Technical White Paper

North American Power Distribution

Prepared By

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Abstract

The following is an overview of power generation, transmission, and distribution in North America. Electrical power is the lifeblood of our ever so gadget-filled, technological economy. For most, it's just a flick of a switch or the push of a button; many end users don't know or care about the complexities involved in the transportation of billions of kilowatts throughout the country.

However, one man by the name of Nikola Tesla had a vision for the use of electrical power back in 1882 when he realized that alternating current was the key to efficient, reliable power distribution over long distances. One obstacle that had to be overcome was the invention of an alternating current AC motor. Tesla demonstrated his patented 1/5 horsepower two-phase motor at Colombia University on May 16, 1888. By 1895 in Niagara Falls, NY the world's first commercial hydroelectric AC power plant was in full operation using Tesla's motor. To this day almost every electric induction motor in use is based on Tesla's original design.

Introduction

The purpose of this paper is to give the reader a basic understanding of the process involved in power generation, transmission/distribution, and common end-user configuration in North America.

Power generation is a topic of endless avenues and is a hot topic in today's economy due to power shortages, and environmental implications which result from our biggest source of generation; coal. This paper will briefly discuss the many types of power generation and the advantages of Hydro Electric power since it is the cleanest, most efficient way to generate large amounts of energy.

After the power is created the next step is transmission, this paper will discuss some of the common or preferred methods of transmitting power over hundreds of kilometers. After transmitted the most important stage would be the
distribution to the end customer, whether that be an industrial, commercial, or residential user. This will involve a discussion of how transformers couple the end user with the complex systems of power in North America.

Power Generation:

Energy is all around us in many forms. Over the past century there have been many clever ways created to harness this energy and effectively put it in a form that can be transported and used for a multitude of applications. Below is a list of the most common methods of converting energy into a usable form. They are in the order of the largest producer to the smallest.

1) Coal
2) Nuclear
3) Natural Gas
4) Hydro Electric (Water)
5) Petroleum
6) Geothermal
7) Solar/Wind/Biomass

In North America of all energy produced 10% is Hydro Electric. Fossil fuels lead the pack with 65% (combined coal and natural gas); these dirty producers provide many benefits to power plant owners. Coal and Natural Gas power

generators can be located very close to the load (end user) allowing for power plant owners to reduce their costs in transmission and construction. Unfortunately fossil fuel power generators are the worst producers of greenhouse gases, and are using up limited resources.

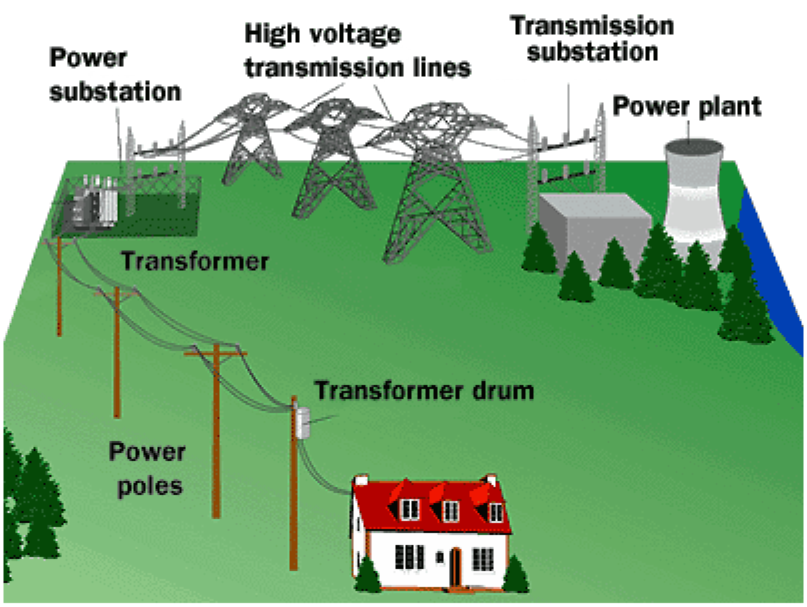
Hydro Electric is a clean and green friendly producer of power; its fall back is that it is very costly to implement the infrastructure. Hydropower plants convert the energy of falling water into electricity. A turbine converts the kinetic energy of falling water into mechanical energy. Hydro plants generally have four main components: Dam, Turbine, Generator, and transmission lines. The Dam raises the water level of the river to create falling water; it also controls the flow of water down the river. The stored energy is then directed to fall onto the turbine blades causing a mechanical motion of the shaft that is coupled into a generator. The generator is basically a motor that is spinning backward causing an electromagnetic field to induce a voltage on three sets of windings. Any change in the magnetic environment of a coil of wire will cause a voltage (electro magnetic field) to be "induced" in the coil. No matter how the change is produced, a voltage will be generated.

