
An abstract geometric composition featuring several large, overlapping triangles in shades of orange, yellow, and black. These shapes are set against a dark background that contains a repeating pattern of the text "BASICS SERIES CUTLER-HAMMER 101" in a light, semi-transparent font. The triangles vary in size and orientation, creating a dynamic and layered visual effect. The overall aesthetic is modern and architectural.



WELCOME

Welcome to Module 4, which is about the transformer.

In this module you will begin to appreciate how the topics discussed in previous modules form the critical foundation for new topics. Topics from Modules 2 and 3 – such as electromagnetism, power, utility systems, and electrical distribution – all contribute to a more solid understanding of transformers.

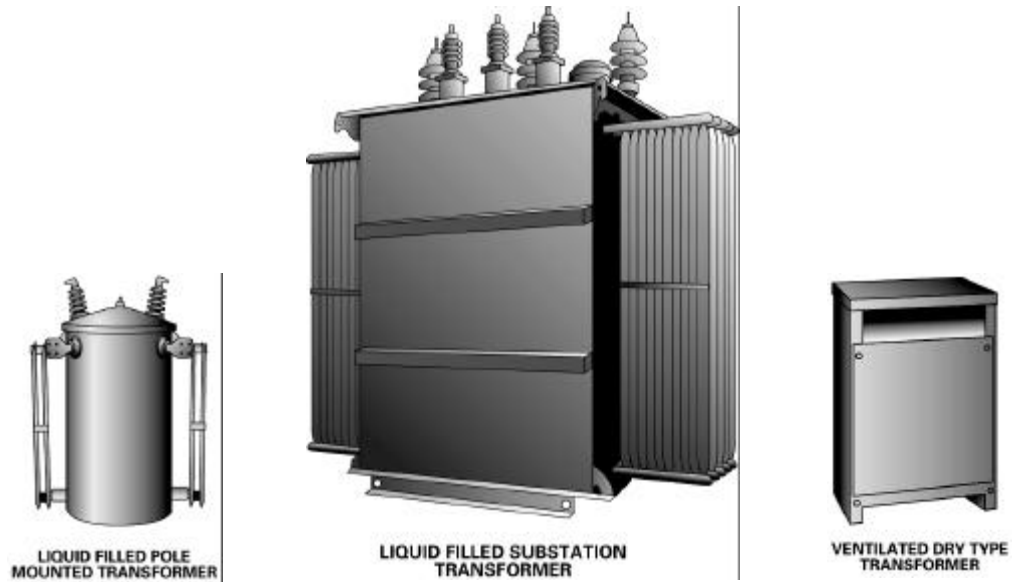


FIGURE 1: INDUSTRIAL TRANSFORMERS

Like the other modules in this series, this one presents small, manageable sections of new material followed by a series of questions about that material. Study the material carefully then answer the questions without referring back to what you've just read. You are the best judge of how well you grasp the material. Review material as often as you think necessary. The most important thing is establishing a solid foundation to build on as you move from topic to topic and module to module.

A Note on Font Styles

Key points are in bold.

Glossary items are italicized and underlined the first time they appear.

Viewing the Glossary

You may view definitions of glossary items by clicking on terms and words that are underlined and italicized in the text. You may also browse the Glossary by clicking on the Glossary bookmark in the left-hand margin.

TRANSFORMERS

WHAT YOU WILL LEARN

We will **step through each of these topics** in detail:

Section Title	Page Number
• Introduction	4
• What Is a Transformer?	5
• Input Connections	6
• Output Connections	6
• Windings	6
• Core	7
• How Does a Transformer Work?	8
• Induced Voltage	8
• Eddy Currents	9
• Turns Ratio	10
• Step-Up vs. Step-Down	11
• Is There Something for Nothing?	11
• Voltage Taps	12
• Review 1	13
• Transformer Configurations	14
• Configuration for Single Phase Power	14
• Configuration for Three Phase Power	16
• Delta and Wye Defined	17
• Configurations for a Three Phase Transformer	18
• Types of Transformers	21
• Power Transformer	21
• Distribution Transformer	22
• Autotransformer	23
• Isolation Transformer	24
• Instrument Transformer	25
• Current Transformer	25
• Potential Transformer	26
• Review 2	27

TRANSFORMERS

WHAT YOU WILL LEARN (CONTINUED)

Section Title	Page Number
• Principles of Operation and Terminology	28
• Coupling Coefficient	28
• Transformer Ratings	29
• Frequency	29
• Basic Impulse Level (BIL)	30
• Sound	30
• Altitude	30
• Transformer Losses and Efficiency	31
• Copper Loss	32
• Heat Dissipation (Cooling)	32
• Methods of Dissipating Heat	33
• Liquid-Filled Transformers	33
• Dry Type Ventilated Transformers	34
• Dry Type Specialty Transformers	35
• Helping the Customer	36
• Review 3	37
• Glossary	38
• Review Answers	42

TRANSFORMERS

INTRO- DUCTION

Transformers are all around you. They come in a wide range of shapes, sizes and application purposes. To get a general idea of where transformers are used, let's look at a simple electrical utility system.

