Electrical Tech Note — 218

Biosystems & Agricultural Engineering Department
Michigan State University

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 desires level for the intended use. For example a building may be served with 3-phase power at 480/277 volts. That same building will most likely need 120 volts to supply general use receptacles. A transformer is used to change the 480/277 volts to 208/120 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.

Electrical Power Delivery System: The electrical power direct from the generator at the power plant is at about 15,000 volts. Transformers increase that voltage for delivery across the country. Some of those 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.

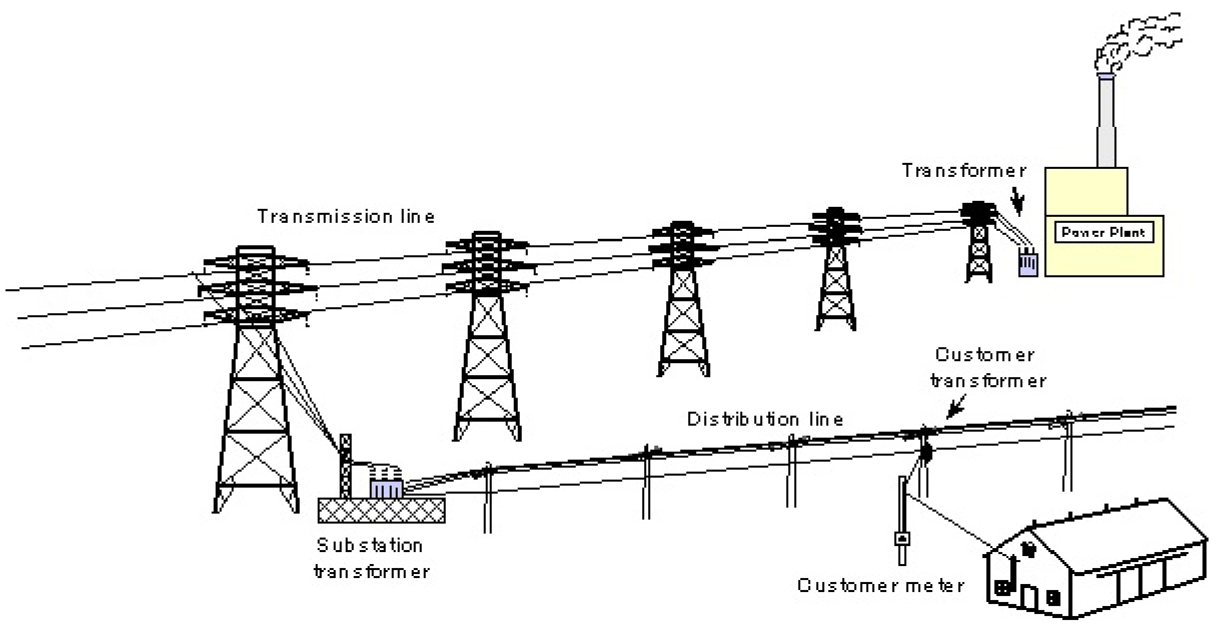

Figure 218.1 Electrical energy from the power plant is usually delivered to an area using high voltage transmission lines and then the voltage is lowered for distribution to customers.

Transformers are used to decrease the voltage from the transmission line to much lower levels for delivery to homes, farms, and businesses. A common single-phase distribution line operates at 7200 volts. Transformers at a fenced in location called a substation are

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used to lower the voltage from the transmission voltage level to the 7200 volts of the distribution line. The distribution substation is also shown 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 usually located at the top of the electrical pole in the yard lowers the 7200 volts of the distribution line to 120 volts and 240 volts needed for use in the home or on the farm.

How A Transformer Works: A typical transformer has two separate sets of insulated electrical wire wrapped around the steel core. This is shown in a simplified form in Figure 218.2. One principle of electricity is that when electrical current flows through a wire, a magnetic field builds up around the wire. The other important principal is that when a wire is placed in a magnetic field which is moving, electrical current will start to flow in the wire. In a transformer, electrical current is passed through one coil of wire called a winding. This winding is called the input winding or the primary winding. This electrical current produces a strong magnetic field in the steel core of the transformer. Because this is alternating current which travels back and forth through the wire 60 times every second, the magnetic field is constantly building up and collapsing 60 times every second. The moving magnetic field passes through the other coil or winding of the transformer and causes current to flow in that winding. So, electricity from the primary winding is turned into a magnetic field and then turned back into electricity at the secondary winding. This process makes it possible to change the level of voltage. The input winding (generally the higher voltage) is called the primary winding, and the output winding (generally the lower voltage) is called the secondary winding.

