Trade of Electrician

Standards Based Apprenticeship

Introduction to AC

Phase 2

Module No. 2.1

Unit No. 2.1.9

COURSE NOTES

Created by Gerry Ryan - Galway TC

Revision 1. April 2000 by
Gerry Ryan - Galway TC
John Watters - Sligo TC

Revision 2. Nov. 2002 by
Gerry Ryan - Galway TC
Chris Ludlow - DundalkTC

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Chris Ludlow - DundalkTC

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Chris Ludlow - DundalkTC

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Dublin 4
Ireland

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Introduction

Welcome to this section of your course, which is designed to introduce you the learner, to Alternating Current theory.

Objectives

By the end of this unit you will be able to:

- Understand the basic principle of a simple AC generator
- Understand how an alternating EMF is generated
- Explain the term "frequency"
- Understand the terms Peak, RMS and Average values of a sine wave
- State the effect of a resistor in an AC circuit
- State the effect of a capacitor in an AC circuit
- State the effect of an inductor in an AC circuit
- List fuels used to generate electricity in Ireland
- State ESB distribution network voltages
- Understand the basic principle of a simple DC generator

Reasons

Almost all electricity is generated as AC, so it is very important to understand the effects of these components.

Alternating Current Generator

The basic principle of an AC generator is shown in Figure 1. The coil ends are connected to two slip rings.

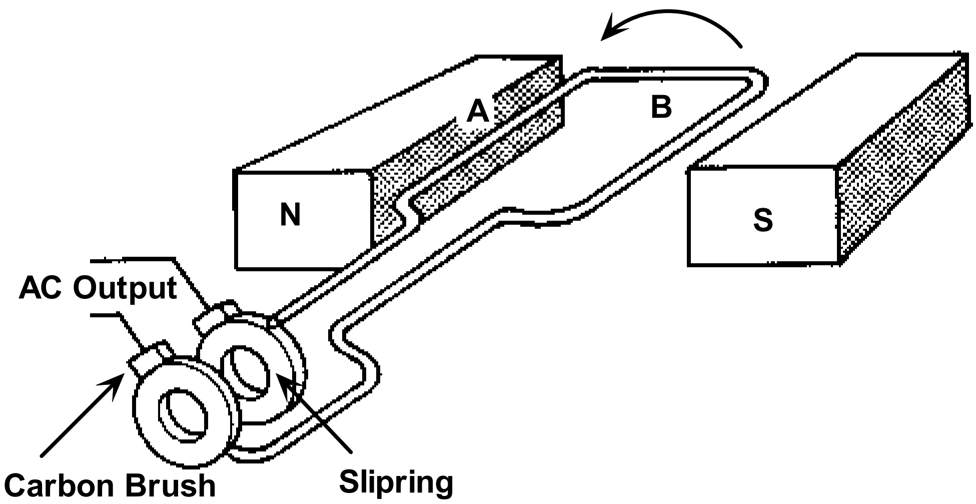


Figure 1.

As the coil sides A and B are rotated by an external force side A will have an EMF induced first in one direction and then in the other direction.

As side A of the coil is permanently connected to one slip ring, this ring will alternate from positive to negative as coil side A rotates past the North and South pole faces. The same process applies to coil side B. The generated output is therefore alternating (AC).

The direction of the induced EMF in each coil side can be determined by the use of Fleming's Right Hand Rule.

Generation of an Alternating EMF

Figure 2 shows a cross-section through a single loop generator.

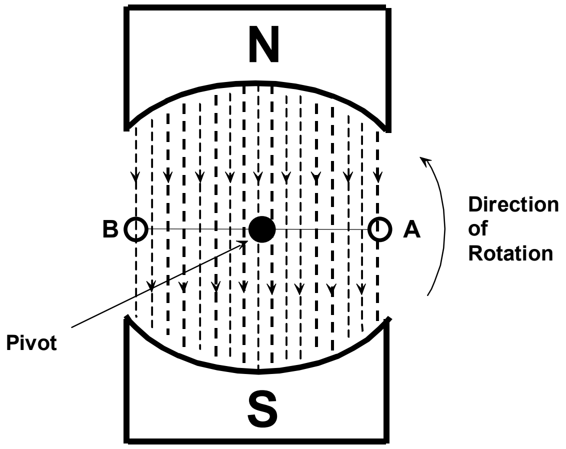


Figure 2.

As the single loop coil AB is being rotated anticlockwise about its pivot we will consider what voltage, if any, is being induced into this coil at definite intervals throughout a 360^0 cycle of rotation, starting at positions 1 and 7, see Figure 3.