Power Transmission/Distribution:

Once the generator has produced the power it is then manipulated for transmission. The voltages generated from the generator are usually in the range of 25KV or lower. This voltage is much too low to send over long distance transmission lines. Power transmissions between the power plants and substations use high voltages in the range of 110KV to 800KV. The reason for this is the higher the voltage used in transmission results in lower current flow, allowing for savings in heat-related line losses.

After the power has been received at the substation it is then stepped down to reasonable voltage for local distribution, this is anywhere from 3.3KV to 25KV. The substation is responsible for distributing power to each of its end users, which may range from a large manufacturing facility, to a strip mall, to a residential home. From the power lines outside your house the voltage must be stepped down again to be useful for the end customer. This can range from 600V three phase down to 115V single phase, this completely depends on the user's service requirements and in what part of the country you are located. Figure 1-0 below shows an overview of power generation from the power plant, the power plant substation, the high voltage transmission lines and the end user substation to the final end users.

Figure 1-0



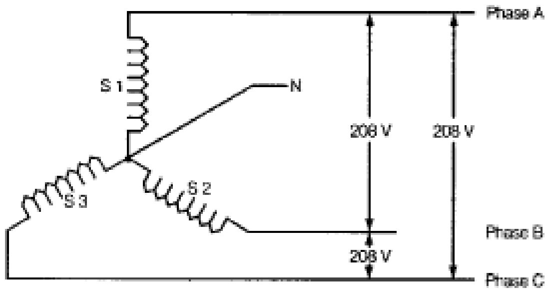
End User Configurations:

Power companies use transformers to step the voltage down and provide the various power configurations available to an end user. In order to get a better understanding of how the different of power configurations are generated a brief discussion on transformer configurations has been included in Appendix A at the end of this paper. This section will discuss some of the common types of end user configurations or services such as **230V/115V single-phase**, **208V three-phase**, **230V/115V three-phase, 230V three-phase, 460V or 480V three-phase, 575V or 600V three-phase**. Before discussing the different types of user configuration, it is important to understand some basic terminology when considering a multiphase power system.

Basic Terminology

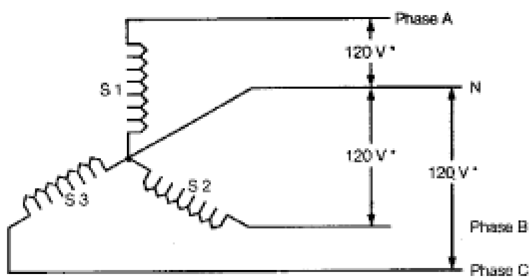
When discussing transformers it is useful to know the difference between **Phase Voltage** and **Line Voltage**. **Phase voltage** can be thought of as the voltage measured between any two phases, and **line voltage** is the voltage measured from any one phase to neutral. Below are examples showing these voltage potential measurement points in a standard 208V, 3ph, 4-wire transformer.

Figure 1-1 **Phase Voltage** Measured on a 208V, 3ph Wye Configured Transformer:



As you can see the Phase Voltage is measured from Phase A to Phase B or Phase A to Phase C or Phase B to Phase C.

Figure 1-2 **Line Voltage** Measured on a 208V, 3ph Wye Configured Transformer:

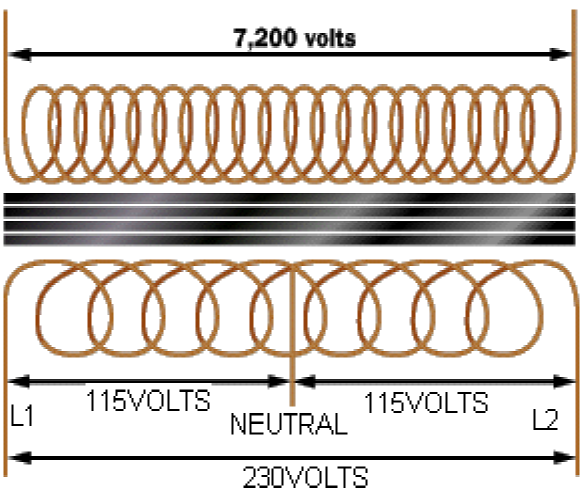


As you can see Line Voltage is the measurement is Between Phase A and Neutral, Phase B and Neutral, or Phase C and neutral.