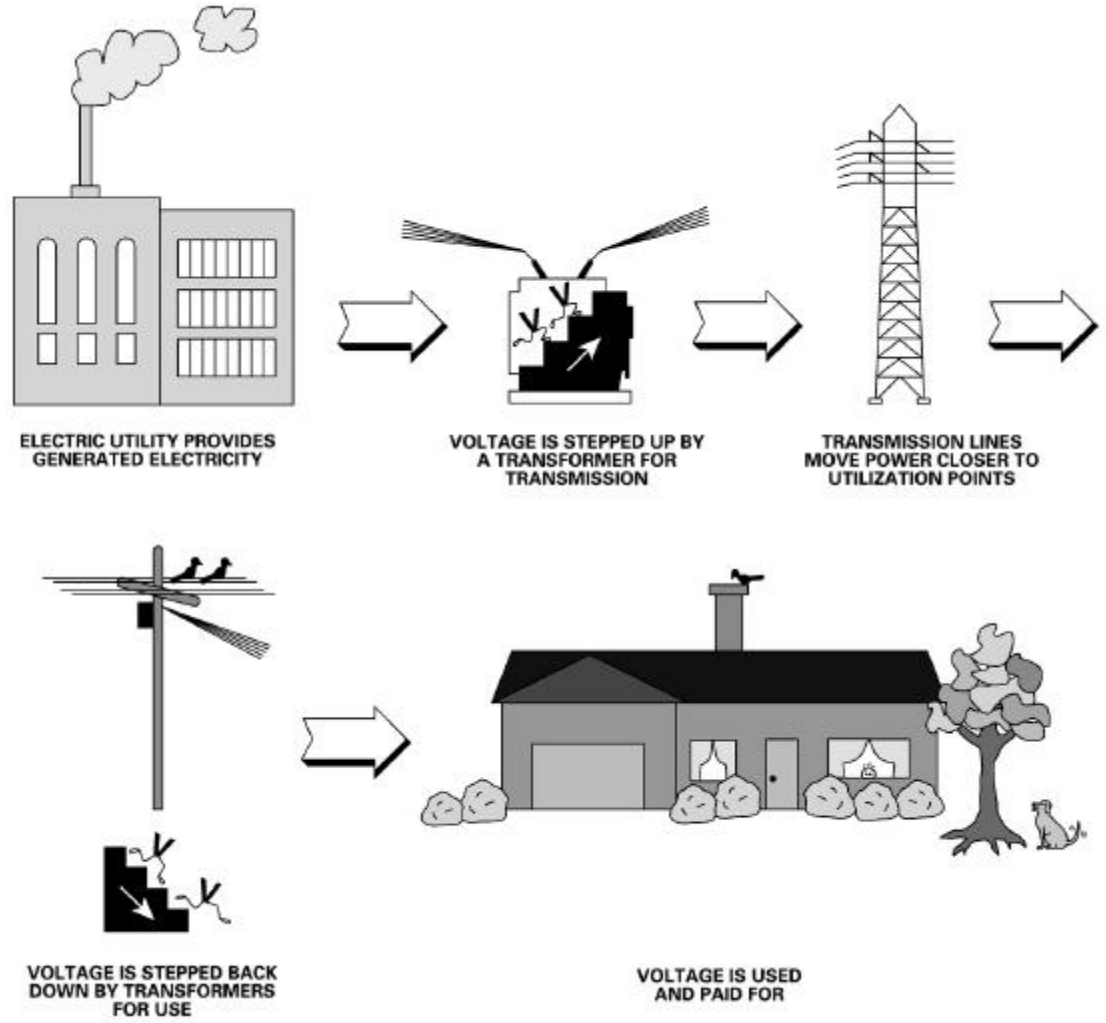


FIGURE 2: SIMPLE DISTRIBUTION SYSTEM

Once electricity is generated, the voltage is increased by transformers. It is then transported to substations, where transformers decrease the voltage to usable levels for industrial plants, shopping centers and homes. These large amounts of electricity are moved at high voltages for a number of reasons, such as lower losses of power and overall efficiency. The bottom line is: it costs less.

WHAT IS A TRANSFORMER?

A transformer is a **device that transfers electrical energy from one electric circuit to another, without changing the frequency, by the principles of electromagnetic induction.** The energy transfer usually takes place with a change of voltage. It either increases (steps up) or decreases (steps down) AC voltage.

A transformer **does not generate electrical power.** It **transfers electrical power** from one AC circuit to another through *magnetic coupling*. This method is when one circuit is linked to another circuit by a common magnetic field. Magnetic coupling is used to transfer electrical energy from one coil to another. The transformer *core* is used to provide a controlled path for the *magnetic flux* generated in the transformer by the current flowing through the *windings* (also called *coils*).

In order to understand the advantage and use of a transformer, let's first look at the basic transformer. There are four basic parts:

- *Input* connections
- *Output* connections
- Windings or coils
- Core

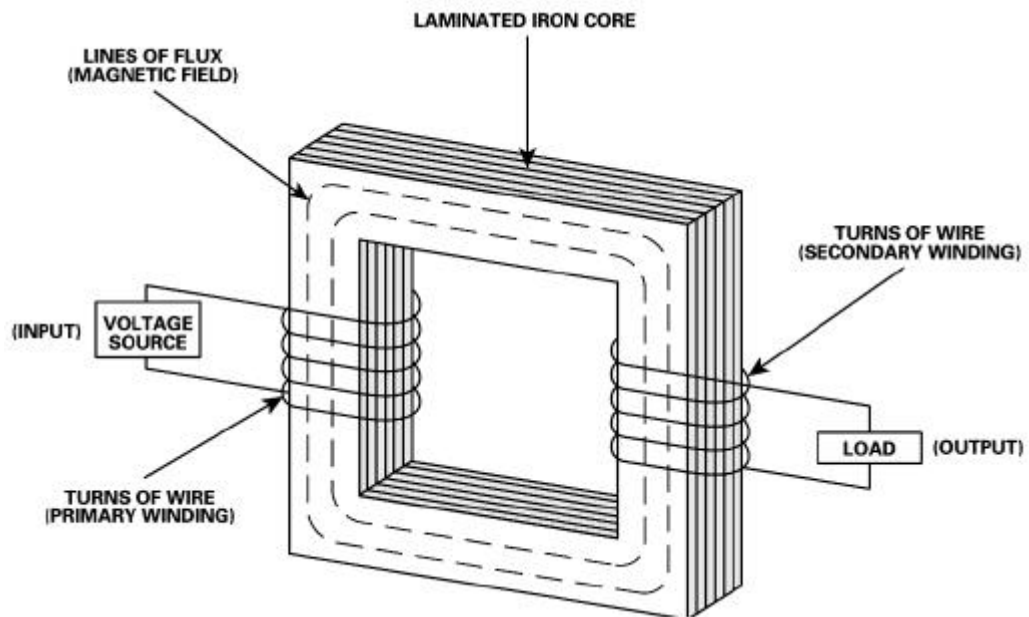


FIGURE 3: PARTS OF A TRANSFORMER

TRANSFORMERS

Input Connections

The input side is called the primary side of the transformer, because **this is where the main electrical power to be changed is connected.**

Output Connections

The output side is called the secondary side of the transformer. **This is where the electrical power is sent to the load.** Depending upon the requirement of the load, the incoming electric power is either increased or decreased.