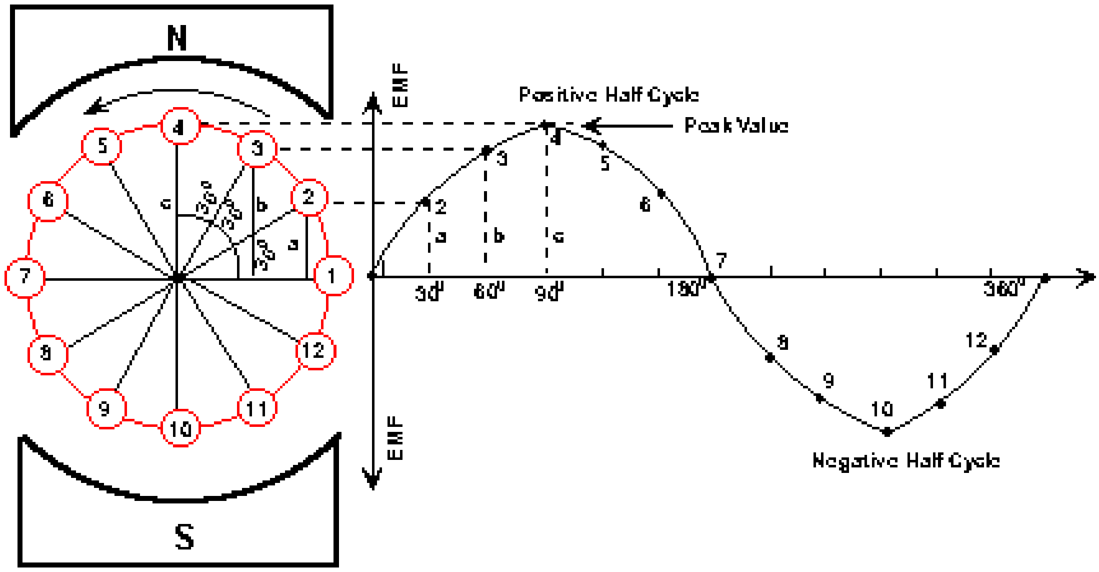


Figure 3.

When the coil sides A and B are rotating parallel to the lines of magnetic flux and hence not cutting any lines of magnetic flux no EMF is being induced in them. This is illustrated in Figure 3, by positions 1 and 7, As the coil AB is rotated further anticlockwise, it can be seen that the coil is cutting magnetic flux lines and hence an EMF is induced into it. This is illustrated in Figure 3, by positions 2 and 8. The magnitude of this EMF is as shown at position 2 of the sine wave.

As the coil AB is rotated further anticlockwise through positions 3 and 9, and then to positions 4 and 10 where the maximum flux is being cut resulting in the maximum voltage being induced into the coil as illustrated at position 4, see Figure 3.

As the induced EMF in the coil AB depends on the amount of flux being cut, which itself depends on the position of the coil, then the magnitude of the induced EMF can be represented by the coil position.

The resulting graph, Figure 4, indicates the EMF induced in the coil for one complete revolution of the coil. The resultant waveform is called a **sine wave**.

A sine waveform consists of equal positive and negative half cycles.

