (P) = (VOLTS x AMPS) x POWER FACTOR

$$\textbf{Power Factor} = \frac{\textbf{WATTS}}{\textbf{VOLTS x AMPS}} \quad \text{or} \quad \frac{\textbf{W}}{\textbf{V x I}}$$

Another formula for calculating power absorbed in a circuit is to use:-

$$\textbf{Power} = I^2R \textbf{ Watts} = I \times I \times R$$

But **I** can also $= \frac{V}{Z}$, so **POWER (P)** can be expressed as:- $\frac{V}{Z} \times I \times R$

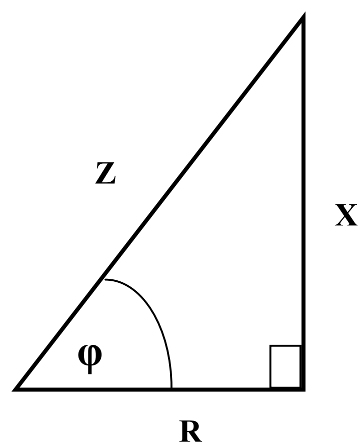
Which in turn becomes:- $VI \times \frac{R}{Z}$

Where, VI is the **Voltamperes**, and $\frac{R}{Z}$ is the **Power Factor**

The Impedance Triangle – Figure 14 shows the Impedance Triangle.

Figure 14

The Impedance Triangle



$\frac{\mathbf{R}}{\mathbf{Z}} = \cos \varphi$ (where **φ** is the phase angle between **V** and **I**)

So ultimately, **Power in an AC circuit = V . I . cos φ (Watts)**

If we put all this into practice, it means:-

- For a **purely resistive** circuit **φ = 0º** and **cos φ = 1**, ∴ **Power = VI Watts**

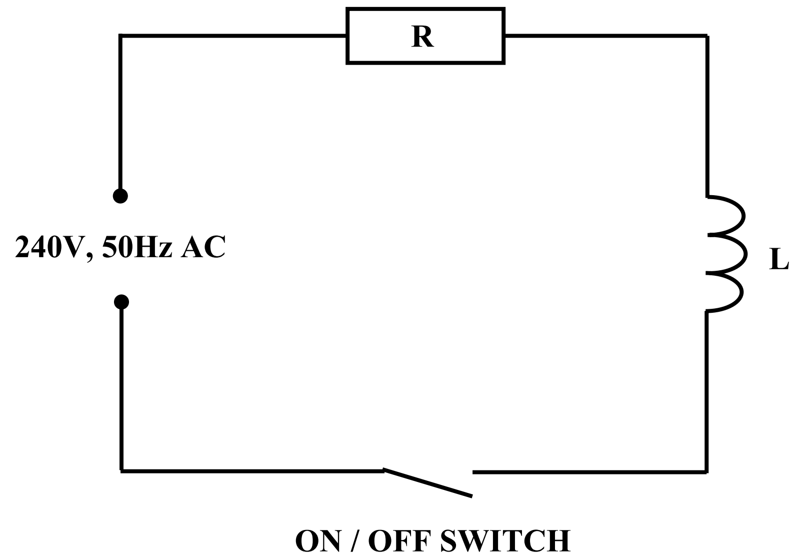
- For a **purely inductive (or capacitive)** circuit **φ = 90º** and **cos φ = 0**, ∴ **Power = 0 (zero)**

- For a circuit containing **some resistance** and **some inductance** (or capacitance) and let us **assume** that the phase angle is say **30º , cos φ = 0.866** so the power absorbed by the circuit would be **86.6%** of the **Voltamps.**

Figure 15

R = 30Ω

L = 0.2H



In Figure 15 above, a coil (inductor) in a special power tool is fed from a **240V, 50Hz AC** domestic power supply,. The circuit has some resistance also as shown.
L = 0.2 Henrys and **R = 30 Ω.** Find the Power dissipated by the tool.