Windings

The transformer has two windings, called the primary winding and the secondary winding, wound around an iron core. **The primary winding is the coil that draws power from the source. The secondary winding is the coil that delivers the energy at a transformed or changed voltage to the load.**

The primary and secondary windings of practically all transformers are subdivided into several coils. This is to reduce the creation of flux that does not link both primary and secondary. The transformer action can only exist when flux (mutual flux) couples both primary and secondary. Flux that does not do so is in effect leakage flux.

They are also subdivided to reduce the voltage per coil. This is important in high voltage transformers, in which insulation thicknesses make up a considerable part of the construction. In practice it is customary to subdivide a winding so that the voltage across each coil does not exceed about 5,000 volts.

Core

The transformer core is used to provide a controlled path for the magnetic flux generated in the transformer. The core is not a solid bar of steel, but is constructed of many layers (laminations) of thin sheet steel. It is laminated to help reduce heating, which creates power losses. Since the two circuits are not electrically connected, the core serves the very important part of transferring electrical power into the secondary winding through magnetic action. The core usually takes the shape of a square or a ring.

There are two general types of cores: *core type*, and *shell type*. They are distinguished from each other by the manner in which the primary and secondary coils are placed around the laminated steel core. They are:

Core type

In this type, the windings surround the laminated iron core. Figure 4 is a picture of an assembled core type transformer.

The primary and secondary coils are wrapped around the core side, with the low-voltage coil leads at the top and the high-voltage leads at the bottom. In practice, the primary winding is divided into an even number of separate coils, with half of them placed around one leg and the other half around the other leg. The same arrangement is used for the secondary winding. In some constructions the primary and secondary coils for each leg are assembled together to form a single unit, after which the assembly is dipped in insulating varnish and baked. This type is typically used with distribution transformers.

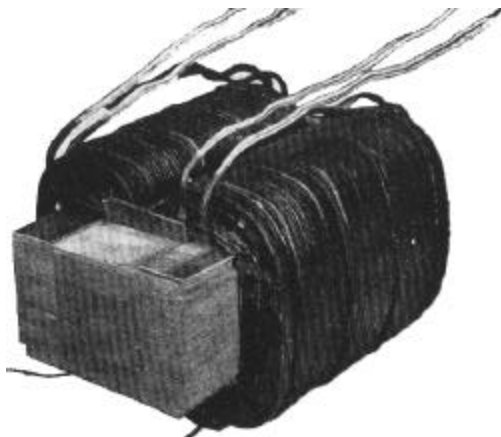


FIGURE 4 CORE-TYPE TRANSFORMER

Shell type

In this type, the core surrounds the windings. Figure 5 is a picture of a partially assembled shell type.

All primary and secondary coils are assembled insulated from each other after which the entire coil assembly is dipped in an insulating varnish and baked.

This type is typically used in very large transformers with high voltages. If a core transformer was used, a relatively large amount of the flux produced by the primary windings would fail to link the secondary windings, and a large leakage flux would result.

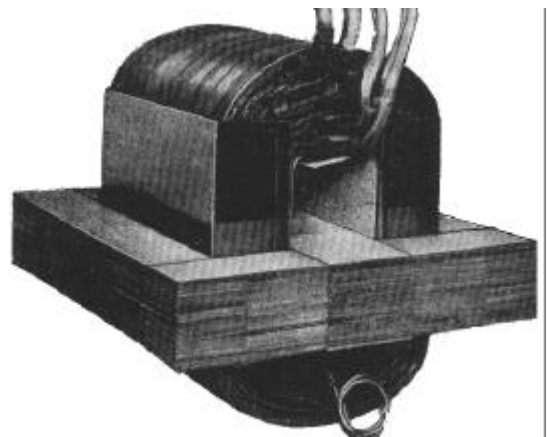


FIGURE 5 SHELL-TYPE TRANSFORMER

TRANSFORMERS

HOW DOES A TRANSFORMER WORK?

Induced Voltage

Now that you know the main parts of a transformer, let's look at how a basic transformer works.

When an input voltage is applied to the primary winding, alternating current starts to flow in the primary winding. As the current flows, a changing magnetic field is set up in the transformer core. As this magnetic field cuts across the secondary winding, alternating voltage is produced in the secondary winding. In short, **a voltage is being induced on the secondary winding.**

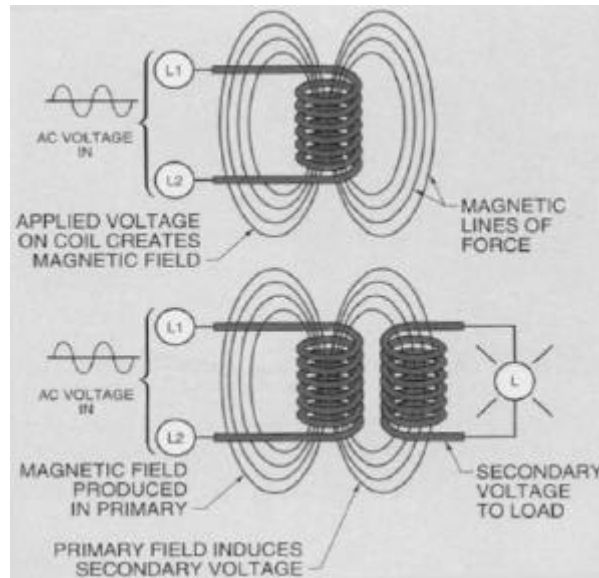


FIGURE 6: HOW INDUCTION WORKS IN A TRANSFORMER

Eddy Currents

As a magnetic field expands and collapses about the windings of the iron-core transformer, its flux lines cut across both the turns of the winding and the core. As a result, **voltages are induced in the core itself**. These voltages in the core create eddy currents. These currents move through the core in circular paths. Since eddy currents create heat in the core and do not aid the induction process, they are a waste of energy, referred to as an eddy-current loss.

Core designs have been created in an attempt to minimize these losses. For example, basic transformers use a laminated core made up of insulated layers, rather than a solid core.