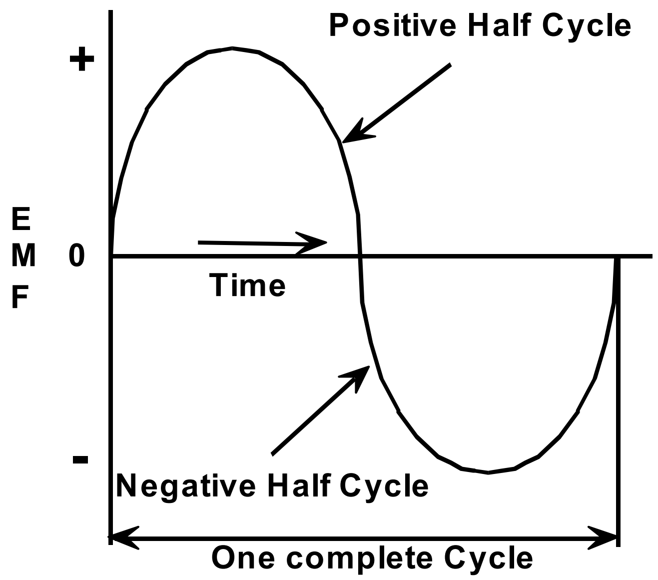
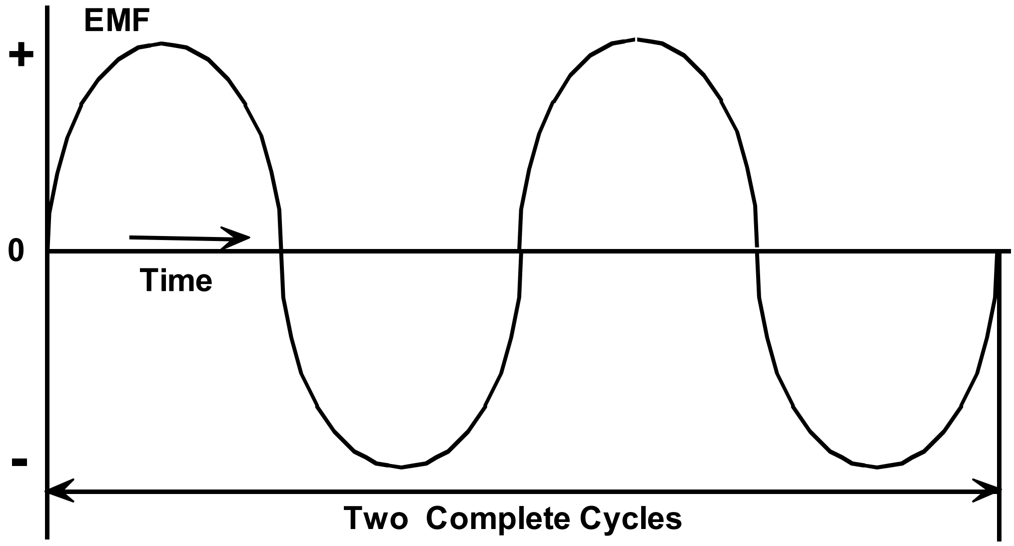


Figure 4.

Figure 4 shows the variation of the induced EMF during one complete revolution of a coil and is termed **one cycle**.

Frequency

If the loop is rotated at the speed of 2 revolutions **each second**, the resultant EMF will complete 2 cycles each second. The number of cycles each second is referred to as **frequency**.



The symbol for frequency is (f). It is measured in cycles per second (CPS) or more commonly Hertz (Hz). The time in which one cycle is completed is known as the **periodic time.** A frequency of 50 Hz is the standard for the supply system in Ireland.

The frequency of a supply can be calculated as follows:

$$\mathbf{f = \frac{1}{T}}$$

Where:

f	=	**frequency in Hertz (CPS)**
1	=	**constant**
T	=	**periodic time (the time in which one cycle is completed)**

Example 1

An alternating voltage waveform has a periodic time of 4 mS. Calculate the frequency of the supply?

Solution

$$T = 4mS = 4 \times 10^{-3} S$$

$$f = \frac{1}{T}$$

$$f = \frac{1}{4 \times 10^{-3}}$$

$$f = \frac{10^3}{4}$$

f = **250 Hz**

Example 2

Calculate the periodic time of a supply, which has a frequency of 50 Hz.

Solution:

$$f = 50$$

$$T = \frac{1}{f}$$

$$T = \frac{1}{50}$$

T = **0.02 Seconds** (or 20 mS)

AC Waveform Values

Figure 6 shows the Peak, Root Mean Square and Average values for a 1 Volt AC supply. These values also apply to the negative half cycle.

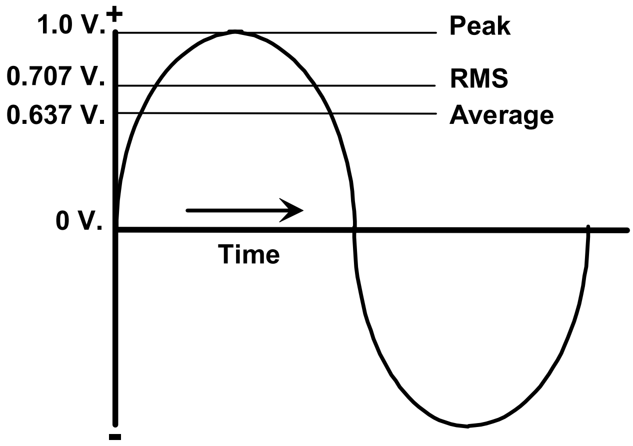


Figure 6

Peak Value of a Waveform

The **Peak** value is simply the highest value on the waveform. It is also known as the **Maximum** value. The peak value of the waveform in Figure 6 is 1 Volt.
This may be written as $\mathbf{V_P = 1\ Volt}$.

