TRIGONOMETRY AND SINGLE PHASE AC GENERATION FOR ELECTRICIANS

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CHAPTER OVERVIEW

3: AC Generation

Thumbnail: Simple Alternator

3.1: Electromagnetic Induction

What is this electromagnetic induction of which you speak?

Electromagnetic induction is when a voltage is created by passing a conductor through a magnetic field.

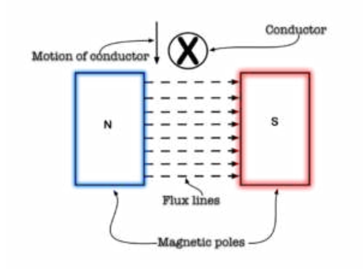


Figure 45. Magnetic poles and induction

The size of the voltage can be varied by three factors:

1. The size of the magnetic field. The more flux lines there are, the more flux lines there are for the conductor to cut. The strength of flux is directly proportional to the induced voltage.
2. The active length of the conductor. Active length meaning the part of the conductor that actually passes through the field. The active length is directly proportional to the induced voltage.
3. The speed at which the conductor passes through the field. The faster the conductor passed through the field, the greater the voltage induced. The speed is directly proportional to the induced voltage.

These relationships to voltage can be broken into this formula:

$$e = \beta l v. \tag{3.1.1}$$

Where:

- e = peak voltage induced in the inductor (volts)
- B = field strength between the poles (Tesla)
- l = active length of conductor (meters)
- v = velocity of the conductor through the field (m/sec)

Example 3.1.1:

A conductor that has an active length of 4 meters passes through a field of 5 Tesla at a speed of 15 meters per second. Determine the peak voltage induced on this conductor.

Solution

(4 m)(5 T)(15 m/sec) = 300 volts peak

That's crazy! Who discovered that? The discovery of electromagnetic induction is attributed to Michael Faraday who discovered that when he passed a magnetic field through a conductor a current would flow. As long as there was motion between the field and the conductor, a voltage could be induced. This could mean the conductor passes through a field or a field passed through a conductor.

3.2: The Alternator

How do we keep the voltage coming?

We have established that if we have a conductor pass through a field or a field through a conductor a voltage is established. This means that voltage is only established when there is constant motion. Instead of having someone passing a conductor through a field rapidly, it was discovered that the conductor could be formed into a loop and rotated through the field to maintain a voltage. This would be an example of what is known as a **simple alternator**.

A simple alternator has two magnetic poles that establish a magnetic field. The conductor (armature) rotates through this field to establish a voltage.

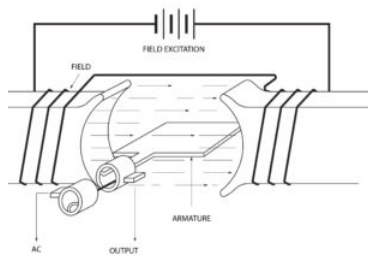


Figure 46. Simple alternator

A **practical alternator** has a stationary conductor and the field rotates.

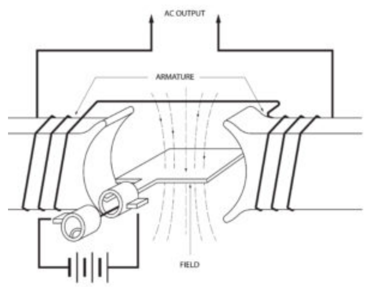


Figure 47. Practical alternator

What are the parts of the alternator?

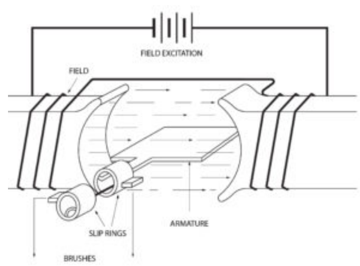


Figure 48. Simple alternator parts

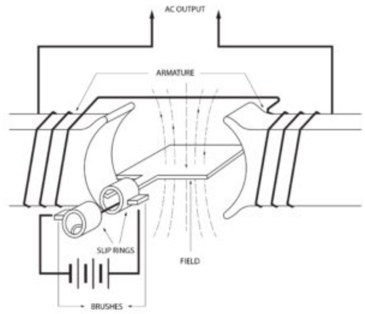


Figure 49. Practical alternator parts

Armature. This part is what the voltage is induced on to. It can be rotating (simple alternator) or stationary (practical alternator).

Slip rings. Made of brass, they rotate and either bring current to the load (simple alternator) or excitation to the field (practical alternator).