$X_L = 2\pi FL = 6.28 \times 50 \times 0.2 = 62.8\ \Omega$

$Z = \sqrt{(R^2 + X_L^{\,2})} = \sqrt{(30^2 + 62.8^2)} = 69.6\ \Omega$

$I = \frac{V}{Z} = \frac{240}{69.6} = 3.45\ A$

$P = I^2R = 3.45 \times 3.45 \times 30 =$ **<u>356 Watts</u>**

<u>OR</u> using the other formula for Power Factor

$\text{Power Factor} = \frac{R}{Z} = \frac{30}{69.6} = 0.43$

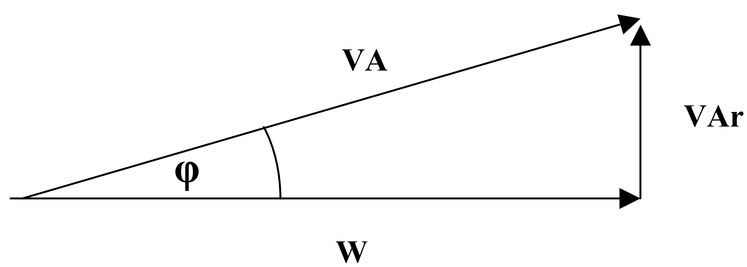
$P = V \cdot I \cdot \cos\varphi = 240 \times 3.45 \times 0.43 =$ **<u>357 Watts</u>**

The Power Triangle – In the same way that we looked at the impedance triangle, we can do the same for power. We now have a basic understanding of the difference between Voltamperes (VA) and Watts (W) and the role of power factor in their differences.

In Figure 16, the horizontal vector (W) represents real or ***ACTIVE POWER***, measured in Watts. VA, the Voltamperes represent ***APPARENT POWER*** and the vertical side of the triangle represents ***REACTIVE POWER*** or wasted power in the circuit.

Figure 16

The Power Triangle



By studying the Power Triangle, it can be seen that if the angle φ is large, ie power factor (cos φ**)** is low, the circuit Reactive power (**VAr)** will be high and there will be a lot of wasted power; meaning we would pay for power that is not being converted into useful energy, ie heat, light, etc. On the other hand, if we can keep power factor high (near to 1 or ***UNITY***) the VA's will almost equal the Watts and wasted energy will be negligible.

4. Safety

Electrical safety should always be of paramount importance. The importance of correct training and a knowledge of the dangers of electricity are essential for those people involved in working in an environment where they are likely to come into contact with live electrical circuits.

It is absolutely essential that all unknown apparatus and circuits ARE ASSUMED DANGEROUS UNTIL PROVEN OTHERWISE. Not only is the shock itself dangerous, but secondary events caused by the shock such as concussion due to a fall, fire, spillage etc should all be taken into account.

The **Electricity at Work Regulations 1989** became law in England and Wales on 1/1/90 and are intended to act as a first line defence to protect personnel from the dangers of electricity in the work place. The Royal Society for the Prevention of Accidents **(RoSPA)** also publishes guidelines for good practice at work and in the home, including first aid and resuscitation of accident victims.

Earth – The terms ***'earth'*** or ***'ground'*** when used in context with electricity, refer to a contact with the general mass of earth. The ground itself is usually seen as an infinite mass of zero potential, or electrically neutral. As we will see later, most electrical supply systems have some reference or connection to ground. Electrical equipment that has exposed metalwork must always be securely bonded to earth, if there is a chance that it could become live in the event of a fault. If exposed metal (handles, cases, pipes, covers, grills, etc) is not bonded to earth, and a live wire comes lose inside of the equipment and touches the case, it could become live at a dangerous voltage. If a person then touches the metal while earthing himself to ground or by holding onto a correctly earthed piece of metalwork with the other hand, a current will flow through the body from the un-earthed metal (at some live potential) to the ground potential at zero potential.

Fuses – Fuses are purposely designed weak links in a circuit to protect the wires, conductors or apparatus from overheating in the event of a fault condition. In the above scenario, if the metalwork were correctly earthed the moment that it became live a large fault current would flow down the earth conductor to ground. This would cause a correctly sized fuse in the power input conductors to 'blow' or open the circuit to clear the fault. Only when the fault is diagnosed and rectified will the equipment be usable.