Root Mean Square Value of a Waveform

If you measure the mains supply you will find it to be 230 Volts.
This is the **Root-Mean- Square** (RMS) value of the alternating voltage. It is also known as the **Effective** value. The RMS value of the waveform in Figure 6 is 0.707 Volt.
This may be written as $\mathbf{V_{RMS} = 0.707\ Volt}$.

The RMS value of an AC voltage **or** current is defined as the equivalent DC value, which would have the **same heating effect**. The RMS or Effective value is the value normally used. All multimeters are designed to read RMS values.

Average Value of a Waveform

The **Average** value of a waveform is calculated over one half of a cycle. It is also known as the **Mean** value. The average value of the waveform in Figure 6 is 0.637 Volt. This may be written as $\mathbf{V_{AVE} = 0.637\ Volt}$. It is simply the mathematical average value of the positive **or** negative half cycle. If an attempt is made to average an alternating waveform over a complete cycle, the negative half of the waveform will cancel the positive half, and so the result is zero.

Relationship Between Waveform Values

If you measure the mains supply with a multimeter you will find it to be about 230 Volts. Remember, this is the RMS value. From this, the peak value can be calculated as follows:

$$\text{Peak Value} = \frac{\text{RMS Value}}{0.707}$$

$$\text{Peak Value} = \frac{230}{0.707}$$

Peak Value = **<u>325 Volts</u>**

The Peak **or** Maximum Value of the 230 Volt mains supply is about 325 Volts. Please note that 325 Volts will be across your body if you receive an electric shock from the 230 Volt mains.

Now that we know the peak value of the supply, the average value can be calculated as follows:

Average Value = Peak Value x 0.637

Average Value = 325 x 0.637

Average Value = **<u>207 Volts</u>**

The average or mean value is rarely used, except in some electronic circuits, e.g. rectifier circuits.

Given the peak value of the supply, the RMS value may be calculated as follows:

RMS Value = Peak Value x 0.707

RMS Value = 325 x 0.707

RMS Value = **<u>230 Volts</u>**

Given the average value of the supply, the peak value may be calculated as follows:

$$\text{Peak Value} = \frac{\text{Average Value}}{0.637}$$

$$\text{Peak Value} = \frac{207}{0.637}$$

Peak Value = **<u>325 Volts</u>**

Example

The peak value of a sine wave is 12 Volts and it has a periodic time of 16 mS.
Calculate the following:

(1) RMS value
(2) Average value of full wave
(3) Average value of half wave
(4) Frequency of supply.

Solution

(1) RMS value = Peak value x 0.707

RMS value = 12 x 0.707

RMS value = **8.484 Volts**

(2) Average value of full wave = 0, since the negative half cancels the positive half exactly.

(3) Average value of half wave

Average value = Peak value x 0.637

Average value = 12 x 0.637

Average value = **7.644 Volts.**

(4) Frequency of Supply

$$f = \frac{1}{T}$$

$T = 16 \text{ mS} = 16 \times 10^{-3} \text{ mS}$

$$f = \frac{1}{16 \times 10^{-3}}$$

$$f = \frac{10^3}{16}$$

$$f = \frac{1000}{16}$$

f = **62.5 Hz**

Purely Resistive AC Circuits

Effect of Resistance in DC and AC Circuits

Purely resistance circuits consist of electrical devices, which contain no inductance or capacitance. Devices such as resistors, lamps (incandescent) and heating elements have negligible inductance or capacitance and for practical purposes can be considered to be purely resistive. For such AC circuits the same rules and laws apply as for DC circuits.
Refer to Figure 7.

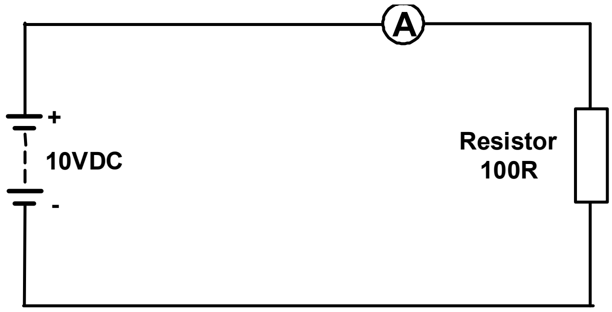


Figure 7

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

$$I = \frac{10}{100}$$

$$I = \underline{\mathbf{0.10\ Amp}}.$$

In the AC circuit shown in Figure 8 there is an alternating supply of 10 Volts RMS applied. This circuit will draw the **same current** as the DC circuit above.