230V/115V Single-Phase Service

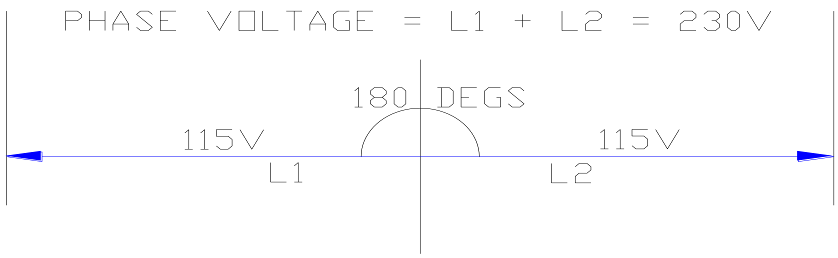
The most common power configuration in North America is the 230V/115V single-phase (1ph) service. This configuration is commonly found in residential and small commercial buildings. The major advantage of this configuration is that the user has access to 115V for common appliances such as lights, computers, TVs, refrigerators, etc, along with 230V to run larger power consuming appliances such as your dryer and stove. Using 230V to run appliances where a lot of power is required is much more effective than 115V because the current drawn is reduce by half allowing for smaller wires, and breakers to be used. In figure 1-3 there is a schematic view of a typical transformer you would find on a pole outside your home providing you 230V/115V 1ph power. As you can see this is a step down transformer, the 7200V is provided by power lines from the substation and is stepped down to 115V/230V.

Figure 1-3 230V/115V Single-Phase Power (1ph):



It is important to know that the voltage on L1 and L2 add together, if you were to measure the **phase voltage** you would measure 230V, similarly measuring **line voltage** you would measure 115V. This is because the voltages are 180 degrees out of phase with each other, and their vector sums are additive. Figure 1-3A shows this 180-degree vector relationship.

Figure 1-3A 208V Vector Relation of Single Phase Power:



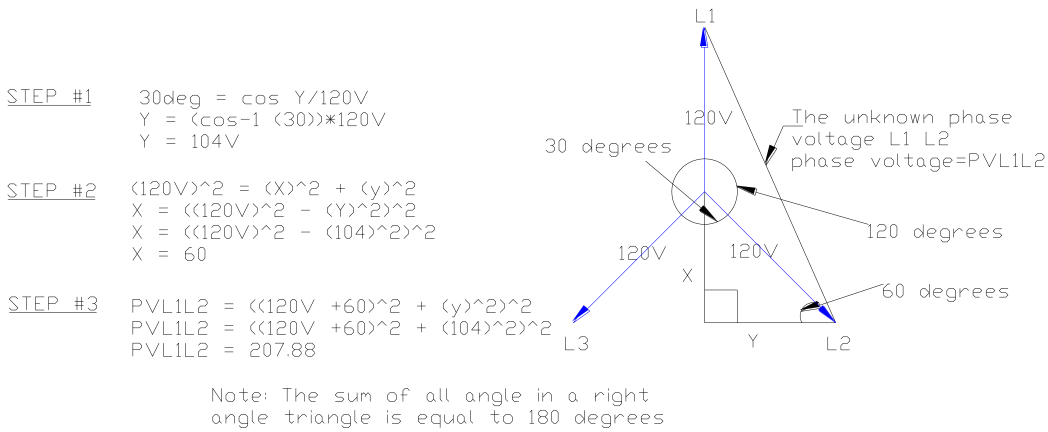
208V Three-Phase (Wye Configuration)

There are many advantages of the 208V three phase end user configuration, most notably, the line voltage on all phases is equal to 120V, additionally phase voltages are equally distributed allowing for a balance in power on each leg, providing both three phase loads and 120V single phase loads with balanced power. Figures 1-1 and 1-2 show a transformer with a wye configuration, and clarify the phase voltages and the line voltages, respectively.