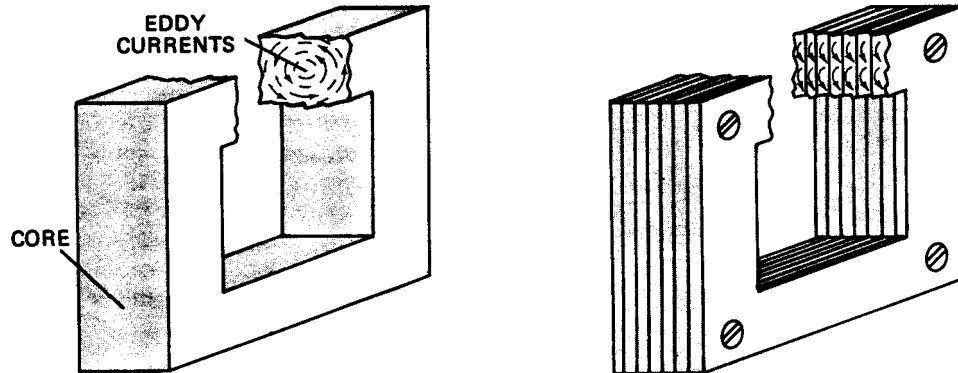


FIGURE 7: REDUCING EDDY CURRENTS BY USING A LAMINATED CORE

Because the sheets are insulated from one another, the resistance across the core is high. Eddy currents are reduced.

IN THE WORKPLACE

Transformers are often subjected to abnormally high voltage stresses caused by abnormal operating conditions, such as lightning and switching. This is especially true of high-voltage transformers, like this one, in use at a power relay station.

The end turns are the ones subjected to abnormal voltages, often high enough to break down the insulation. If this were to happen, current could arc between the turns.

As a protective measure, the turns on the top and bottom of this coil are more widely spaced. They are also more heavily insulated.

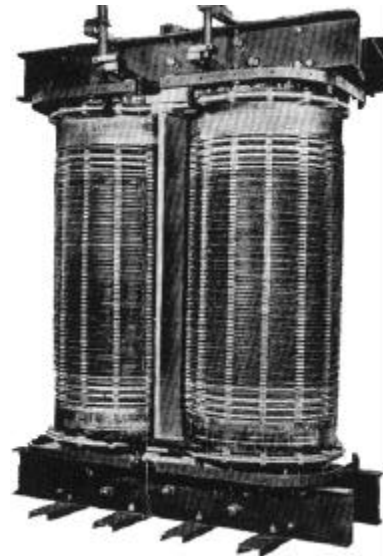


FIGURE 8: END TURNS ARE MORE WIDELY SPACED

TRANSFORMERS

Turns Ratio

The ratio between the number of actual turns of wire in each coil is the key in determining the type of transformer and what the output voltage will be. **The ratio between output voltage and input voltage is the same as the ratio of the number of turns between the two windings.**

$$\frac{\text{Voltage (input)}}{\text{Voltage (output)}} = \frac{\text{Number of Primary Turns}}{\text{Number of Secondary Turns}}$$

The relationship between the number of turns in the secondary and the number of turns in the primary is commonly called the turns ratio or voltage ratio.

It is common practice to write the turns ratio with the primary (input) number first, followed by the secondary (output) number. The two numbers are often separated by a colon.

Consider this example:

Transformer Primary Voltage: 480 volts
Transformer Secondary Voltage: 120 volts

$$\frac{480 \text{ volts}}{120 \text{ volts}} = \frac{4}{1} \text{ (4 primary turns for every 1 secondary turn)}$$

This transformer has four primary turns for every one secondary turn.

Turns ratio is written as 4 to 1, or 4:1.

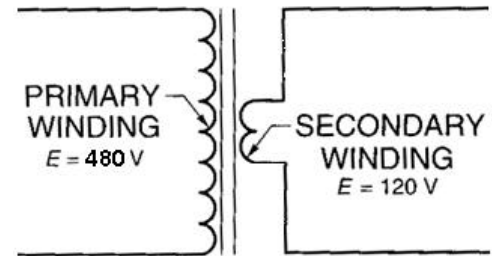


FIGURE 9: TURNS RATIO EXAMPLE

A transformer's output voltage is greater than the input voltage if the secondary winding has more turns of wire than the primary winding. The output voltage is stepped up, and we have a step-up transformer. If the secondary winding has fewer turns than the primary winding, the output voltage is lower. This is a step-down transformer.

Step-Up vs. Step-Down

Step-Up Transformer

The primary winding of a step-up transformer has fewer turns than the secondary winding, with the resultant secondary voltage being higher than the primary.

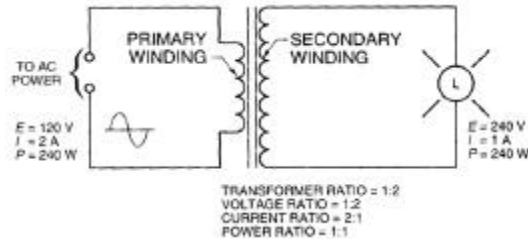


FIGURE 10: STEP-UP TRANSFORMER

Step-Down Transformer

The primary winding of a step-down transformer has more turns than the secondary winding, so the secondary voltage is lower than the primary.

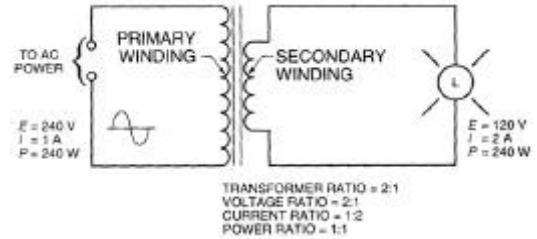


FIGURE 11: STEP-DOWN TRANSFORMER

Is There Something for Nothing?

In Figure 10, the step-up transformer has a 1 to 2 ratio. As a result, the output voltage is doubled. At first, this might seem like we are gaining or multiplying voltage without sacrificing anything. Of course, this is not the case. Ignoring small losses, the amount of power transferred in the transformer is equal on both the primary and secondary sides.

Power is equal to Voltage multiplied by Current. This is expressed by the formula:

$$P = V \times I$$

Power is also always equal on both sides of the transformer, meaning both sides of the equation must have the same value. **This means we cannot change the voltage without changing the current also.**

In Figure 10, we can see that when voltage is stepped down from 240 V to 120 V in a 2 to 1 ratio, the current is increased from 1 to 2 amps, keeping the power equal on each side of the transformer. In contrast, in Figure 11, when the voltage is stepped up from 120 V to 240 V in a 1 to 2 ratio, the current is reduced from 2 to 1 amp to maintain the power balance.

