

TRANSFORMERS

The main *purpose of a transformer* is to *change electrical voltage* from one level to another. A building may have a need for electrical power at several different voltages. A transformer is used to change the voltage to the desired level for the intended use. For example a building may be served with 3-phase power at 480Y/277 volts. That same building will most likely need 120 volts to supply general use receptacles. A transformer is used to change the 480Y/277 volts to 208Y/120 volts needed to supply the 120 volt receptacles and equipment. Electrical power can be moved efficiently across the country with minimal losses if the voltage is made very high. Transformers are used to increase the voltage to very high levels for transmission across the country and to reduce the voltage at each point of use. By increasing the voltage the current level decreases by the same ratio. By lowering the level of current energy losses are reduced.

Electrical Power Delivery System: To transport electrical power long distances it is necessary to decrease the level of current to keep losses at a minimum. Increasing voltage is necessary to reduce the level of current. Power is the product of voltage and current. Some transmission lines on steel towers operate with a voltage as high as 765,000 volts. A simplified electrical power generation and delivery system is shown in *Figure 218.1*.

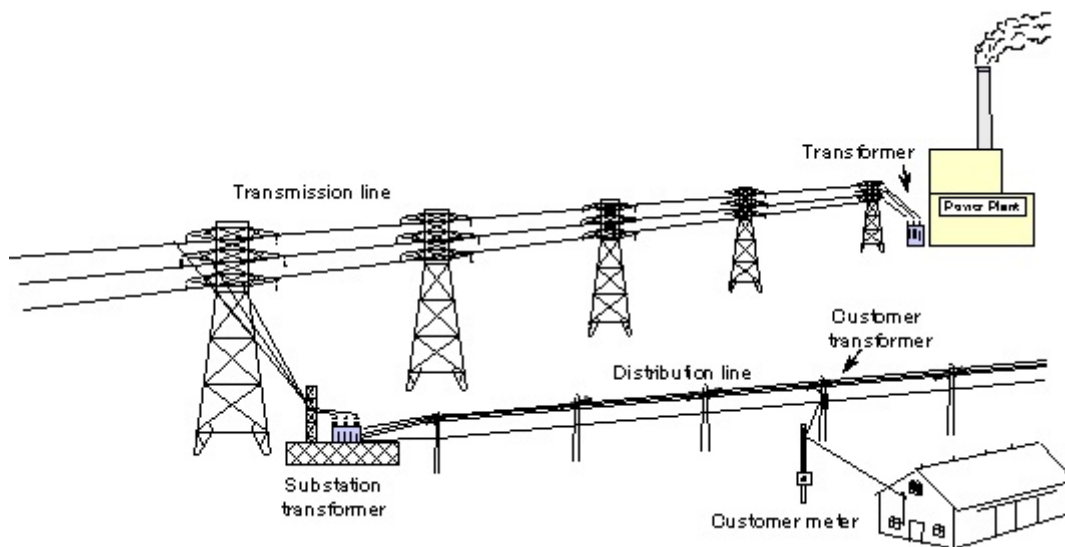


Figure 218.1 Electrical energy from the power plant is usually delivered to an area using high voltage transmission lines and then the voltage is lowered for distribution to customers.

At the point of use transformers reduce voltage to a lower level suitable to distribute the power to customers. A substation lowers the voltage suitable for distribution to customer locations. At customer locations voltage is again lowered to the level needed for customer use. This process is illustrated in *Figure 218.1*.

A typical home or farm using single-phase electrical power will have wires with two voltages. One voltage in a home is 120 volts and the other is 240 volts. A transformer often located at the top of the utility pole lowers voltage suitable for customer use. For a typical dwelling electrical power is reduced to 120 volts and 240 volts.

How A Transformer Works: A typical transformer has two separate sets of insulated electrical wire windings wrapped around a laminated steel core as shown in *Figure 218.2*. Current flowing through these coiled wires produces a magnetic field that goes into the laminated steel core. Electricity from utilities is alternating current that produces a magnetic field that is constantly in motion. The other important principal is that when a wire is placed in a magnetic field that is constantly in motion electrical current will flow in the other winding (secondary winding). The input winding is called the primary winding and the output winding is called the secondary winding. Because there are more turns of wire on the primary winding than the secondary winding, the secondary winding voltage is reduced to 120 volts and 240 volts which is needed for residential customers. The alternating current provided to the customer is known as 60 Hz electrical power. Utility transformers are not built like *Figure 218.2* but they perform exactly the same. This diagram is easier to visualize how a transformer works.