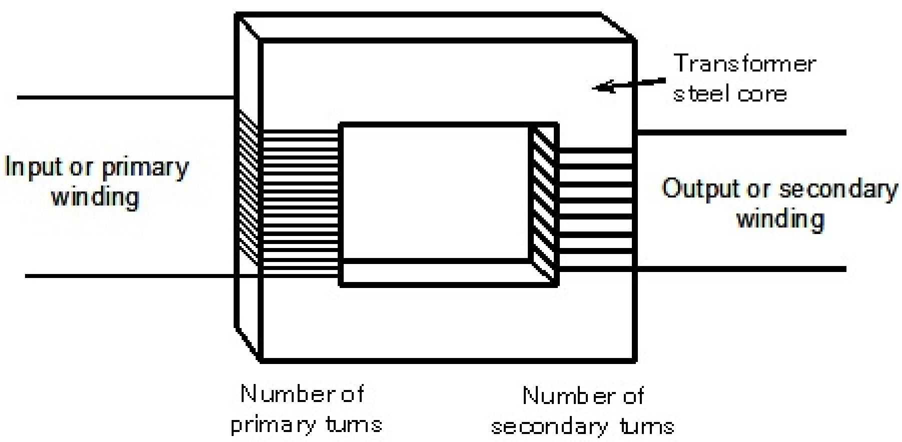

Figure 218.2 A transformer has a coil of wire called the primary winding and a separate coil of wire called the secondary winding wrapped around a steel core.

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 1200 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 40 divided by 1200 times the input voltage. If the input voltage was 7200 volts, the output would be 240 volts. The following formula 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.

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Finding secondary voltage with the primary voltage is known:

$$\text{Secondary Voltage} = \text{Primary Voltage} \times \frac{\text{Number of Secondary Turns}}{\text{Number of Primary Turns}}$$

Example: A transformer energized at 7200 volts on the primary has 1200 turns on the primary winding and 40 turns on the secondary winding. The output of the transformer is 240 volts.

$$\text{Secondary Voltage} = 7200\text{ V} \times \frac{40\text{ Turns}}{1200\text{ Turns}} = 240\text{ V}$$

Finding primary voltage when the secondary voltage is known:

$$\text{Primary Voltage} = \text{Secondary Voltage} \times \frac{\text{Number of Primary Turns}}{\text{Number of Secondary Turns}}$$

Turns Ratio: Generally the actual number of turns on the primary and secondary windings are not known. Instead the ratio of the turns on the primary winding to the number of turns on the secondary winding are known. This is called the turns ratio. The turns ration can be determined if the actual number of turns on the windings are known. The turns ratio can also be determined from the rated primary and secondary voltages. Turns ratio can be determined for a transformer using the following formula.

$$\text{Turns Ratio} = \frac{\text{Number of Primary Turns}}{\text{Number of Secondary Turns}} = \frac{\text{Primary Voltage}}{\text{Secondary Voltage}}$$

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.

$$\text{Turns Ratio} = \frac{480\text{ V}}{120\text{ V}} = \frac{4}{1}$$

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, so the number of turns may be stated next to the diagram. The transformer shown in Figure 218.3 is typical of the type used to supply single-phase power to homes and farms. It has three wires coming from the secondary winding. 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 of a typical utility transformer pole that is not shown in Figure 218.3.

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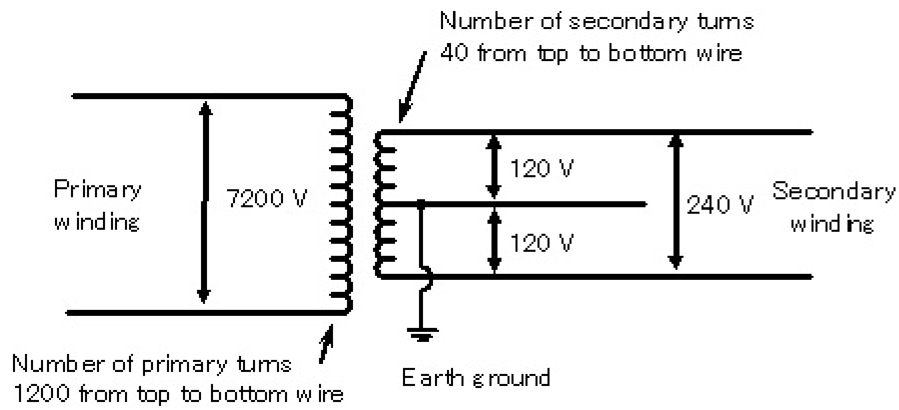

Figure 218.3 This diagram of a transformer shows how the 7,200 volts of the primary distribution line is changed to 120 volts and 240 volts for use in a home or farm building.

Power Supplier 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 terminals are usually 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 or the input winding. The connections are usually made inside of the transformer and the grounded wire of the primary line is often connected to the grounded wire of the home or farm, and also to a terminal on the side of the transformer tank.