Brushes. Made of graphite carbon, they are stationary and either pass current to the load (simple alternator) or current to the field (practical alternator).

Field poles. They are either stationary (simple alternator) or rotating (practical alternator).

Prime mover. This part spins the armature (simple) or the field (practical). Examples include:

- combustion engine
- hydro dam
- hand crank
- windmill

Which is better the simple or the practical?

If you guessed the practical, you would be right. The brushes of a simple alternator have to be sized for the load. If you have a large load that draws a lot of current, then your brushes would have to be sized accordingly. Whereas, with the practical alternator the brushes bring current to the field and can be small yet still allow enough current to adjust the field. With either alternator, the easiest way to adjust the voltage is by varying the field strength. It is possible to vary the speed on the alternator to adjust the voltage, but this will also change the frequency.

3.3: How a Waveform Is Generated

AC generation with an alternator

If Faraday has taught us anything it is this: Any time you pass a conductor through a magnetic field, you induce a voltage. If we take that conductor and turn it into a loop and spin it continually through that magnetic field, we have created an alternator.

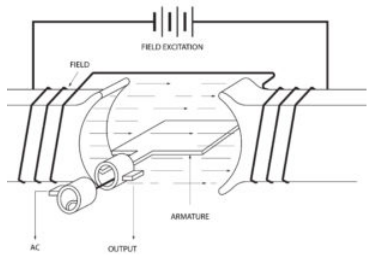


Figure 50. Alternator picture

This means that a voltage will constantly be induced. However, this is not a flat line voltage like direct current. It creates an oscillating voltage that rises and falls.

Is this what you mean by sine wave generation?

Yup, this is exactly what I mean. As the conductor spins through the field, there will be times that it does not cut any lines of flux. There will be times when it cuts some of the lines of flux, and there will be times that it is cutting the maximum amount of flux lines that it can. This means that at some point during the sine wave generation there will be no voltage generated. Then there will be some voltage generated, and then there will be a maximum voltage generated. This creates this thing of beauty. A sine wave.

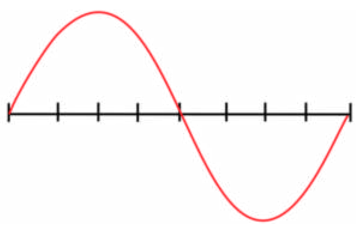
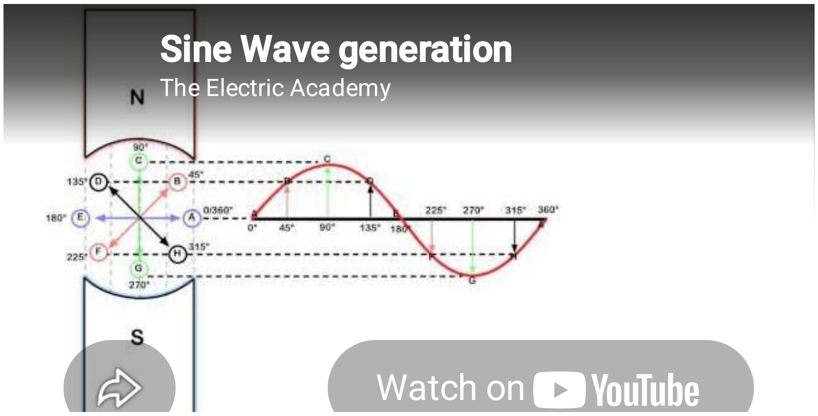


Figure 51. Sine wave

Oh yeah, I think I have seen that before

This wave pattern occurs often in nature, including ocean waves, sound waves and light waves. In fact, if you take the hours of daylight in a day and graph it out with the months of the year, guess what? A sine wave is generated. If you'd like to read an interesting article on the seasons and sine wave generation, read Calculus of the seasons. Isn't nature cool? But I digress. This sine wave is extremely important when it comes to electrical generation. Future postings will discuss its importance and go into in-depth analysis of the waveform.



3.5: Frequency and Alternators

In the last chapter, we learned the term **cycle** means from the point in a waveform to where the waveform starts to repeat itself. When we discuss the term **frequency**, we are referring to how many cycles can occur in one second. Frequency is measured in **hertz** (shout out to Heinrich Hertz) or **CPS** (cycles per second). Two factors affect the frequency in an alternator: rotation speed and the number of poles.