In other words, **voltage and current may be changed for particular reasons, but power is merely transferred from one point to another.**

One big advantage of increasing the voltage and reducing the current is that power can be transmitted through smaller gauge wire. Think about how much wire is used by a utility company to get electricity to where it is used. For this reason, the generated voltages are stepped up very high for distribution across large distances, then stepped back down to meet consumer needs.

Voltage Taps

As you know, the turns ratio determines the voltage transformation that takes place. **There are times that the actual incoming voltage is different than the expected normal incoming voltage. When this happens, it could be advantageous to be able to change the turns ratio in order to get the desired (rated) output voltage.** You might view this as fine tuning the input voltage to get the desired output. Voltage taps, designed into the transformer's primary winding, deliver this desired flexibility.

Suppose a transformer has a 4 to 1 turns ratio. Remember, that means the primary has 4 times as many turns as the secondary, which tells you the transformer is a step-down transformer. If the input voltage is 480 volts, the output would be 120 volts.

What if the input delivered to the transformer primary is less than the expected normal of 480 volts, say 456 volts for this example? This could be significant if getting 120 volts from the secondary is critical. **Tapping the primary in a number of different spots helps to eliminate the problem by providing a means to adjust the turns ratio, and fine-tune the secondary output voltage.**

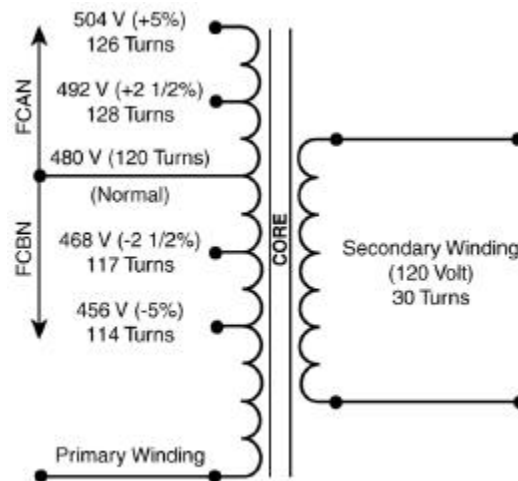


FIGURE 12: MULTI-TAPPED SINGLE-PHASE TRANSFORMER

This transformer has taps at 2 1/2% and 5% below the normal voltage of 480 volts. In the industry, this would be referred to as having two 2 1/2% full capacity below normal taps (FCBN). These two taps provide a 5% voltage range below the normal 480 volts.

When taps are provided above the normal as illustrated, they are called full capacity above normal taps (FCAN).

For standardization purposes, taps are in 2 1/2% or 5% steps. The tap arrangement used on many transformers is two-2 1/2% FCAN and four-2 1/2% FCBN, which provides a 15% total range of tap voltage adjustments.

REVIEW 1

Answer the following questions without referring to the material just presented. Begin the next section when you are confident that you understand what you've already read.

1. In your own words, state the definition of a transformer.

2. In your own words, state the purpose of the transformer core.

3. If the turns ratio of a transformer is 5:1, and the primary has 100 turns, then there must be _____ turns are on the secondary?

4. The transformer in question 3 is a step-up transformer.

TRUE FALSE

5. A step-up transformer steps the voltage from 120 volts to 360 volts. The current on the input side is 6 amps. The current on the output side is _____ amps.

6. If the incoming voltage is not reliably exact at all times, _____ can be added to the primary winding to make sure the output voltage remains constant.

TRANSFORMERS

TRANSFORMER CONFIGURATIONS

Transformers are built in both single-phase and three-phase power. Up to this point, we have focused on single-phase power. You will recall from earlier modules that **single-phase means two power lines as an input source**. This means that a voltage transformation is accomplished with one primary and one secondary winding.

You also know from previous modules that most power distributed today is three-phase AC. **Since power companies distribute generated power on three lines as three-phase power, three-phase transformers with three windings are integral to the electrical power system.** The three windings of the three-phase transformer are connected in the proper sequence to match the utility's incoming power.

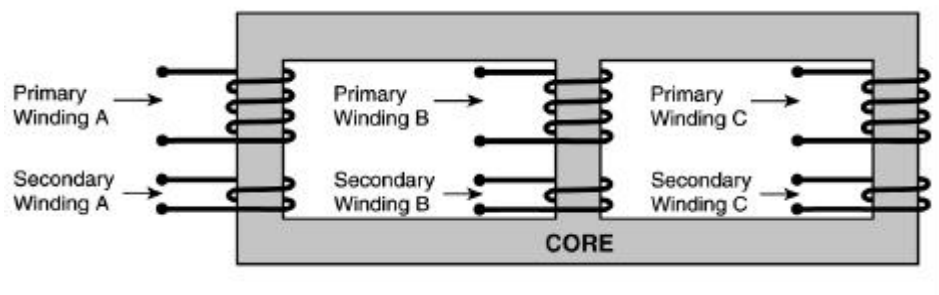


FIGURE 13: THREE-PHASE TRANSFORMER CORE AND COILS

Configuration For Single Phase Power

There are different configurations for both single-phase and three-phase systems. Let's look at single-phase first.

Single-phase transformers are often used to supply power for residential lighting, receptacle, air-conditioning, and heating needs.

A transformer with a 120 volt AC secondary can take care of the lighting and receptacles. **But, a transformer with a 240 volt AC secondary could handle all the residential needs mentioned.** A 240 volt AC secondary could handle the heavier 240 volt power requirements of air conditioning and heating. The same 240 volt AC secondary could handle the 120 volt AC needs by tapping the secondary in the center.

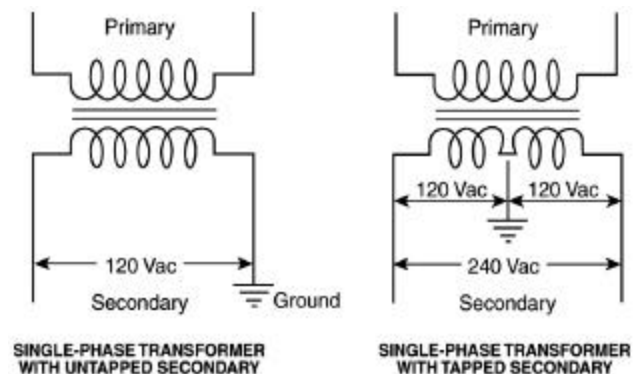


FIGURE 14: 120 VS 240 VOLT SECONDARY

Configuration For Single Phase Power (continued)

Single phase transformers can be made even more versatile by having both the primary winding and secondary winding made in two equal parts. The two parts of either winding can then be reconnected in series or parallel configurations.