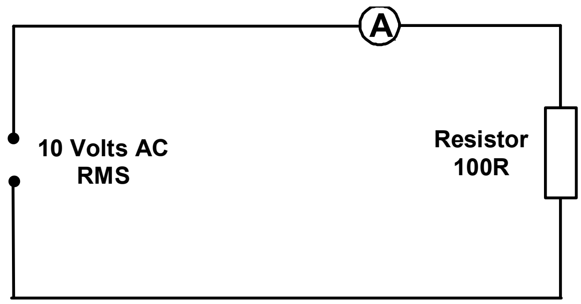


Figure 8

In an AC circuit with **only resistance** present:

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

When an AC circuit contains only resistive devices, Ohms Law, Kirchoff's Laws, and the Power Laws can be used in exactly the same way as in DC circuits.

The Effect of Capacitance in DC and AC Circuits

Figure 7 shows a **DC supply** connected to a non polarised capacitor. When the supply is switched on, the ammeter will indicate current flowing initially, and then the reading will fall off to zero. This indicates that the capacitor is charged. Because there is virtually no resistance in the circuit, the charging of the capacitor is almost instantaneous.

In a DC circuit containing only capacitance, no current flows after the initial charging current.

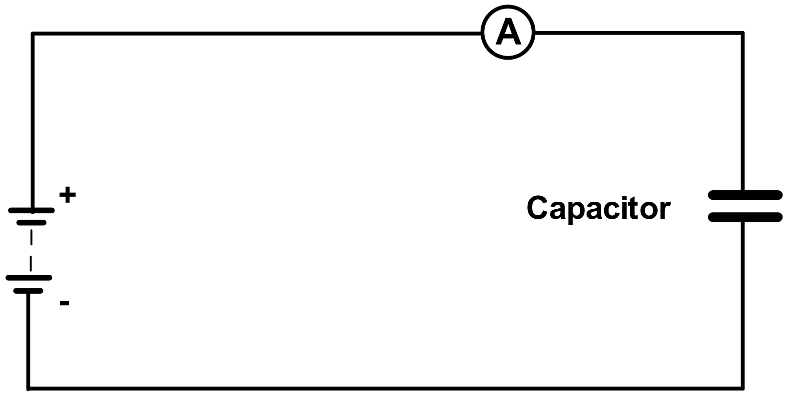


Figure 7

Figure 8 shows a lamp connected in series with a non-polarised capacitor across 12 V DC supply. When the switch is closed, the lamp may flicker "on" for an instant as the charging current flows through it.

This current flow reduces to zero as the capacitor charges to full capacity. At this stage the applied voltage is across the terminals of the capacitor and the voltage across the lamp has reduced to zero.

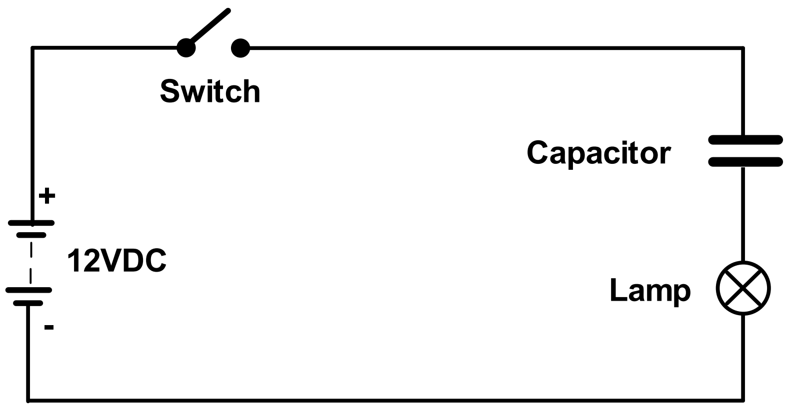


Figure 8

Figure 9 shows the same circuit now connected to an **AC supply.**

When the switch is closed, the capacitor is charged with one polarity and then it discharges; next the capacitor is charged with the opposite polarity, and then it discharges again.

The cycles of charge and discharge current provide an alternating current in the circuit, at the same frequency as the applied voltage. This is the current, which lights the lamp.