At first glance it can be difficult to understand why on a 208V three phase service the voltage between L1 and N, is 120V, L2 and N is 120V, but the voltage between L1 and L2 is only 208V, not 240V. There is a perfectly logical explanation for this. The voltages on L1, L2 and L3 are out of phase with each other by 120 degrees, this means that at any instant in time the line voltages of L1, L2, and L3 are never equal to each other, since the voltage and current are alternating from zero to +120V to –120V but not all at the same time. The best way to describe this is to use vectors to represent each line voltage and angles to show the relationships between phases. This way, using trigonometry the 208V can

easily be calculated. Figure 1-4 shows how vectors can represent the line voltages and the angles between them, and how to use fundamental math to calculate the phase voltages.

Figure 1-4 Calculating 208V Phase Voltage (L1,L2) in a Three-Phase Wye Transformer:



230V/115V Three-Phase (High Leg Delta Configuration)

This configuration is most common in the southern states and is referred to as the farmer configuration. This is because as farmers upgraded their equipment they found they required three-phase power to run new three phase motors, but still needed to run the farmhouse off of 120V/240V. A solution was found by using a transformer with a high leg delta configuration.

This transformer configuration is usually seen as a 240V transformer with one winding configured with a center tap, this tap is usually the common point or neutral, see Figure 1-5 below. The advantage of this configuration is that it allows

a delta transformer to offer the features of three phase-balanced loads along with a 120V to connect lights and control power. The disadvantage of this configuration is that the line voltage of 120V can only be found on two of the lines (usually L1 and L3 to neutral). The middle leg L2 is referred to as the high leg. This is because its line voltage L2 to neutral measures

208V; the high leg can be calculated by multiplying the phase A to neutral voltage times 1.732 (120 x 1.732 = 208). Figure 1-6 shows how this is calculated.

Figure 1-5 230V Four wire (High Leg Delta) Configuration:

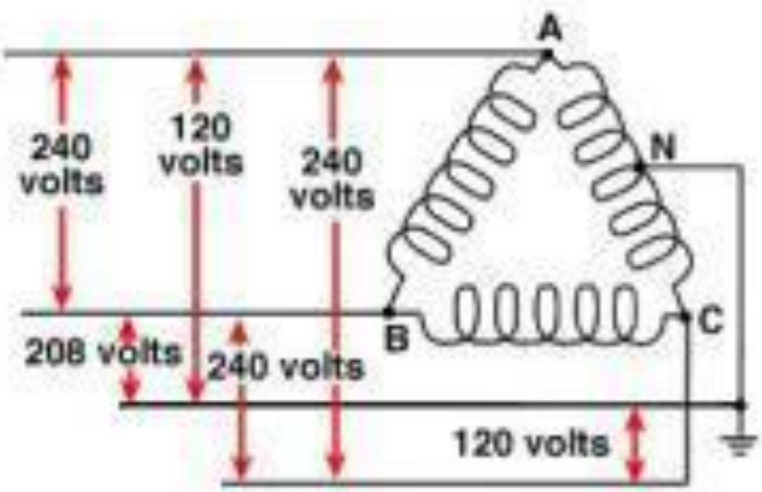
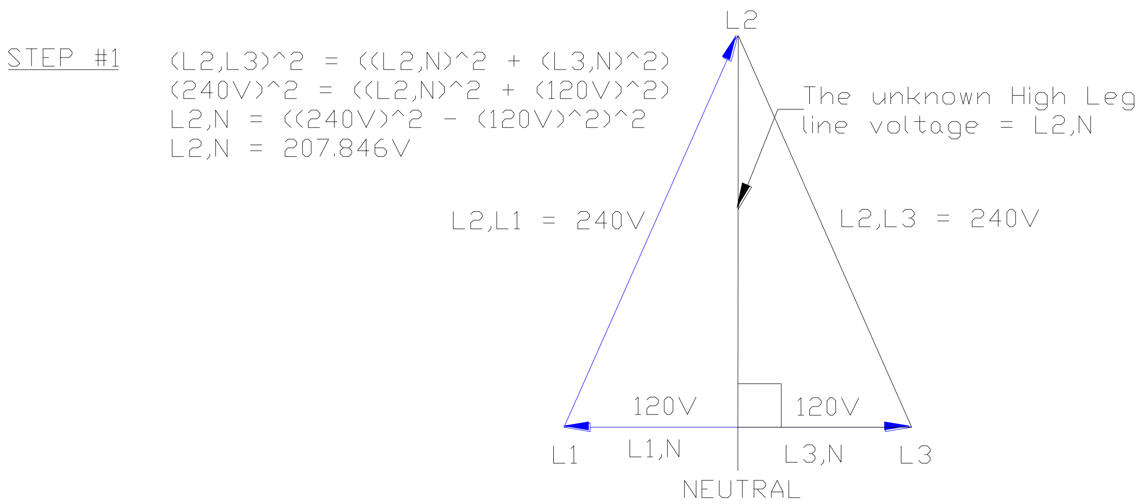