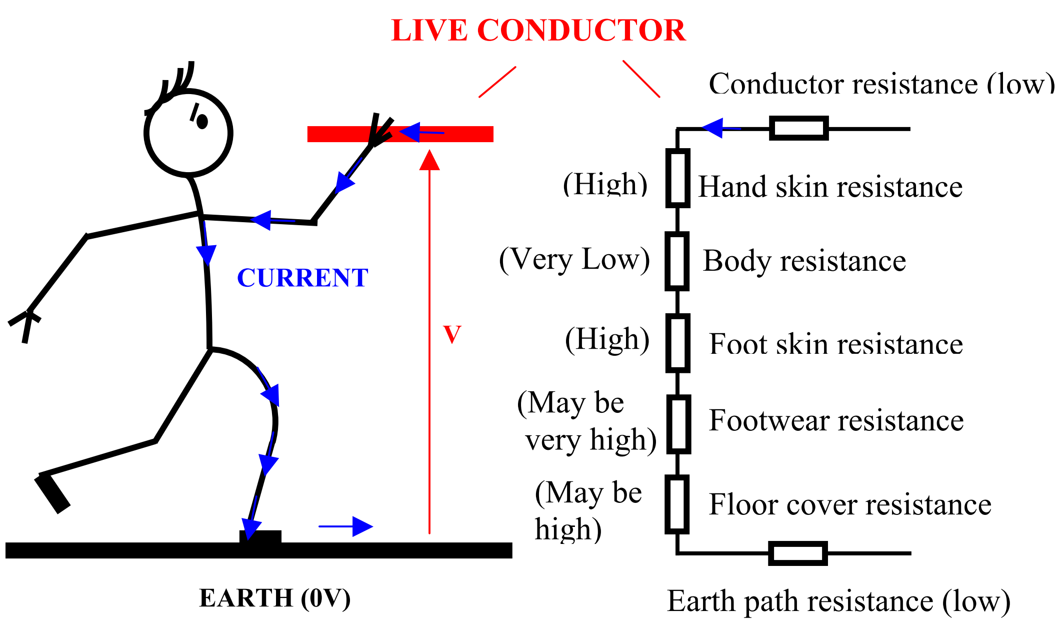
Fuses are not designed to operate in the event of, nor will they protect people from electric shock. Special earth leakage current monitoring devices (RCD's) are used specifically for this purpose and when an earth fault current is detected (usually 30mA for portable equipment), the device trips and interrupts the current flow.

Electric shock – If a part of the body comes into contact with a *live* (voltage present) conductor a current will flow through the body from the point of highest potential – usually the conductor, to the point of lowest potential – usually the ground or grounded metalwork.

The human brain sends small electro-chemical signals to the muscles in order that they react normally. If your hand accidentally grasps a live conductor a larger current is passed through the muscles and pain is felt, but even though the brain is sending signals to relax the muscles and let go, the larger current swamps the brain current and keeps the hand even tighter on the conductor. This may cause burning of the skin, and the increased levels of carbon in the burn will lower the skin resistance and increase the current.

The amount of current that your body will pass depends upon several factors. The current path will be approximately as shown in Figure 17 below.

Figure 17



The actual current that flows through the body will be limited by the body's impedance. The actual impedance will depend upon:-

- Skin type and condition at points of current entry and exit
- Applied voltage
- Area of contact with live conductor
- Water content of body
- If the skin is burnt

- Time of contact

Figure 17 shows how the current flows through the body, and shows andequivalent *circuit'* that lists the individual resistances that will oppose the shock current (remember Ohm's Law).

Of course, if the voltage was high and/or the hands and feet were soft and wet, the current could be high enough to cause severe electric shock or death. Fortunately people working with electrical apparatus rarely have bare feet or wet hands, and the soles of their footwear and floor covering tend to make the overall resistance high and so keep the shock current to a safer level - although painful!

