

AC Power Part 4 - Transformers

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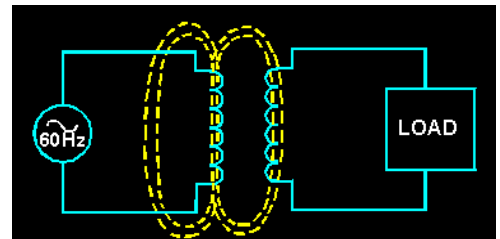
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Last month we studied the properties and effects of resistive, inductive and capacitive loads in an AC circuit. This month we will take self induction a step further and apply it to that very simple machine that is at the heart of AC power - the transformer.

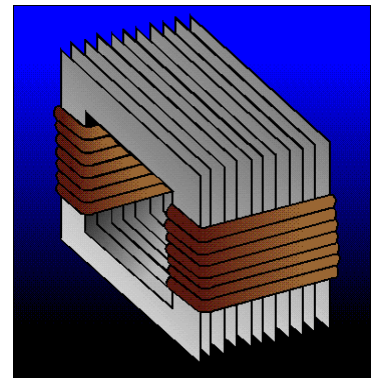
As I mentioned in Part 1, one of the unique qualities of AC power is that its voltage can be changed easily and in either direction - up or down. This allows us to generate power at some voltage and step it up to a higher voltage for long distance transmission. This decreases losses due to heat and significantly reduces the wire size. Once it reaches its point of use, voltage can be reduced to a useable intensity. The key element in this process is the transformer and the key to its operation is a phenomenon known as mutual induction.

Mutual Induction

If two coils of wire are placed near each other (see Figure 1), an alternating current flowing in one will create a magnetic field that induces a voltage and current in the one nearby even though they are not in direct contact. The reason this occurs is because the lines of flux associated with the magnetic field extend well beyond the coil that created them. This property is called mutual inductance or mutual induction and it is the basis of the transformer. The transformer gets its name from the process of transforming electrical energy into magnetic energy and then back to electrical energy. The coil that produces the magnetic field is called the primary (input) and the coil that intercepts that field is called the secondary (output).



Although some transformers consist of coils separated by an air gap, most utilize insulated wire wound about a laminated iron core (see Figure 2). The iron core increases transformer efficiency by directing nearly all of the flux produced by the primary through the secondary coil. The



laminations reduce eddy current losses that would be much higher in a solid core design. Depending upon the design and capacity, transformer efficiency can range from 20% to 99%. Larger ones, designed for power distribution applications, generally operate at 98% or better. Another important property of the transformer is electrical isolation. Since the primary and secondary coils are not in contact the power source is isolated from the point of use.

Voltage, Current and the Turns Ratio

According to Faraday's law, voltage produced in the secondary of a transformer depends upon the voltage in the primary and the number of turns (loops) in the primary and secondary coils. This may sound a little complicated but it turns out that this relationship can be stated very simply with something called the turns to voltage ratio. The equation below, where V is voltage, N is the number of turns, p is the primary and s is the secondary, explains this relationship.

$$V_s = (N_s / N_p) \times V_p$$

Secondary voltage is directly proportional to the product of the turns ratio and primary voltage. If N_s is greater than N_p the voltage in the secondary coil will be greater than that of the primary coil and the transformer is called a step up transformer. If the opposite is true, we have a step down transformer. For example, suppose a transformer has a primary with 1000 turns and a secondary with 100 turns. Based on the equation above the turns ratio is 1/10 or 0.1. If the voltage feeding the primary is 1200V then the secondary voltage will be 120V.

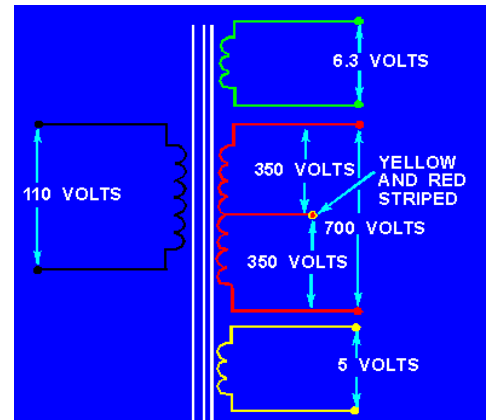
But, what about current - - how do we calculate its change? Well, the transformer is a pretty intelligent machine because it automatically adjusts current in order to keep power (in watts) constant. A slight modification of the original equation will explain this relationship.

$$I_s = (N_p / N_s) \times I_p$$

In the equation above, current (I) replaces voltage and the turns ratio is reversed. When there are fewer turns in the secondary a transformer steps down voltage but it increases current and thus keeps power constant. In the case of our step down transformer example above, if the primary is fed by 1200V @ 1A then the secondary would provide 120V @ 10A. Both volt / amp combinations provide 1200 watts of power.