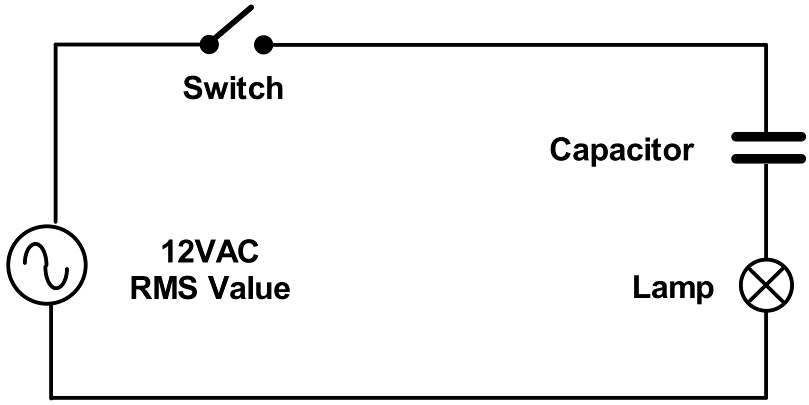


Figure 9

Figure 10 shows the same circuit with a lower value capacitor. This capacitor takes a lower value charge and discharge current and therefore the lamp will be dimmer. The lower value capacitor has more opposition to alternating current and so less current flows in the circuit. From this we can see that the circuit has **more reactance for less capacitance.**

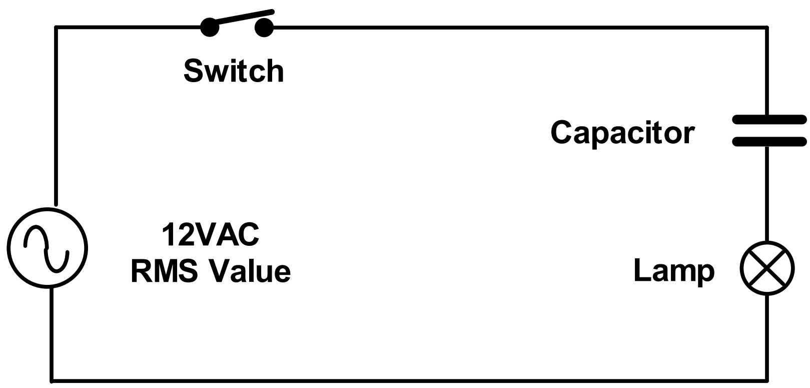


Figure 10

Capacitive Reactance is the **opposition** offered to the flow of **alternating current** in a circuit containing a **capacitor**.

X = **Reactance**

Capacitive Reactance is measured in **Ohms** and is denoted in a circuit by the symbol $\mathbf{X_C}$.

Summary:

- When DC is applied to a circuit containing a capacitor in series with a lamp, the capacitor acts, as a blocking device and the lamp does not light.

- When AC is applied to a circuit containing a capacitor in series with a lamp, the capacitor allows current to flow through the process of charging and discharging the capacitor and as a result the lamp illuminates.

- In an AC circuit containing a capacitor, the lower the capacitance value the lower the current flow. This means that, the lower the capacitor value, the greater the opposition to current flow. This opposition is known as Capacitive Reactance (X_C).

- A discharged capacitor behaves like a closed switch.

- A charged capacitor behaves like an open switch.

The Effect of Inductance in DC and AC Circuits

Inductance is only effective in a circuit when current is changing. The reason for this is that a **changing current** results in a **changing magnetic field**, which in turn produces a **back EMF**.

In a DC circuit, the effect described above occurs only when circuit current is changing.
At "Switch On" (an increasing current causing an expanding magnetic field) and
at "Switch Off" (a decreasing current causing a collapsing magnetic field).

Some inductors have a very low resistance and this will result in high currents flowing when they are connected in DC circuits.

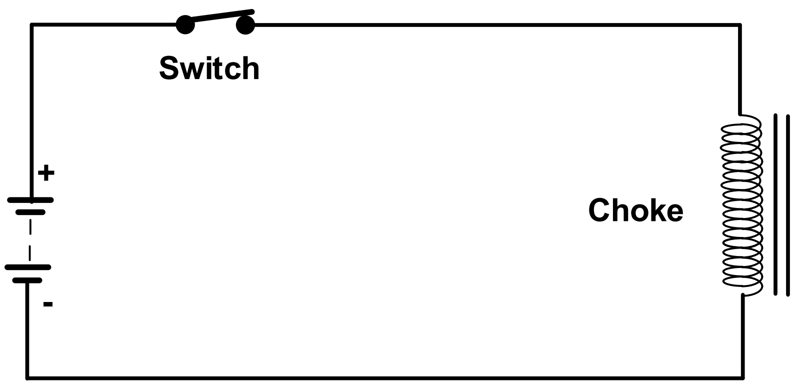


Figure 13

Figure 14 shows a DC supply connected to a circuit consisting of an inductor, which has an inductance value of 1 Henry and a resistance value 1 Ohm, in series with a lamp.

When the DC supply is switched on, the lamp will be bright. This indicates that the inductor has little opposition to current flow in the circuit.

