Reading 9

Ron Bertrand VK2DQ
http://www.radioelectronicschool.com

ALTERNATING CURRENT - PART 1

This is a very important topic. You may be thinking that when I speak of alternating current (AC), I am talking about the household electrical supply. True, the household supply is AC, however, so is the signal from a radio transmitter. The only difference is the frequency.

FARADAY'S LAW

When relative motion exists between a conductor and a magnetic field an EMF is induced into the conductor.

This is a very important law. We will take our time and try to thoroughly understand it. What Faraday discovered was a way of producing electrical pressure (voltage or EMF) from a magnetic field.

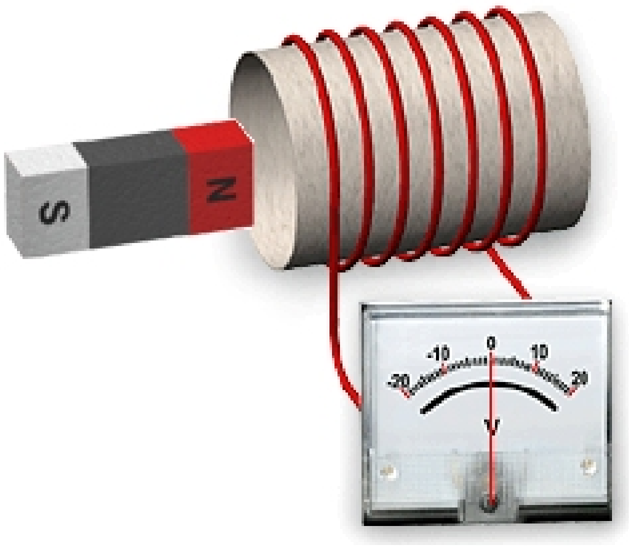
Faraday's law requires relative motion. This means there must be motion between the conductor and the magnetic field. This does not mean that the magnetic field must move. Neither does it mean that the conductor must move. Provided there is relative motion between the magnetic field and the conductor, a voltage will be induced into the conductor. In practice this means the conductor can be stationary and the magnetic field must be moved relative to it. Alternatively, the magnetic field can be stationary and the conductor moved through it.

A Mind Experiment

Imagine a cardboard tube. I have successfully used the cardboard tube from an empty toilet roll. The tube is wound with at least 50 turns of insulated conductor. So in fact we have made a simple coil. To the ends of the coil we attach a voltmeter. We have not discussed meters yet but I think you can follow along if I just say it is an instrument with a needle, which indicates if voltage is present. In fact I used a special type of voltmeter called a Galvanometer, which is just an ordinary voltmeter, but instead of the needle (pointer) of the meter having zero on the left, the zero is centred in the middle of the scale. The advantage of this is that the meter's pointer can deflect left or right of centre depending on the polarity of the voltage being measured.

So here we are with a galvanometer connected to out toilet roll coil. Now imagine taking a permanent magnet, a bar magnet, and inserting it quickly into the centre of the coil. When you do so the pointer will deflect in one direction as you insert the magnet. When the magnet stops moving the meter will return to zero.

Figure 1 – Setup for the mind experiment.



You still have the magnet inside the toilet roll coil. Now pull the magnet out. As you do the pointer will again deflect, indicating a voltage on the coil, however this time the deflection will be in the opposite direction to when we inserted the magnet.

What we have done is demonstrated Faraday's law of induction. When we inserted the bar magnet inside our coil we produced relative motion between the conductor turns on the coil and the magnetic field of the bar magnet. Once the magnet was in and stopped moving, the relative motion stopped, and the induced voltage fell to zero again. When we removed the magnet from the coil, relative motion existed again, but since the magnet was being extracted rather than inserted, the polarity of the induced voltage was in the opposite direction and the meter's pointer deflected accordingly.

Now, if you happened to have made the electromagnet we discussed in an earlier reading, you could place the electromagnet inside the toilet roll coil. If you then energised the electromagnet by applying a voltage to it, the expanding magnetic field would induce a voltage into our toilet roll coil. After a few moments the induced voltage would fall to zero. Now, if we disconnected the voltage to the electromagnet, the magnetic field around it would collapse (relative motion) and a voltage would be induced into the coil. You may not know it but you have just demonstrated the operation of a device to be discussed shortly, called a transformer.