Winding Configurations

Transformers allow an extremely flexible secondary output and are not limited to a single secondary winding. Figure 3 shows an example of a typical power supply transformer. The primary is fed by 110V and induces three individual secondary coils providing 5V, 6.3V and 700V. The 700V coil shows another feature of the transformer. A "tap" placed at the center of the coil provides two 350V outputs in addition to its full voltage output. Multiple taps may also be placed in a single coil.



Three Phase Transformers

Transformers used in three phase applications can consist of three, single phase transformers or a single one wound in a manner that accommodates all three phases. The primary and secondary windings of the three phase transformer are configured in two basic patterns - - Delta and Wye. The primary and secondary can be any combination of the two (ie Wye/Delta, Delta/Wye, Delta/Delta and Wye/Wye). In this column we will consider the Delta and Wye secondary characteristics only. I will give you some resources if you are interested in pursuing the effect of a particular primary on a secondary.

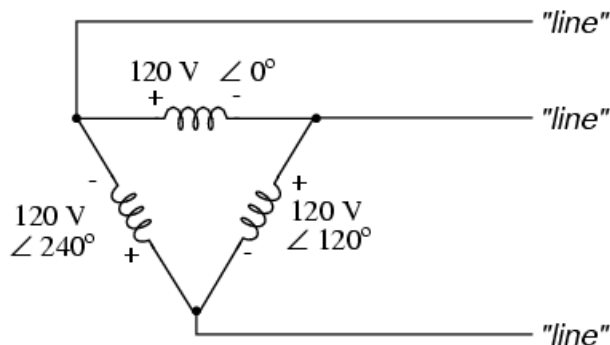


Figure 4 is the schematic of a Delta secondary that produces three individual phase voltages of 120V. The Delta gets its name from the Greek letter that has a similar appearance. Now, you might think that such a configuration would short circuit since they are connected in series. But, note

the angle associated with each phase starting at the top and proceeding counter clockwise. If you refer to the three phase power curve in Figure 3 of Part 2, you will see that the voltages cancel one another and no current flows through the circuit. If, however, a load is connected across any two of the three "lines", a current will flow and the line to line voltage will be the sum of the phase voltages which equals 240V.

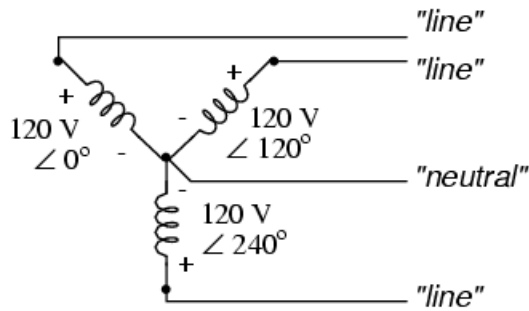


Figure 5 is the schematic of a WYE secondary that also produces three individual phase voltages of 120V. It gets its name from its resemblance to the letter Y and is sometimes called a "star". At the junction of the three phases a separate connection, known as a "neutral" is usually

supplied. A load connected between the "neutral" and any of the three "lines" will see a voltage of 120V. But, when a load is connected across any two of the three "lines" the voltage will not be the sum of the two phases. Instead it will be approximately 208V. The reason this occurs is due to the phase angle and the way the coils are connected. Although we will not show one here, a phasor diagram would illustrate that the voltage vector created by any two WYE phases produces a voltage that is only 1.732 that of the phase voltage. If you are interested in viewing WYE and Delta phasors, check out "The Changing Voltage Puzzler" on my web site.

Based upon the line to line voltage, it would appear that the WYE transformer is less efficient than the Delta. But, an interesting event occurs within the Delta configuration. A phasor diagram would show that the line to line current is only 1.732 of the phase current. Therefore the relationship below will hold true for any circuit regardless of whether it is Delta and WYE connected.

$$\text{Power (Watts)} = \text{Volts} \times \text{Amps} \times 1.732 \times \text{power factor}$$

I hope that this brief introduction to AC power has been useful. There is a lot more to learn so here are several web sites that you can visit for more training. In the future, I will do a similar series on AC motors.

All About Circuits - http://www.allaboutcircuits.com/vol_2/index.html

Integrated Publishing - EE Training Series - <http://www.tpub.com/content/neets/>

Electronics - Tutorials - <http://www.electronics-tutorials.ws/index.html>

Siemens - <http://www3.sea.siemens.com/step/templates/lesson.mason?bep:2:1:1>

Electrician's Toolbox - <http://www.elec-toolbox.com/>

RLC Circuits - Java Applet - <http://www.walter-fendt.de/ph14e/accircuit.htm>

Joe Evans is responsible for customer and employee education at PumpTech Inc, a pumps and packaged systems manufacturer and distributor with branches throughout the Pacific Northwest. He can be reached via his website www.PumpEd101.com. If there are topics that you would like to see discussed in future columns, drop him an email.