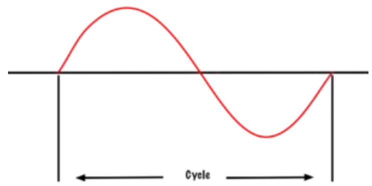


Figure 52. Sine wave cycle

Rotation speed

As the armature rotates through the field, it starts to create a waveform (as we saw in the last chapter). One full mechanical rotation of the armature creates one full sine wave on a two-pole alternator. If the two-pole alternator spins three complete revolutions in one second, it will create three full sine waves in that one second. We would say that the frequency is at three cycles per second or three hertz (as the cool kids say).

A machine's rotational speed is measured in rotations per minute or **RPM**. However, we are not concerned with minutes, but rather, with seconds when dealing with frequency. Therefore, RPM must be converted to rotations per second (**RPS**). As there are 60 seconds in a minute, all we have to do is to divide the RPM by 60 to convert it to RPS.

For example, if the armature is spinning at a rate of 1800 RPM on a two-pole alternator, we can say that it is spinning at 30 rotations per second. If this alternator has two poles, then in one second it will generate 30 cycles of voltage. It then could be said to have a frequency of 30 cycles per second or 30 Hertz. The frequency of an alternator is directly proportional to the rotational speed of the alternator.

Number of Poles

If we add poles to the alternator, we can change the frequency. In a two-pole alternator, Side A of the armature (Figure 53) passes from north to south, and then south to north, to create one complete sine wave. I f we add two more poles, as in Figure 54, then Side A of the armature will move past two north poles and two south poles in one full mechanical revolution.

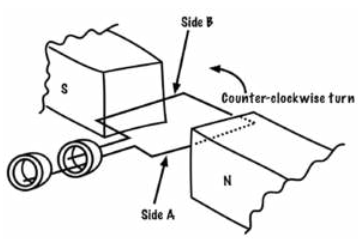


Figure 53. Two pole alternator

Two full sine waves are created in one complete mechanical revolution. If a two-pole alternator creates one cycle of voltage in one second (or one hertz of frequency), a four pole alternator will create two cycles of voltage in one second (or two hertz).

The frequency of an alternator is directly proportional to the number of poles in the alternator.

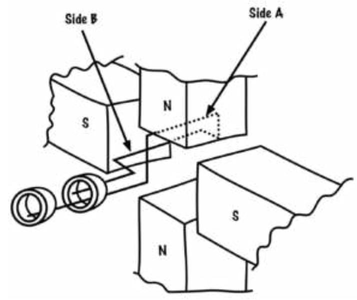


Figure 54. Four pole alternator

Formula time!

Knowing that rotation speed is directly proportional to frequency and that the number of poles is directly proportional to frequency, we can use a formula. The formula looks like this:

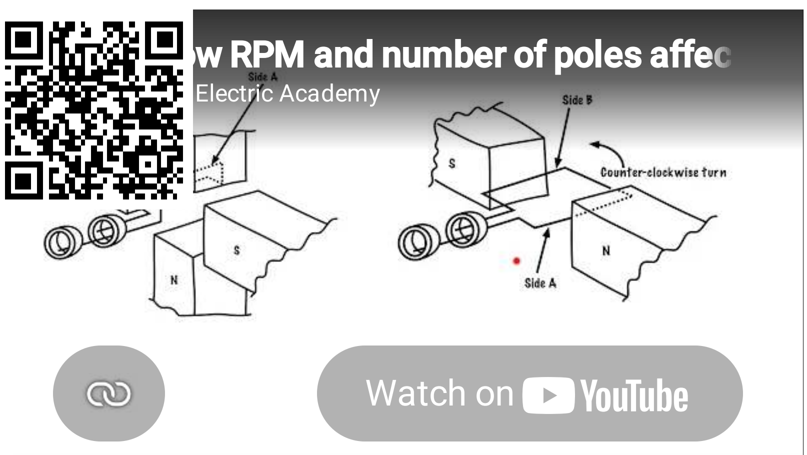
$$f = \frac{P}{2} \times \frac{N}{60} \qquad \text{(Frequency formula)}$$

where…

- f = frequency in hertz
- P = number of poles
- N = rotational speed in RPM

We divide the number of poles by two because there will always be a set of two poles. You can’t have a north pole without a south. We divide the RPM by 60 because we are concerned with rotations per second, not rotations per minute. The formula in Figure 56 can be combined to look like this:

$$f = \frac{PN}{120} \qquad \text{(Combined frequency formula)}$$



Video! This video will walk you through how frequency is related to the RPM and the number of poles of an alternator.

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