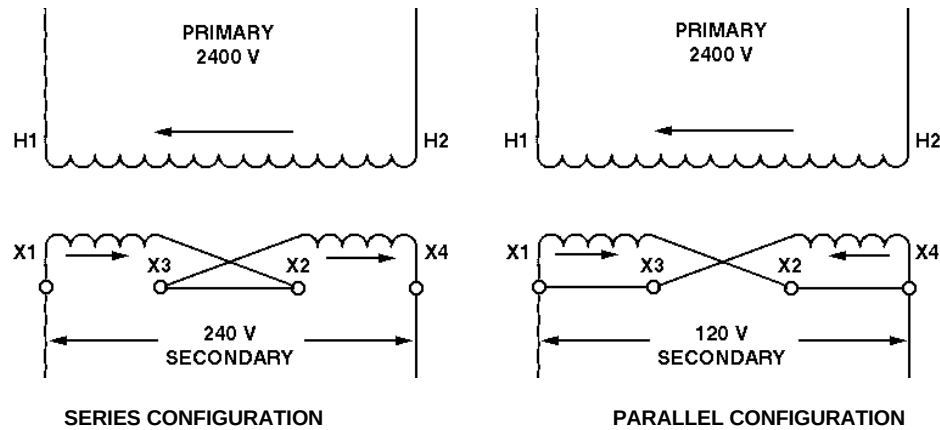


FIGURE 15: SINGLE-PHASE TRANSFORMER WITH SECONDARY DIVIDED INTO SECTIONS

Single-phase transformers usually have their windings divided into two or more sections. When the two secondary windings are connected in series, their voltage is added. When the secondary windings are connected in parallel, their currents are added.

For example, assume each secondary winding is rated at 120 volts and 100 amps. When series-connected, it would be 240 volts at 100 amps, or 24KVA. When parallel-connected, it would be 120 volts at 200, amps or 24KVA.

In series connections, care must be taken to connect the coils so that their voltages add. If the reverse happens, a short-circuit current would flow in the secondary, causing the primary to draw a short circuit from the source. This would damage the transformer, as well as the source.

TRANSFORMERS

Configuration For Three Phase Power

Power may be supplied through a three-phase circuit containing transformers in which a set of three single-phase transformers is used, or one three-phase transformer is used.

Using three single-phase transformers to accomplish the task is cumbersome, but it can be done. When used in this way, the arrangement is called a transformer bank.

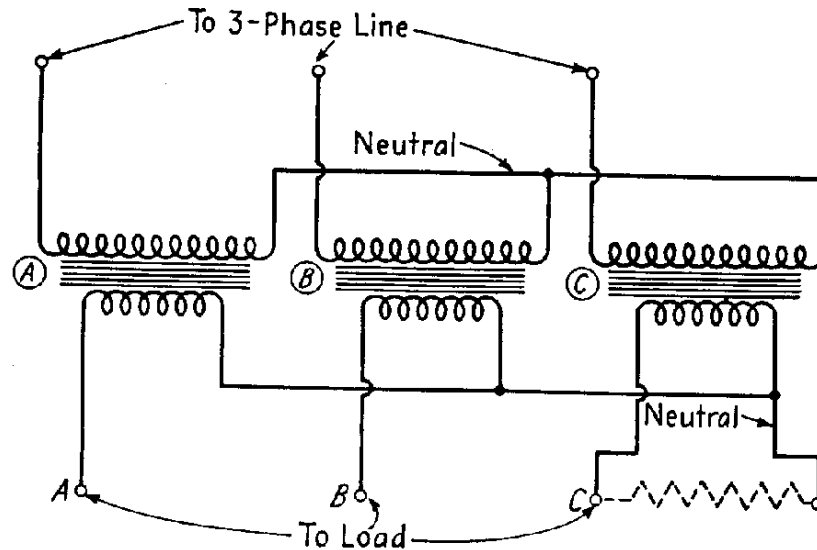


FIGURE 16: THREE SINGLE-PHASE TRANSFORMERS USED FOR THREE-PHASE POWER

When a considerable amount of power is involved in the transformation of three-phase power, it is more economical to use a three-phase transformer. The unique arrangement of the windings and core saves a lot of iron.

Delta and Wye Defined

There are two connection configurations for three-phase power: Delta and Wye.

Delta and wye are Greek letters that represent the way the conductors on the transformers are configured. In a delta connection, the three conductors are connected end to end in a triangle or delta shape. For a wye, all the conductors radiate from the center, meaning they are connected at one common point.

Both the primary and secondary can have either of these configurations. The four possible connection configurations are:

Primary	Secondary
Wye	Wye
Wye	Delta
Delta	Wye
Delta	Delta

They can be used with either three single-phase transformers or one three-phase transformer. Figure 16 shows three single-phase transformers in a wye-to-wye configuration. Figures 17 and 18 show three-phase transformers, in a wye-to-delta configuration, and a delta-to-delta configuration respectively.

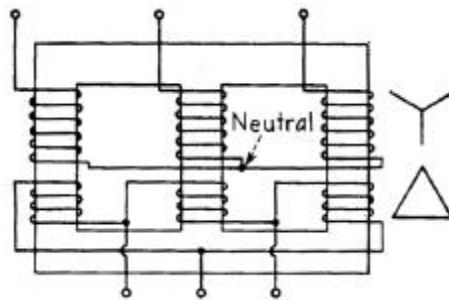


FIGURE 17: CORE-TYPE WYE-TO-DELTA

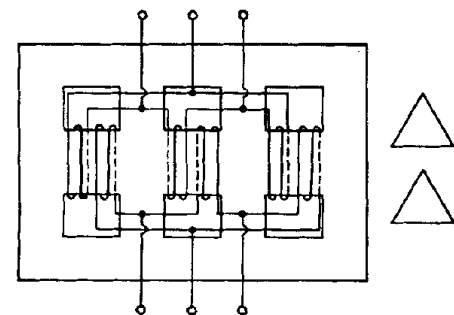


FIGURE 18: SHELL-TYPE DELTA-TO-DELTA

Recalling the electrical symbol for a transformer from Module 3, Fundamentals of Electrical Distribution, the delta and the wye symbols are often used to indicate the primary and secondary winding connections in a one-line diagram.