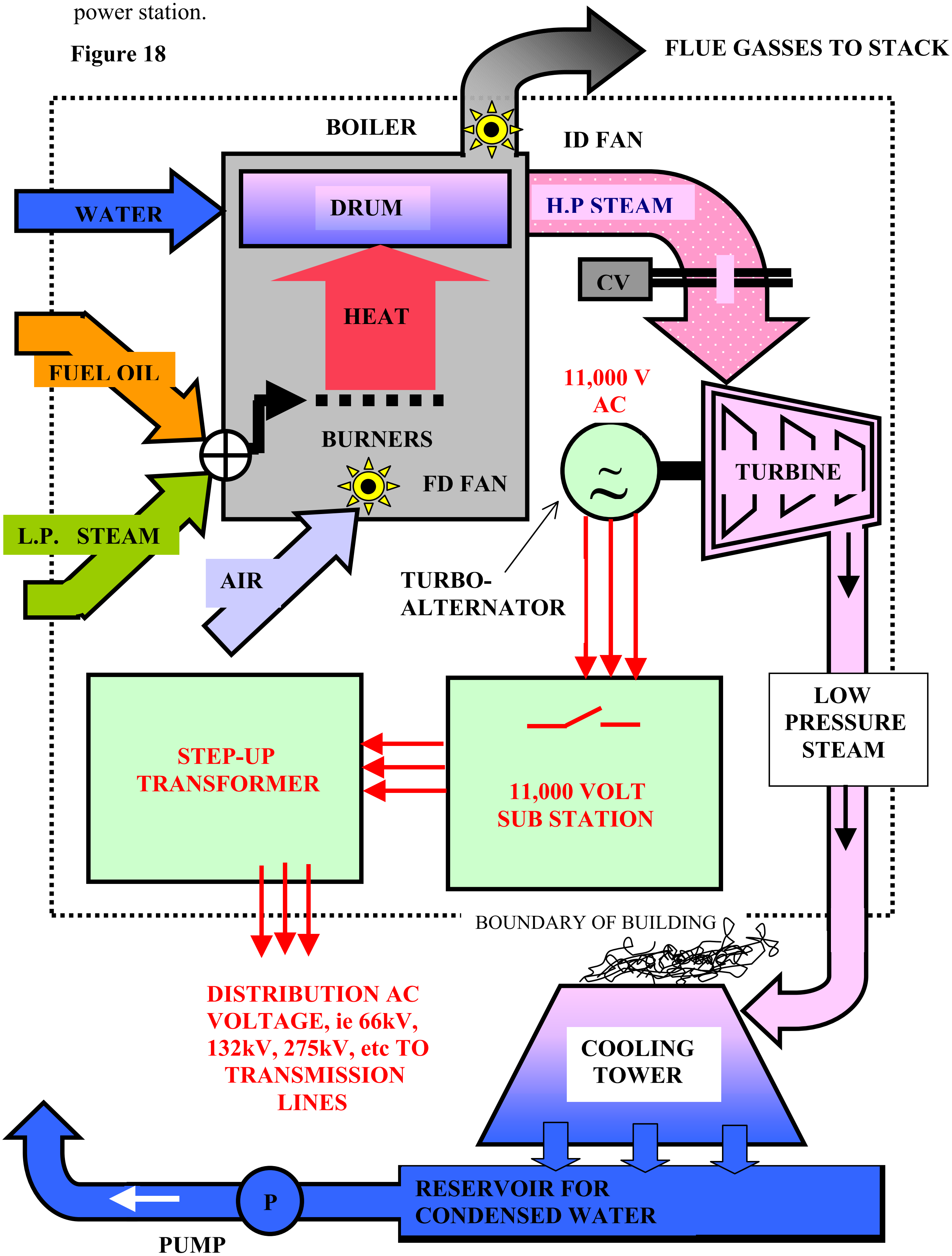
The effects of shock currents differ from person to person, but we know that 1 milliamp can cause sensation, and 100 milliamps is likely to be fatal, particularly if it passes through the heart. The time in which the shock current flows is also important, for example, 500 milliamps *may* be tolerated without any ill effects as long as it flows for only 20 milliseconds. On the other hand, 50mA could be fatal if flowing for 10 seconds. The shock current causes many effects but the most serious is ventricular fibrillation of the heart (the beat becomes irregular) and compression of the chest, which prevents breathing.

In the event of encountering a victim of electrocution where they appear to still be in contact with the live conductor/apparatus, <u>on no account should the person be touched directly with any part of the body until the source of current has been switched off.</u> Failure to observe this fundamental rule will almost certainly increase the casualty list to two!

5. How is electricity generated?

The Power Station – Figure 18 shows a block diagram of a typical oil fired power station.

Figure 18



The Boiler

The boiler is similar in principle to a domestic hot water boiler but on a very much larger scale of maybe 15 metres wide by 20 metres high. It is basically a large cavern like furnace with walls and ceiling covered in refractory material. Embedded into the walls are lots of steel tubes running vertical and parallel to each other, carrying water around the boiler to a large drum at the top (a bit like a kettle).

The Turbine

This is a machine containing a central shaft fitted with hundreds of blades like a fan, which passes through several stages. When high pressure steam is blown into the inlet manifold it strikes the blades causing the shaft to rotate at a speed proportional to the inlet steam pressure. As the steam passes through the turbine, its pressure is slowly reduced as it passes through each of the different stages, finally exiting as low pressure steam.