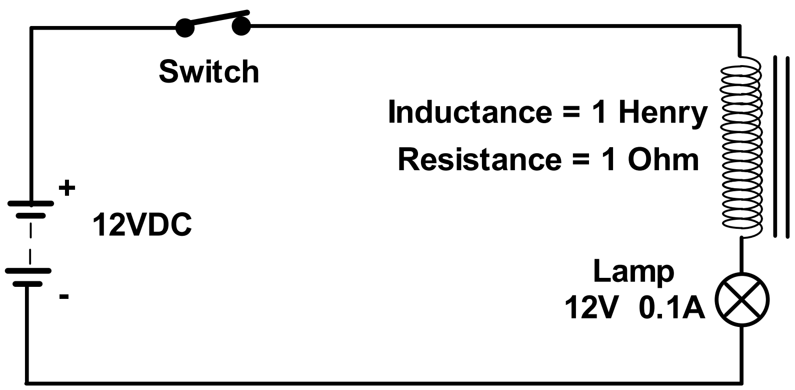


Figure 14

Figure 15 shows the same circuit now connected to an **AC supply.**

It must be remembered that an ***alternating current*** is continuously changing, i.e. the current is rising and falling. This results in a magnetic field which is continuously changing in strength and polarity. As a result of this the inductor has a continuous effect on an AC circuit.

For the circuit shown there will be a back EMF induced in the inductor, which according to Lenz's Law opposes the supply voltage. This in turn opposes the current flow in the circuit.

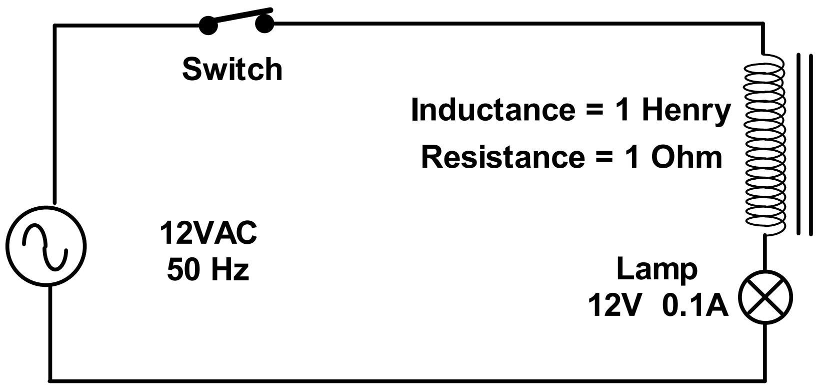


Figure 15

The opposition to the flow of alternating current in the inductor, is called Inductive Reactance, symbol (X_L). Inductive reactance in common with capacitive reactance and resistance is measured in Ohms. The resistance of the coil will depend on the CSA, length and type of wire used in its construction.

Although the inductor in the circuit has a resistance of 1 Ohm, it has an Inductive Reactance of 314 Ohms approximately, under the circuit conditions described. The lamp will be dim, indicating a high opposition to current flow. Contrast this with the DC circuit, dealt with previously, where the lamp was bright.

Electricity Distribution Network

The Electricity Supply Board (ESB) operates 19 major power stations and is responsible for the generation, transmission and distribution of electricity in Ireland. The ESB is also the largest provider of renewable power, with hydro-electric power stations on the Erne, the Shannon, the Lee and the Liffey. A wholly-owned subsidiary of ESB, Hibernian Wind, is developing and operating wind farms.

Generation of Electricity

Many types of fuel are used to create steam and rotate turbines, which are coupled to 3-Phase AC generators. These generators produce electricity at 10,000 Volts (10kV) 50 Hz.

A sample of the range of energy sources used by ESB generating stations is as follows:

- Coal (Moneypoint)
- Gas (Aghada)
- Hydro (Ard na Chrusha)
- Oil (Tarbert)
- Oil / Gas (Poolbeg)
- Peat (Shannonbridge)
- Pumped Storage (Turlough Hill)

Distribution of Electricity

The National Grid is an electricity transmission network of lines and cables throughout the country. It operates at very high voltages (up to 400,000 Volts).

At power stations, electricity is transformed to the higher voltage levels of 110,000, 220,000, or 400,000 Volts. It is then fed into a transmission network of approximately 6,000km of overhead lines and underground cables. These cables carry the electricity throughout the country. This network incorporates over one hundred high voltage transformer stations. At these stations the voltage is reduced to distribution voltages of 38,000, 20,000 and 10,000 Volts. Some larger industrial premises are supplied directly at these voltages.