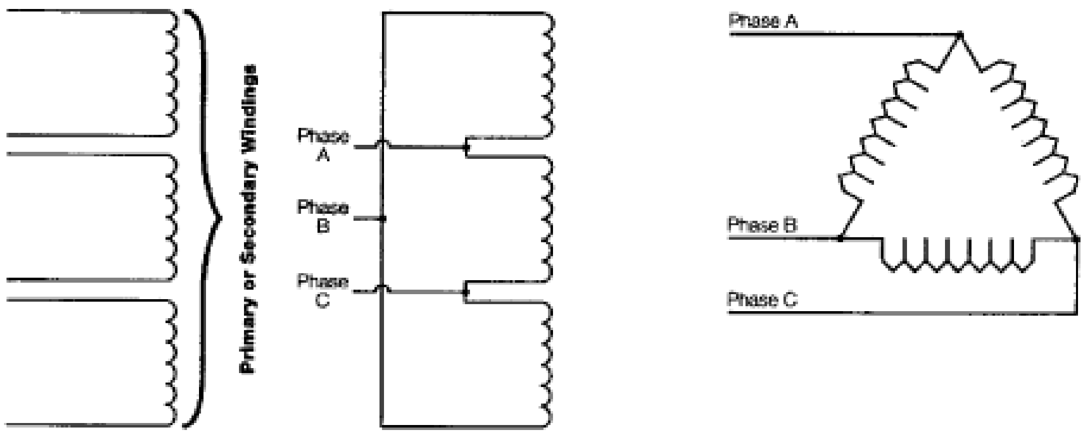
Figure 1-6 Calculating the High Leg Voltage in a High Leg Delta Configuration:



230V Three-Phase (Delta Configuration)

A very common end user configuration is the 230V three-phase transformer, it is also known as a delta configuration. It does have a disadvantage compared to 208V Wye and that is there is no neutral, this means 120V is not available. The advantage is that there are only three conductors (L1, L2 and L3). The arrangement of the windings can be described as connecting the three windings in an equilateral triangle; this means the end of each of the three windings is connected to another to form a triangle. This results in a three wire three-phase system; see Figure 1-7 for a wiring diagram.

Figure 1-7 230V/460V/480/575/600V Three wire (Delta) Configuration:



460V or 480V Three-Phase (Delta Configuration)

Similarly to the 230V three-phase Delta configured transformer, the 460 volt three phase three wire operates exactly the same except the phase voltage is 460V not 230V. The voltage level can range from 460V to 480V and is dependant on the area the service is located. 460V does have the same disadvantage when compared to 208V Wye and that is there is no neutral this means 120V is not available. One advantage even over 460V delta is that the voltage is much higher resulting in less current needed to run the same size of motors. When motors run at a higher voltage they run cooler and last longer because they do not have to run at such high amps to maintain horsepower. The arrangement of the windings can also be described as connecting the three windings in an equilateral triangle; this means the end of each of the three windings is connected to another to form a triangle. This results in a three wire three-phase system; see Figure 1-7 for a wiring diagram. Note that the phase voltage of L1, L2 is equal to 460V, L1, L3 = 460V, and L2, L3 = 460V.