The Alternator

Sometimes called an AC generator, this is a rotating electrical machine driven by the output shaft of the turbine (or diesel engine, etc). The alternator is almost identical to a large electric motor but working the other way around. (nb. *We will cover electric motors in a later paper).* Essentially, the central rotor is fitted with powerful electro-magnets, and the stationary housing of the machine has three different sets of coils wound into slots machined into the walls. With the shaft rotating and the electro-magnets on, a sinusoidal electric current is induced in each of the coils that the magnets pass over in turn. This current causes a high voltage -typically 11,000V AC, to be created at the alternator's three output terminals.

How they all work together

De-ionized (softened) water is pumped into the boiler until the tubes and drum are nearly full. Heavy fuel Oil from storage tanks is pumped to the boiler where it is blasted into a fine flammable mist by low pressure *atomizing* steam and sprayed into the furnace by the burners. The mixture is ignited and the water in the tubes heats up. Steam is produced in the drum at very high temperature and pressure, for example 900°C and 1500 pounds per square inch. Two large fans play an important role here – the FD fan (forced draught) is fanning the flames at the burners and the ID fan (induced draught) is ensuring that all the flue gasses produced in the furnace are sucked out up the chimneystack. The high-pressure steam passes from the boiler drum, through an automatic regulating valve (CV) and into the primary stage of the turbine. The enormous pressure against the blades cause the shaft to rotate at quite high speed. By the time the steam exits the final stage of the turbine blade system it is at quite low pressure.

To keep the efficiency of the station as high as possible, the low pressure steam is taken to a cooling tower, where it is condensed naturally back into water which drips into a reservoir below the tower. This water can then be pumped back to the boiler to begin the cycle again. The whole system is critically monitored and controlled for safe operation and protected from over pressure, over temperature, over speed, flame failure, pump and fan failure, etc.

The turbo-alternator is mechanically coupled to the output shaft of the turbine either directly or via a gearbox. When the generated voltage and speed of the alternator is correct, the electrical frequency is matched to the frequency of the National Grid using a device called a 'synchroscope'. When the two frequencies are identical (controlled by the speed of the alternator) the circuit breaker in the 11,000Volt sub station can be closed. This switch allows high voltage current to flow to a step-up transformer where the AC voltage is boosted to the grid level, ie 132, 275 or 400kV etc, for national distribution.

The National Grid

In the UK, most of the electricity generating stations export their individual power outputs to network, which runs around the country know as the National Grid. If the grid is thought of as a continuous loop or ring, power can be fed into or taken out of from two directions. This means that in the event of a fault at any point in the system, power can be re-routed from elsewhere while a complete section is isolated for maintenance. The national grid in the UK is also connected to a similar grid in France via under sea transmission links, and electricity is traded both ways.

During the summer months a relatively small number of power stations will export power to the grid to supply the UK base load. During times of peak electricity demand, such as a severe winter more power stations will come on line to supply the power (Megawatts) that is required. High power demand can be seen when there is a television program broadcast of national interest, and even higher peaks as millions of kettles are turned on in the advertisement break. Although we take it for granted, it is essential that the system has enough spare capacity to cope with such demands, and overloads that could result in power cuts or 'black-outs' do not occur.

The transmission lines that we see criss-crossing the countryside are carrying AC power. AC power is used in preference to DC because it is more efficient to transport. The very high transmission voltages on the lines are necessary in order to keep the current low, and make it possible to use smaller, lighter cables between the pylons. Main sub-stations close to large towns on the grid network, convert the high voltage to a lower level, for example 11,000V, for local area distribution before being reduced again to 415V for use in factories, shops, offices, housing estates, etc.

The Kyoto Agreement

One of the main problems with power stations burning fossil fuel (coal and oil) is the emission of **CO_2 (Carbon Dioxide)** and other gasses from the smoke stack. CO_2 is one of a basket of six so called ***'greenhouse gasses'*** thought to be responsible for **global warming** and the depletion of the earth's ozone layer over the North and South Poles.

The **Kyoto Conference** was held in **1997** and was attended by the world's leading industrialized nations. Along with other countries, the UK Government made a binding agreement to cut emissions of these harmful gasses by **12.5% of the 1990 level** by the period **2008 to 2012**.