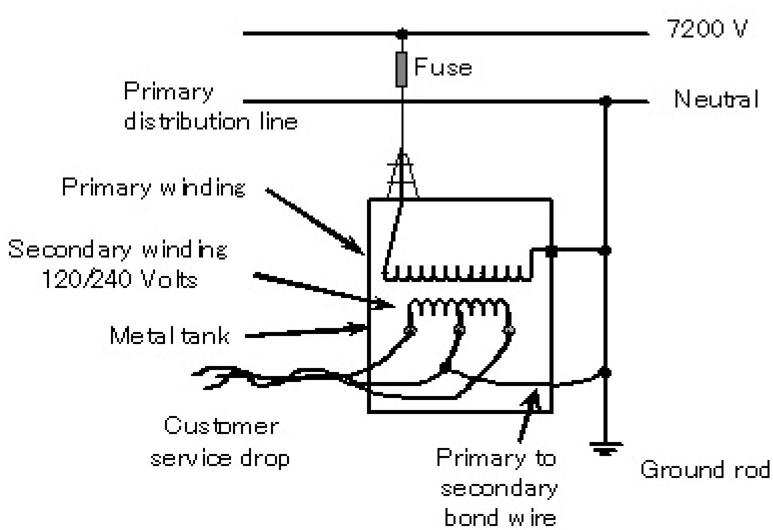

Figure 218.4 A power supplier transformer on a pole has the windings and steel core contained on the inside of the transformer tank.

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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 in amperes or volt-amperes. Generally the rating is in thousands of volt-amperes or kVA. The letter **k** is the metric symbol for 1000 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 7200 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 1000 and then dividing by the winding voltage as shown in the following formula.

Single-Phase Transformers:

$$\text{Transformer kVA rating} = \frac{\text{Winding Voltage} \times \text{Winding Current}}{1000}$$

$$\text{Winding current} = \frac{\text{kVA rating} \times 1000}{\text{Winding voltage}}$$

For the example of the 25 kVA transformer, the primary winding can handle 3.47 amperes and the secondary winding to the home or farm can handle 104 amperes. These are continuous current ratings. The windings can handle this much current indefinitely. Utility transformers are designed to deliver current at much higher levels for short periods of time without damaging the windings. The current for each winding is found as followings:

$$\text{Primary winding current} = \frac{25\text{ kVA} \times 1000}{7200\text{ V}} = \frac{25{,}000\text{ VA}}{7200\text{ V}} = 3.47\text{ A}$$

$$\text{Secondary winding current} = \frac{25\text{ kVA} \times 1000}{240\text{ V}} = \frac{25{,}000\text{ VA}}{240\text{ V}} = 104\text{ A}$$

3-Phase Transformers: When changing the voltage of 3-phase power a transformer will either have three sets of windings or three individual transformers will be connected together to form what is known as a 3-phase transformer bank. Formulas for determining the kVA rating needed when the current and voltage are known requires the multiplication by the square root of three which is the number 1.73. When determining the full-load current of a 3-phase transformer bank with the system phase-to-phase voltage known as well as the kVA rating of the transformer, the value 1.73 is in the numerator of the formula.

$$\text{Transformer kVA rating} = \frac{1.73 \times \text{Winding Voltage} \times \text{Winding Current}}{1000}$$

$$\text{Winding current} = \frac{\text{kVA rating} \times 1000}{1.73 \times \text{Winding voltage}}$$

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Example: The minimum rating of 3-phase transformer required to supply 100 amperes at 208 volts is 36 kVA. Actually a standard 3-phase transformer rating is 37½ kVA.

$$\text{Transformer kVA rating} = \frac{1.73 \times 208\ \text{V} \times 100\ \text{A}}{1000} = 36\ \text{kVA}$$

Example: A 3-phase transformer rated 75 kVA and connected to a 480 volt source to supply 208 volts will have a primary (480 V) full-load current rating of 90.3 amperes and a secondary (208 V) full-load current rating of 208 amperes.

$$\text{Primary Full-Load Current} = \frac{75\ \text{kVA} \times 1000}{1.73 \times 480\ \text{V}} = \frac{75{,}000\ \text{VA}}{1.73 \times 480\ \text{V}} = 90.3\ \text{A}$$

$$\text{Secondary Full-Load Current} = \frac{75\ \text{kVA} \times 1000}{1.73 \times 208\ \text{V}} = \frac{75{,}000\ \text{VA}}{1.73 \times 208\ \text{V}} = 208\ \text{A}$$

Transformers connected for 3-phase operation can be connected in two configurations, wye and delta. A complete discussion of the typical types of 3-phase electrical systems used in residential, farm, commercial, and industrial buildings is covered in Tech Note 220.

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