575V or 600V Three-Phase (Delta Configuration)

Again this is very similar to the 460V three-phase Delta configured transformer, the 575 volt three phase three wire operates exactly the same except the phase voltage is 575V not 460V. It does have the same disadvantage when compared to 208V Wye and that is there is no neutral, this means 120V is not available. One advantage even over 460V delta is that the voltage is even higher resulting in less current needed to run the same size of motors. Again the arrangement of the windings can also be described as connecting the three windings in an equilateral triangle; this means each end of each of the three windings is connected to another to form a triangle. This results in a three wire three-phase system; see Figure 1-7 for a wiring diagram. Note that the phase voltage of L1, L2 is equal to 600V, L1, L3 = 600V, and L2, L3 = 600V. Figure 1-7A is a chart summary of the different types of power commonly seen on sites throughout North America.

Figure 1-7A Commons Site Power Summary

Common Site Power	*Advantages*	*Disadvantages*
460V or 600V, three phase Delta configuration	Lower Full Load Amps Smaller Service, Costs Less Motors Last Longer at Higher Voltage	Require a 460/120V Transformer 460V Rated Panel Components cost More
230V, three phase Delta configuration	Lower Full Load Amps than 208V No Manufactured Leg Service installation is less	Require a 230/120V Transformer Large Motors require VFD's
230V/120V,three phase High Leg	Lower Full Load Amps than 208V No Transformer Required for 120V	High Leg can be wired incorrectly Large Motors require VFD's
208V/120V, three phase wye	Smooth 3 phase power Three 120V lines	Motors draw higher Amps on 208V Large Motors Require VFD's and draw high amps
230V/120V, single phase Service	More readily Available More cost effective for small systems	Motors above 7.5hp are not available 1ph. Draws higher Amps and requires a larger service

Conclusion

In summary there are a number of different configurations available, it depends on your specific site and what part of North America you are located. When going to a site to work on a system, or to determine what type of power to use on a new site, it is important to understand what power is available. The best way to do this is ask your local utility provider what type of transformer or service is being used for that location. The common types you will find are what were discussed in this paper---single phase, wye, delta, high leg delta, or a delta configuration. Another important part of the site power configuration is what voltage and current is available---115V/230V 1ph, 120/208V 3ph, 115/230V 3ph, 230V 3ph, 460V 3ph, or 600V 3ph.

As discussed throughout this paper North American power generation and distribution is a very complex system and is an essential part of our lives. Understanding the limitations and advantages of these systems will only aid in promoting the need to conserve energy and look for new, cleaner, more economical sources of energy.

List of Resources:

1) www.federalpacific.com
2) www.phaseconverterinfo.com
3) Delmar's Standard Textbook of Electricity----By Stephen L. Herman

Appendix A: Transformers

A transformer can be defined as an electric device that changes voltage in direct proportion to current; all values of a transformer are proportional to the turn's ratio. Below is a group of formulas that show the relationship between voltages, current, and turns. Figure 1-8 shows a basic schematic of a transformer as you can see there is a primary and secondary winding, the number of times the wire is wrapped around the iron core is referred to as the turns. The turn's ratio is the primary turns divided by the secondary turns. The input side of a transformer is the primary side; the output of a transformer is referred to as the secondary side.

Figure 1-8 Basic Transformer Schematic:

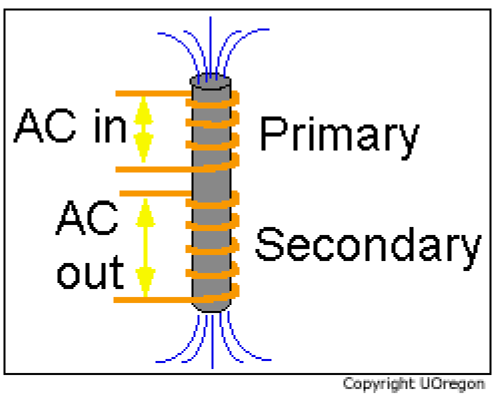


Figure 1-9 show a one to one turns ratio transformer. This transformer has 115V on the primary and 115V on the secondary the primary current is 1 amp and the secondary current is 1 amp. This is because there are the same amount of winding on the primary and the secondary.