The problem of generating sufficient electricity for the national requirements while cutting back on fossil fuel emissions is growing. Many old coal and oil-fired power stations are being de-commissioned, and newer much larger stations are being built deploying other technologies such as hydro-electric using water, and nuclear reactor powered using radioactive materials known as Plutonium and Uranium. Nuclear power stations do not emit these gasses, but they remain highly controversial in other ways following catastrophic accidents such as Chernobyl in1986.

Other ways of generating 'clean' electricity are by using wind turbines and harnessing waves / the sea, but both of these methods are too small using today's technology to supply the required national capacity.

6. S.I. Units and multipliers

The international system of units known as the S.I. (Systeme Internationale d'Unites) was adopted in 1969. A base unit exists for all dimensionally independent physical quantities including: time, mass, electrical current, temperature, etc. It is not always practical to use the base unit when referring to a quantity, so standard multipliers are used to divide or multiply by 10, 100, 1000, etc.

For the purpose of electrical quantities and properties outlined in earlier chapters, we can apply appropriate multipliers or dividers as shown in figure 19 below.

÷ 1,000,000		÷ 1000		BASE UNIT		x 1000		x 1,000, 000
μA		mA		Amp		kA		MA
μV		mV		Volt		kV		MV
μΩ		mΩ		Ohm		kΩ		MΩ
μW		mV		Watt		kV		MV
N/A		N/A		VoltAmps		kVA		MVA
N/A		N/A		VAr		kVAr		MVAr
μH		mH		Henry		N/A		N/A
μF		N/A		Farad		N/A		N/A

Note:- The use of N/A means that the multiple is rarely used in general engineering

Figure 19

What Is Electricity Quiz 1

Team IMO

ASM Name:	*Date:*
Time allocated:	*Time Taken:*

1. Electric current is the movement of what?

(Answer)

2. What do we call a material that will not pass current?

(Answer)

3. An Ammeter can measure electric current. True or False?

(Answer)

4. When a resistance is connected across a battery, a voltage will flow through it. True or False?

(Answer)

5. What is the total resistance if two resistors R1 and R2 are are connected in parallel? R1 = 2Ω, R2 = 0.5Ω

(Answer)

6. If a current of 0.4A flows through a resistor of 560 Ω what is the voltage?

(Answer)

7. Which of the following statements is False?
(a) Power (W) = Current (I) x Current (I) x Resistance(R)
(b) 1 Joule = 1 Amp x 1 Watt x 1 Second
(c) 1 Watt = 1 Volt DC x 1 Amp DC
(d) 1 Amp for 1 second through 1 Ohm = 1 Joule

(Answer)

8. What name relates to the fundamental shape of AC?

(Answer)

9. In an AC circuit, which direction does current flow?
(Answer)

10. In an AC circuit, when V and I both reach a positive peak at exactly the same time, they are said to be "_____"
(Answer)

11. In a purely inductive circuit I leads V by 90º. True or False?
(Answer)

12. What is the name of the law that relates current change In an inductor to back EMF?
(Answer)

13. Write a formula for impedance (Z)?
(Answer)

14. Write a formula for power in an AC circuit
(Answer)

15. Simply, what is Reactive Power?
(Answer)

Team IMO

What is Electricity Quiz 2

ASM Name:	*Date:*

Time allocated:	*Time Taken:*

1. What is an Alternator?

(Answer)

2. Name 3 conditions that must be met before an Alternator can be switched onto the National Grid.

(Answer)

3. What is a typical transmission voltage on National Grid power lines?

(Answer)

4. Why is power transmitted at high voltages?

(Answer)

5. Which gas is produced by burning coal or oil?

(Answer)

6. What are 'greenhouse' gasses thought to cause?

(Answer)

7. Which famous conference called for limits on harmful emissions?

(Answer)

8. Which regulations cover electrical safety in the work place?

(Answer)

9. Name 3 factors that define the level of shock that a person would receive by touching a live conductor.
(Answer)

10. What level of shock current could be fatal over several seconds (A) 50mA
(Answer)

11. Using the best multiplier of S.I. base units, express:- **(i) 500V x 100A** **(ii) $\frac{75}{1,000,000}$ FARADS**
(Answer)

12. How long does it take for the UK mains to complete 10 cycles?
(Answer)