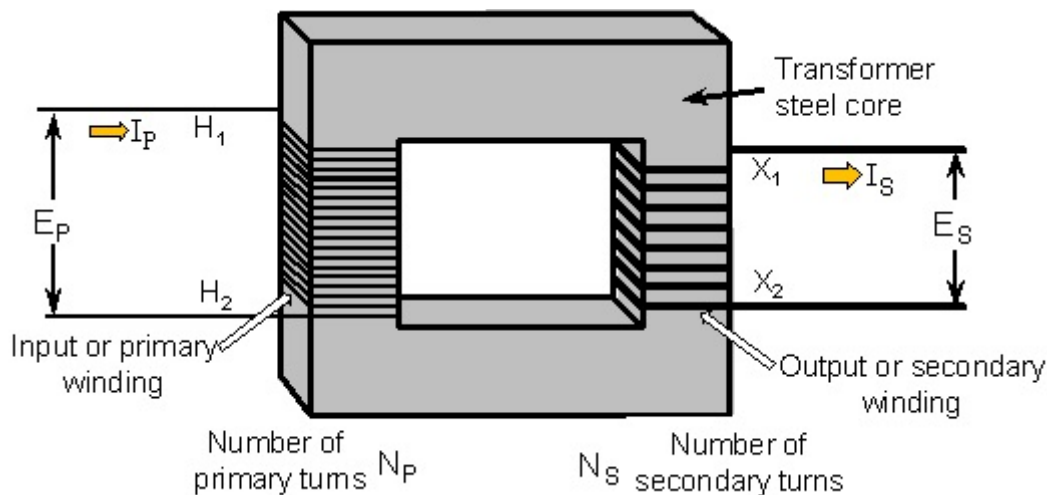


Figure 218.2 A transformer has a coil of wire called the primary winding and a separate coil of wire called the secondary both winding wrapped around the same laminated steel core.

The secret to changing the voltage in a transformer is the number of times a coil is wrapped around the steel core. If the output or secondary winding has half as many turns on the core as the input or primary winding, then the output voltage will only be half as much as the input voltage. Assume that there are 1,200 turns of wire on the primary winding and only 40 turns of wire on the secondary winding. This means that the output voltage of the transformer will be 1,200 divided by 40 turns. This is called the **turns ratio** which for this example is 30 to 1. If the primary input is 7,200 volts, the output secondary will be 240 volts. Simply divide 7,200 volts by 30 to get 240 volts. The following equation shows how to get output or input voltage when the other voltage and the number of turns on the transformer primary and secondary windings are known. The equations and calculations are on the next page.

Finding secondary voltage with primary voltage known:

$$E_s = \frac{E_p}{TurnsRatio} \quad E_p = E_s \times TurnsRatio \quad \text{Eq. 218.1}$$

Example: A transformer energized at 7,200 volts on the primary has 1,200 turns on the primary winding and 40 turns on the secondary winding. The output of the transformer is 240 volts.

$$E_s = 7200V \times \frac{40T}{1200T} = 240V$$

Finding primary voltage when secondary voltage is known:

$$E_p = E_s \times TurnsRatio \quad E_p = E_s \times \frac{N_p}{N_s} \quad \text{Eq. 218.2}$$

Turns Ratio: Generally the actual number of turns on the primary and secondary windings are only known to the transformer manufacturer. Instead of the ratio or number of turns on the primary voltage (E_p) and the secondary winding voltage (E_s) are provided on the transformer nameplate. The turns ratio can be determined by dividing the primary voltage by the secondary voltage.

$$TurnsRatio = \frac{N_p}{N_s} \quad TurnsRatio = \frac{E_p}{E_s} \quad \text{Eq. 218.3}$$

Example: A single-phase transformer has an input (primary) rated at 480 volts and an output (secondary) rated at 120 volts. The turns ratio for this transformer will be 4 to 1.

$$TurnsRatio = \frac{480V}{120V} = \frac{4}{1}$$

Transformer Diagram: A diagram is used to indicate a transformer in an electrical circuit. *Figure 218.3* shows a typical diagram for a transformer which may supply single-phase electrical power to a home or farm. The primary input wires are shown on the left, and the secondary output wires are shown on the right. It is usually difficult to show the actual number of turns of wire on the windings. If the input and output voltage is known, turns ratio is not needed.