Figure 1-9 One to One transformer:

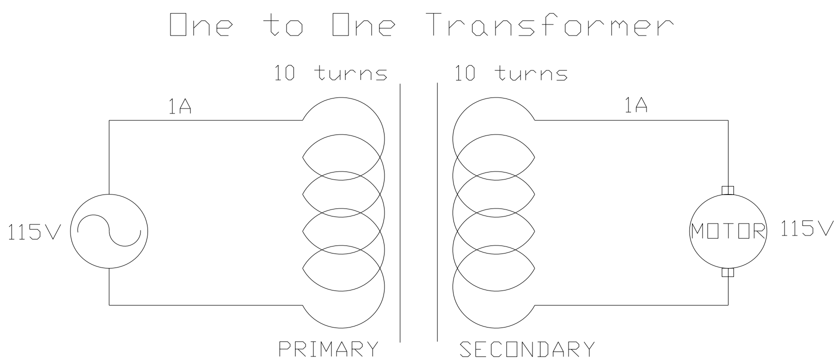
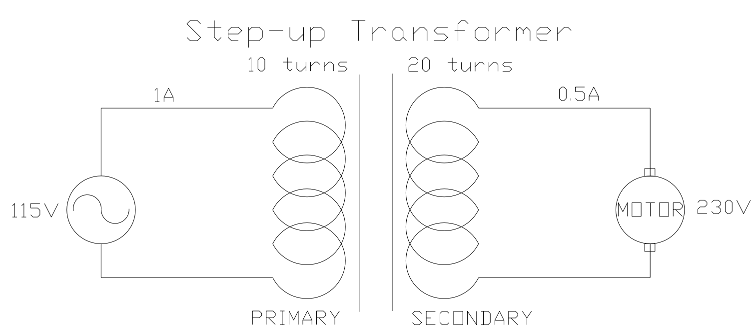


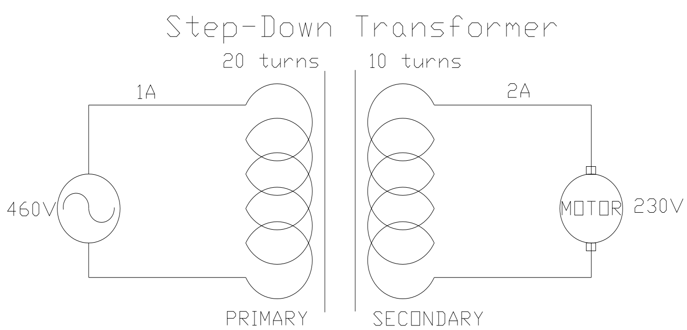
Figure 1-10 show a step-up transformer. This transformer has 115V on the primary windings and 230V on the secondary windings the primary current is 1 amp and the secondary current is 0.5 amps. This is because there are the twice the amount of winding on the secondary then there are on the primary. The voltage will double and the current will be halved, this is because the relationship of voltage and current are inversely proportional.

<u>Figure 1-10 Step Up transformer:</u>



Similarly Figure 1-11 shows a step-down transformer. This transformer has 460V on the primary windings and 230V on the secondary windings the primary current is 1 amp and the secondary current is 2 amps. This is because there is twice the amount of winding on the primary then there are on the secondary. The voltage will halve and the current will double, again this is because the relationship of voltage and current are inversely proportional.

Figure 1-11 Step down Transformer:



Below are the relationships between the Voltage, Current, and the Turns of a transformer.

Relationship Between Voltage and # of Turns/Windings:

Primary Voltage/ Secondary Voltage = # of Primary Turns/ # of Secondary turns

Relationship Between Voltage and Current:

Primary Voltage/ Secondary Voltage = Secondary Current/ Primary Current

Relationship Between # of Turns/Windings and Current:

# of Primary Turns/ # of Secondary turns = Secondary Current/ Primary Current

Three phase transformers are built by winding six windings on a single core and placing it in an enclosure filled with dielectric oil. The dielectric oil helps provide electrical insulation between windings and the case, and also cools the components to prevent deterioration of the winding insulation, which can be caused by moisture.

There are only four possible configurations of a three-phase transformer: Delta to Delta- this configuration is found mostly in industrial settings; Delta to wye- this is usually installed in commercial and small industrial buildings; wye to Delta is used only for high voltage transmission and; wye to wye is a rarely used configuration due to unbalancing issues and harmonics. The basic configuration commonly see on site are shown above.