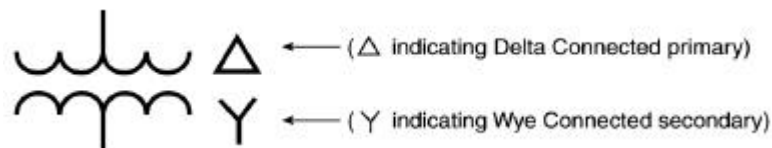


FIGURE 19: TRANSFORMER ELECTRIC SYMBOL

Delta and Wye Defined (continued)

Many high schools use a wye-to-wye step-down transformer bank, as shown here. The versatility of the power is the key to its popularity.

The system provides three-phase, 208-volt power for three-phase motor loads, such as heavy equipment in the Industrial Education department. It also provides single-phase, 208-volt power for small single-phase motor loads, such as science lab equipment.

Of course, it can also produce single-phase, 120-volt power for lighting loads, used throughout the building.

IN THE WORKPLACE

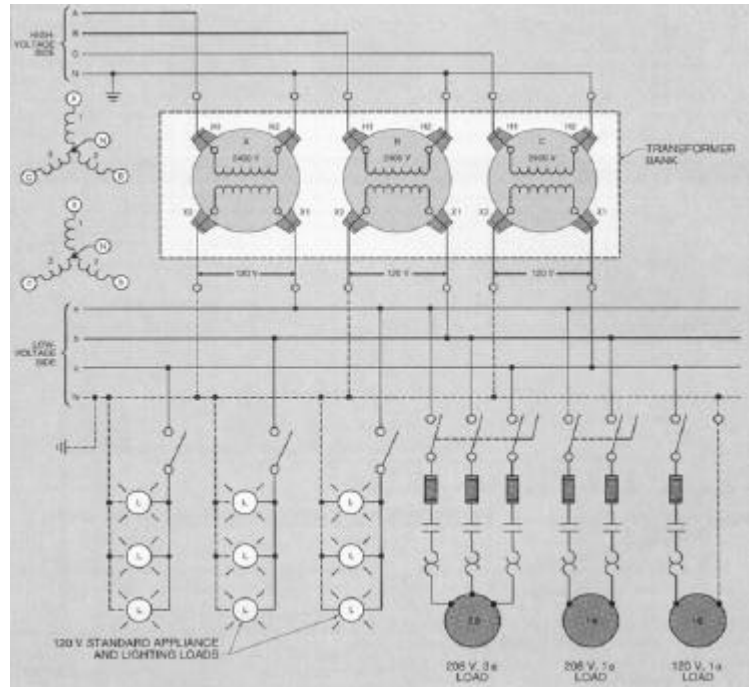


FIGURE 20: WYE-TO-WYE STEP-DOWN TRANSFORMER BANK (THREE SINGLE-PHASE TRANSFORMERS)

Configurations for a Three-Phase Transformer

Three-phase transformers have six windings; three primary and three secondary. The six windings are connected by the manufacturer as either delta or wye. As previously stated, the primary windings and secondary windings may each be connected in a delta or wye configuration. They do not have to be connected in the same configuration in the same transformer. The actual connection configurations used depend upon the application.

In a three-phase transformer, there is a three-legged iron core. Each leg has one primary and one secondary winding. Figure 20 shows graphically what the delta and wye winding connections look like for a three-phase transformer.

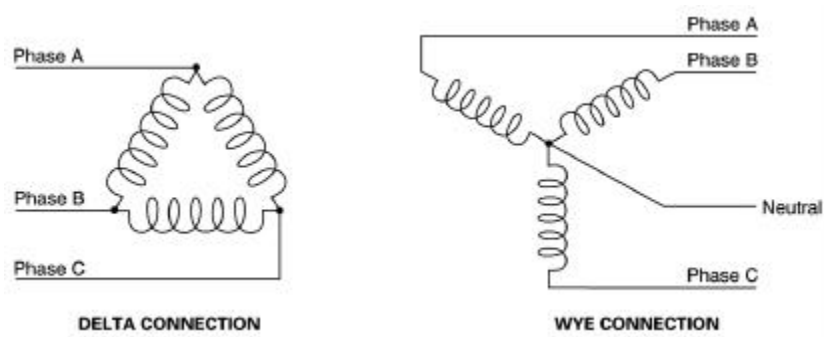


FIGURE 21: DELTA AND WYE WINDING CONNECTIONS

Configurations for a Three- Phase Transformer (continued)

The delta-connected winding in a three-phase transformer is a lot like three single-phase windings connected together.

A delta-connected secondary is illustrated here, with the primary not shown for simplicity. All the illustrated voltages are secondary voltages available to the load.

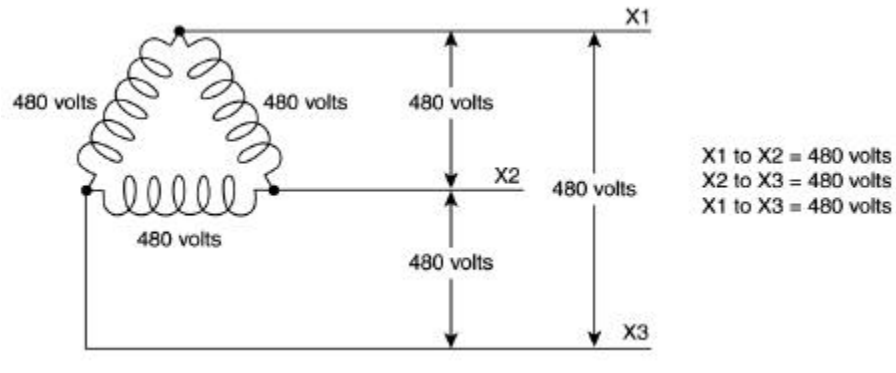


FIGURE 22: DELTA (Δ) CONNECTED WINDING

There are equal voltages across each winding. Each of the voltages represents one phase of a three-phase system. The voltage is always the same between any two wires.

One of the phases, between X1 and X2 for example, can be used to supply single-phase loads. All three phases together supply three-phase loads. Notice in the illustration that X1, X2 and X3 are used to designate connection points. An “X” indicates a low voltage connection, and an “H” indicates a high voltage connection. This type of connection is referred to as a three-phase, three-wire connection.