THE AMOUNT OF INDUCED VOLTAGE

How much voltage is induced with our coil experiment is determined by the number of turns on the coil, the strength of the magnet we use, and the speed of the relative motion.

Of course, if we were able to continue to move our bar magnet in and out of the coil at high speed without stopping, we would get a continuously induced voltage.

Remember how the needle of the galvanometer deflected first one way and then the other. This is because when the magnet is inserted, the induced voltage is one polarity (negative or positive) and when the magnet is withdrawn the polarity reverses. This is an ALTERNATING VOLTAGE. An AC voltage is one which changes polarity periodically. If we connect an alternating voltage to a circuit we will get an ALTERNATING CURRENT. This is a current that flows in the circuit first in one direction and then in the other direction.

CYCLES PER SECOND

Going back to out toilet roll coil. Placing the magnet into the coil and then removing it is one cycle. If we could take the magnet in and out of the coil every second, the polarity of the induced voltage would go through one cycle in one second. Mechanics call this revolutions per second. In electronics we once used cycles per second, but now use Hertz. So when you see 'Hertz' just think of 'cycles per second'.

This method of inducing an EMF was the first method used in household power generation. Although the very first household power was direct current (DC), the method used to produce it was electromagnetic induction.

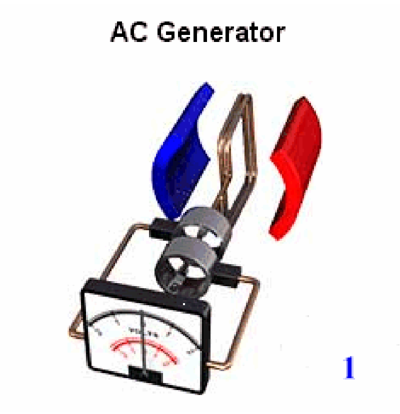
The alternating voltage connected to the household supply from the power grid changes polarity 100 times a second (50 cycles per second) and reaches 240 Volts RMS (← don't ask now.....later).

WHERE HAVE ALL THE ELECTRONS GONE

Bit of a strange subtitle but it's all I could think of at the time. What I want you to think about is the electrons in your household wiring! They don't move from the power station through the conductors to your house. The household supply is AC at 50 Hertz (Hz). So the electrons in the conductors in your house are probably the same electrons that were there when the wiring was installed in your home. The AC supply just causes them to move first one way and then the other. We discussed earlier how slow electrons really move. So if they (the electrons) are changing direction 50 times a second they would not be getting anywhere. They just seesaw back and forth. For the effects of an electric current to work we don't have to make the electrons move in one direction all the time we just have to make them move. Think about that.

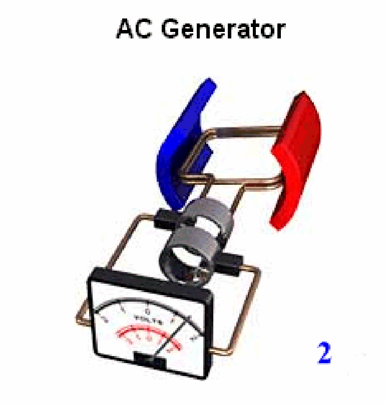
Let's get rid of our toilet roll coil and look how some real AC voltage is made in the power station. The device which creates the household power is called a generator. It works by creating relative motion between a conductor and a magnetic field.

The figure marked '1' is a simplified AC generator. The blue and red segments are the north and south pole of a permanent magnet. Between the magnet, in the magnetic field, we have a coil of wire. Only two turns are shown but in practice there would be many turns. The coil in a generator is called the armature. The ends of the coil are connected to a galvanometer via slip rings and brushes. We are going to make the armature rotate and we don't want the wires to become twisted where they connect to the galvanometer, so we feed them out through slip rings. The armature is in the starting position (vertical). We are going to rotate the armature clockwise.