The transformer diagram shows how 120 volts can be obtained when the secondary transformer voltage is 240 volts. This allows the customer to have 240 volts and 120 volts from the same transformer. There is a **center tap** made for the transformer secondary winding. Between the center tap wire and any of the other two wires is 120 volts. This wire is required by the electrical code to be connected to the earth by means of a grounding connection such as a special 8 foot long rod driven into the earth. There are many other ways to ground a customer electrical system that are known to licensed electricians. The symbol for an earth grounding connection is shown in *Figure 218.3*.

The *National Electrical Code* requires the middle wire of the secondary winding be grounded to the earth often with a ground rod. The middle wire is called the *neutral*. The voltage from the bottom wire to the top wire is 240 volts. This is how two voltages are produced for use in a home or a farm building. From the bottom wire to the middle wire is 120 volts and from the middle wire to the top wire is 120 volts. The top and bottom wires are called the ungrounded (hot) wires, and the middle wire is called the grounded (neutral) wire. There is other grounding to the earth at the utility transformer pole that is not shown in *Figure 218.3*.

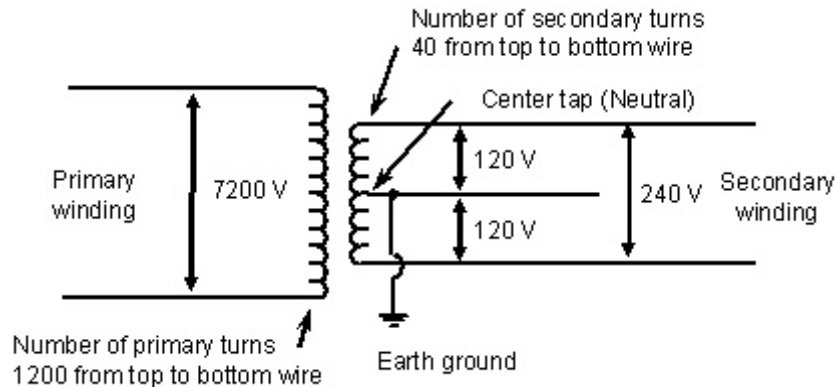


Figure 218.3 This diagram of a transformer shows how the 7,200 volts of the primary distribution line is changed to 120 volts and 240 volts for use in a home or farm building.

Utility Transformer: The power supplier transformer on a pole contains the two windings inside of a steel tank. The high voltage terminal is usually on top of the transformer and the low voltage customer terminals are on the side of the tank. There are actually three secondary terminals which deliver single-phase power to homes and farms. A diagram of a power supplier transformer is shown in *Figure 218.4*. Sometimes the transformer has two insulators on top and sometimes only one. It may seem that only one primary wire connects to the transformer but there are actually two wires. It may be difficult to tell how the primary grounded wire is connected to the transformer primary

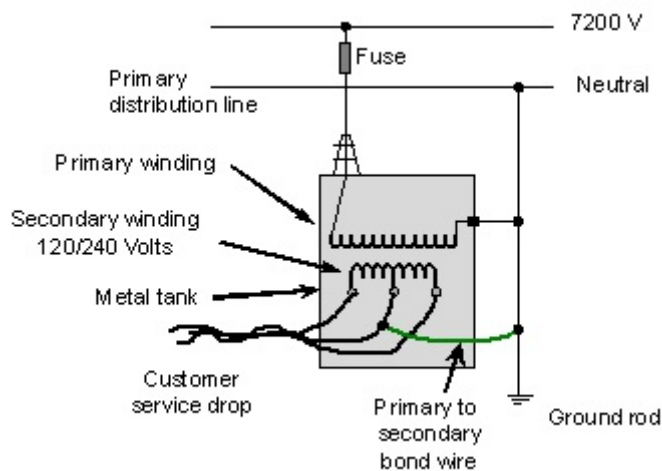


Figure 218.4 A power supplier transformer on a pole has the windings and steel core contained on the inside of the transformer tank.