Electricity is distributed at these 'medium' level voltages over an extensive distribution network of 80,000km of overhead lines and underground cables to smaller local substations close to customers' premises. At the local substations, it is finally transformed down to the normal mains voltage level for use by customers.

By using very high voltages, the amount of energy that is wasted as heat, due to resistance in the transmission cables is greatly reduced. For every doubling of the transmission voltage, the amount of power wasted, is reduced by 75%.

Direct Current (DC) Generator

The basic difference between the AC generator and the DC generator is the way the generated EMF and current are extracted from the rotating coil, which cuts the magnetic field. In the case of the AC generator the induced EMF is extracted via fixed carbon brushes in contact with the rotating slip rings. In the case of the DC generator, the induced EMF is extracted via fixed carbon brushes in contact with the rotating commutator, as shown in Figure 18. A simple DC generator as shown, has a single loop coil with its ends connected to two copper segments forming its commutator which is mounted on a shaft.

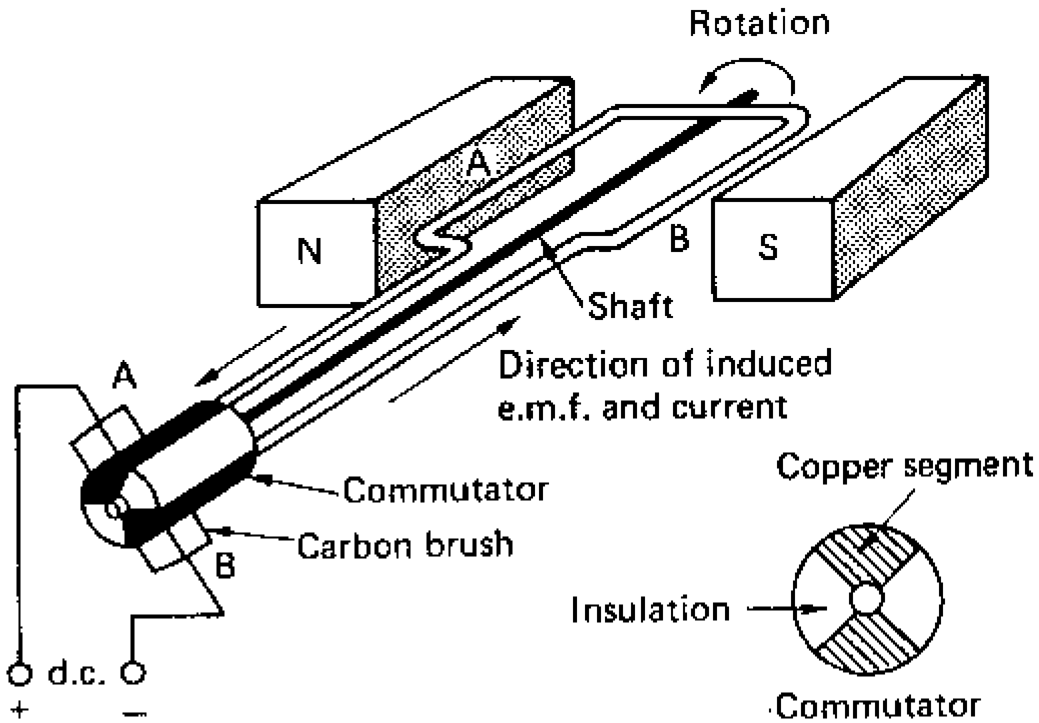


Figure 18

This output from the generator is a pulsating DC voltage as shown in Figure 19.

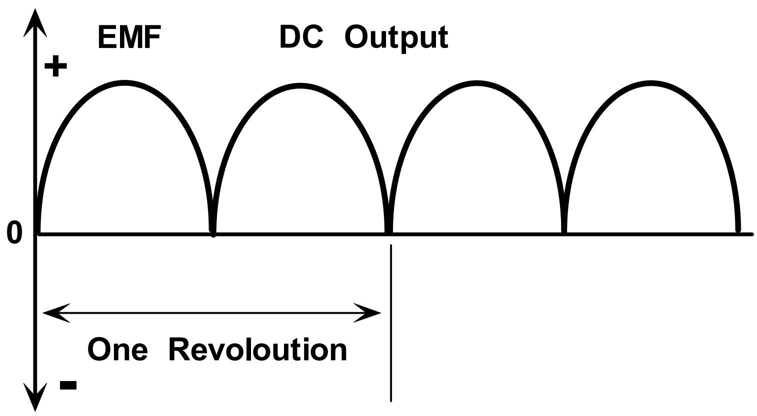


Figure 19

Practical DC generators have many conductor loops and commutators with large numbers of segments so the output voltage can be almost constant.