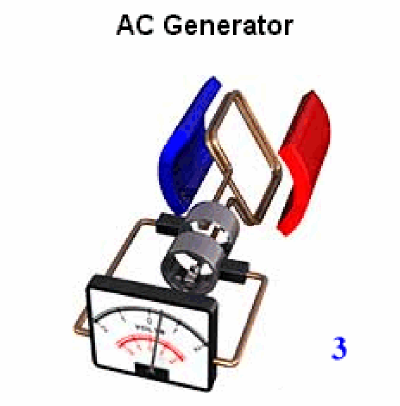


Look at the galvanometer. Notice how its pointer is in the centre when it has no voltage applied.

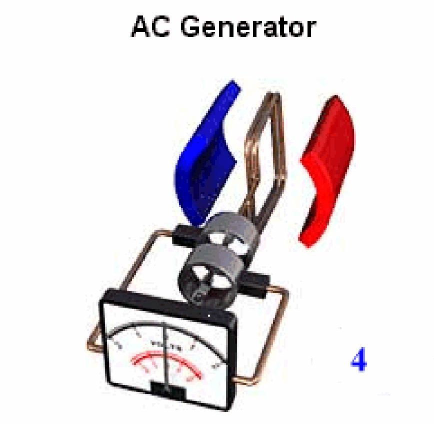
Figure 2 shows what happens when we have rotated the armature clockwise by almost 1/4 of a turn or 90 degrees. The galvanometer has deflected to the right indicating an induced voltage in the armature. In the diagram we have not quite arrived at 90 degrees. At 90 degrees the induced voltage will be at a maximum because at 90 degrees we have maximum relative motion between the armature and the poles of the permanent magnet.



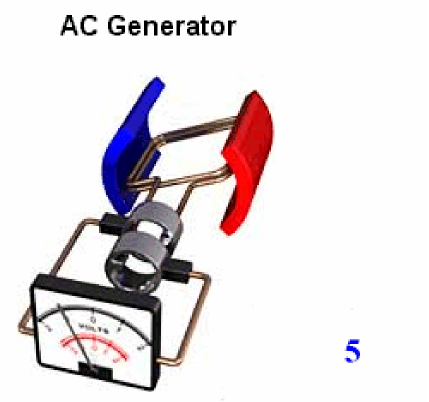
In figure 3 the armature has gone past 90 degrees. It's at about 170 degrees, almost 1/2 of a turn. Look at the galvanometer. It has fallen and is almost back at zero (the centre). It will actually reach the centre (zero) when the armature reaches 180 degrees, or 1/2 of a turn.



In figure 4 the armature is at 180 degrees and the induced voltage on the galvanometer is zero. We have now gone though one half of a cycle.



In figure 5 the armature is at about 240 degrees. LOOK what the galvanometer has done. It has deflected to the opposite side of zero. This indicates that the induced voltage has changed polarity. The maximum induced voltage will occur at 270 degrees or 3/4 of a turn.



After going through 270 degrees the induced voltage will again begin to fall to zero and will become zero when the armature is back in the position shown in figure 1.

Well there you have it. In the next reading we will discuss the shape of the voltage produced by the AC generator in more detail.

You may be wondering why we use AC in the household supply. Seems like a lot of trouble with all the electrons changing direction 50 times a second.

There are significant advantages of AC over DC and I am sorry but I am not going to go into that now.

It is interesting to note that Thomas Edison advocated DC for household power distribution claiming that it was safer. Tesla on the other hand advocated AC as a more efficient means of power distribution. Edison installed the first DC generators for power distribution, however Tesla's AC distribution is what eventually won out and for good reason.

By the way, the difference between an AC generator and a DC generator is very little. An AC generator has slip rings like that shown above. A DC generator has a device connected to the armature called a commutator, which provides a DC output from generators. Unfortunately or fortunately you don't need to know how this works.

Don't forget Faraday's Law….

When relative motion exists between a conductor and a magnetic field an EMF (electron-moving force) is induced into the conductor.

End of Reading 9.
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E-mail: manager@radioelectronicschool.net
http://www.radioelectronicschool.net