Transformer (xfmr) Primary & Secondary Current Ratings: For the purpose of calculations it is assumed the product of primary voltage and primary current ($E_P \times I_P$) is equal to the product of secondary voltage and secondary current ($E_S \times I_S$). Refer to Eq 218.4. Actually there are small losses which will make the product of primary voltage and current slightly larger than secondary produce of voltage and current, but this small difference is generally not considered in calculations.

$$E_P \times I_P = E_S \times I_S \quad \text{Eq. 218.4}$$

If Eq. 218.4 is true than when E_P and E_S are not the same value, I_P and I_S will not be the same value. If E_S is smaller than E_P , I_S will have a larger value than I_P . If primary and secondary voltage are known as well as either I_S or I_P , the other current can be calculated using either Eq. 218.5 or Eq. 218.6.

$$I_P = I_S \times \frac{E_S}{E_P} \quad I_P = \frac{I_S}{\text{TurnsRatio}} \quad \text{Eq. 218.5}$$

$$I_S = I_P \times \frac{E_P}{E_S} \quad I_S = I_P \times \text{TurnsRatio} \quad \text{Eq. 218.6}$$

Example: A 25 kVA single-phase transformer has a primary energized at 480 volts with a secondary output of 240 volts and a full load secondary current of 104 amperes. Determine the primary full-load current. (Use Eq 218.5)

$$I_P = 104A \times \frac{240V}{480V} = 52A$$

As is evident by this calculation, the size of the primary wire supplying this transformer is permitted to be much smaller than the size of the secondary wire supplying the load.

Transformer Ratings: Transformers are rated in the amount of current each winding can handle at a given voltage which is expressed in voltage times current or volt-amperes, VA. Generally the rating is in thousands of volt-amperes or kVA. The letter **k** is the metric symbol for 1,000 and VA represents volt-amperes. The primary and secondary windings are designed to both have the same kVA rating. Assume the transformer used in the earlier example has a rating of 25 kVA and a primary winding operating at 7,200 volts and a secondary winding operating at 240 volts. The amount of current each winding can handle is determined by multiplying the kVA rating by 1,000 and then dividing by the winding voltage.

Transformers kVA, single-phase:

$$kVA_{1-phase} = \frac{E_P \times I_P}{1000} \quad kVA_{1-phase} = \frac{E_S \times I_S}{1000} \quad \text{Eq. 218.7}$$

For the previous example of the 25 kVA transformer, the primary winding full-load current was 52 amperes when the secondary winding is delivering 104 amperes to the customer load. These are continuous current ratings. The windings can handle this much current indefinitely. Utility transformers are designed to deliver overload current at higher levels for short periods of time without damaging the windings.

A task frequently experienced by an electrician or an engineer is to determine the minimum size of wire required for the primary feeding the transformer and the secondary wire delivering current to the load. Specific rules can be found in *Article 450 of the National Electrical Code*. The task is to determination of the full-load rating of both the primary and secondary of the transformer. For a single-phase transformer simply multiply the kVA rating by 1,000 and then divide by either the primary voltage or the secondary voltage. The following equations are used for that purpose.

$$I_s = \frac{kVA \times 1000}{E_s} \quad I_p = \frac{kVA \times 1000}{E_p} \quad \text{Eq. 218.8}$$

Transformer kVA, 3-phase: A 3-phase load may be supplied with a 3-phase transformer or the load can be supplied using individual single-phase transformers. For more on this subject see *Tech Note 220*. The 3-phase transformer will be supplied with three conductors where the current sine wave is 120° out of phase with the current sine wave of the other two conductors. The equations are similar to single-phase but for 3-phase calculations an additional factor must be used in the equations. This additional factor is the *square root of 3* which is the number 1.73. When determining the full-load current of a 3-phase transformer with the system phase-to-phase primary or secondary voltage known the 3-phase transformer kVA rating includes the value 1.73. Here are several equations useful when working with 3-phase transformers.

$$kVA = \frac{1.73 \times E_p \times I_p}{1000} \quad kVA = \frac{1.73 \times E_s \times I_s}{1000} \quad \text{Eq. 218.9}$$

$$I_s = \frac{kVA \times 1000}{1.73 \times E_s} \quad I_p = \frac{kVA \times 1000}{1.73 \times E_p} \quad \text{Eq. 218.10}$$

Example: The maximum secondary current rating of the 3-phase transformer required for a 208 volts secondary of a 37.5 kVA transformer is ?

$$I_s = \frac{37.5kVA \times 1000}{1.73 \times 208V} = 104A \quad I_p = \frac{37.5 \times 1000}{1.73 \times 480} = 45A$$

The calculation is the same as single-phase except for the factor 1.73.