TRANSFORMERS

Configurations for a Three- Phase Transformer (continued)

The wye-connected winding is often called a “star connection.”

Wye connections provide two voltages because of the neutral connection. These are shown below. In other words, **the wye has four leads, three phase leads and a neutral lead.** This is also known as three-phase, four-wire connection.

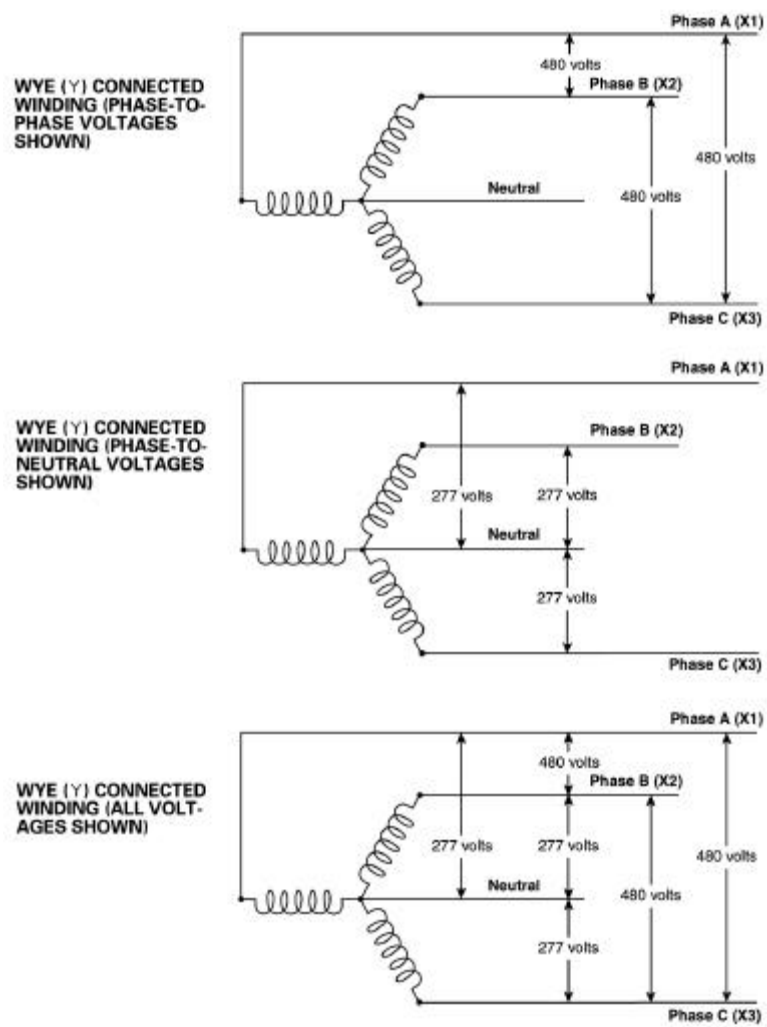


FIGURE 23: WYE (Y) CONNECTED WINDING

Any line-to-neutral voltage (voltage across a phase) is always less than the line-to-line voltage.

If one voltage is known, the other can be calculated. The line-to-line voltage is 1.732 times the line-to-neutral voltage. You can prove this calculation for yourself using the voltages provided in the illustrations.

TYPES OF TRANSFORMERS

If we look at an entire electrical utility system, we find that transformers are used to meet a wide variety of needs.

Some transformers can be several stories high. This type might be found at a generating station. Other transformers are small enough to hold in your hand. This type might be used with the charging cradle for a video camera. No matter what the shape or size, the purpose remains the same: transforming electrical power from one type to another, such as stepping up or down the power.

Let's take a closer look at several transformer types in use today.

Power Transformer

The power transformer is used **primarily to couple electrical energy from a power supply line to a circuit system**, or to one or more components of the system.

In one type of power transformer, there are three separate secondary windings, each designed for a different current and voltage output. **All of the windings are identified by color-coded insulation on the wire leads.**

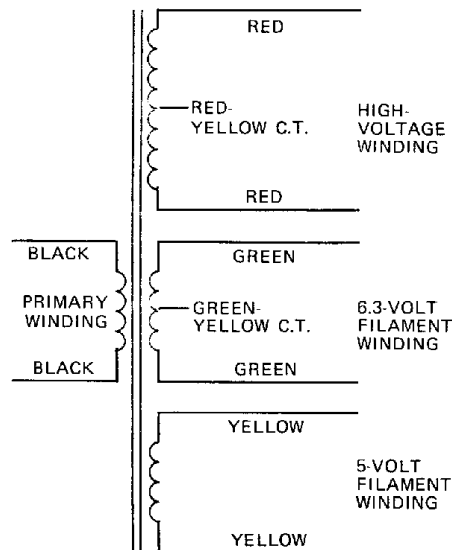


FIGURE 24: COLOR-CODED POWER TRANSFORMER LEADS

A power transformer used with solid state circuits is called a rectifier transformer.

A power transformer's rating is given in terms of the secondaries' maximum voltage and current-delivering capacity. For example, a power transformer that is to be operated from a 60-hertz, 120-volt power line may read:

600 V. CT @ 90 ma, 6.3 V @ 3 amp, 5 V. @ 2 amp

TRANSFORMERS

Power Transformer (continued)

The efficiency of a power transformer with a power rating between 50 and 400 watts can range from 82 to 94 percent.

Transformers with higher power ratings are usually more efficient because of the larger wire gauge used in the windings, and the larger cross-sectional area of the core.

Distribution Transformer

A pole-type *distribution transformer* is **used to supply relatively small amounts of power to residences**. It is used at the end of the electrical utility's delivery system. Let's trace the path of this power from the generating station to a house.

Power transformers are used at generating stations to step up the generated voltage to high levels (115 to 765 kV) for transmission. Transmission voltages are stepped down (34 or 69 kV) by transformers at substations for local distribution.

From this point, the electrical power is fed to a distribution substation or even directly to a factory. At the factory, transformers once again step the voltage down to usable levels. For home use, the voltage is stepped down in a number of steps, with the last step handled by the local pole-type or pad-mounted (mounted on the ground) distribution transformer.

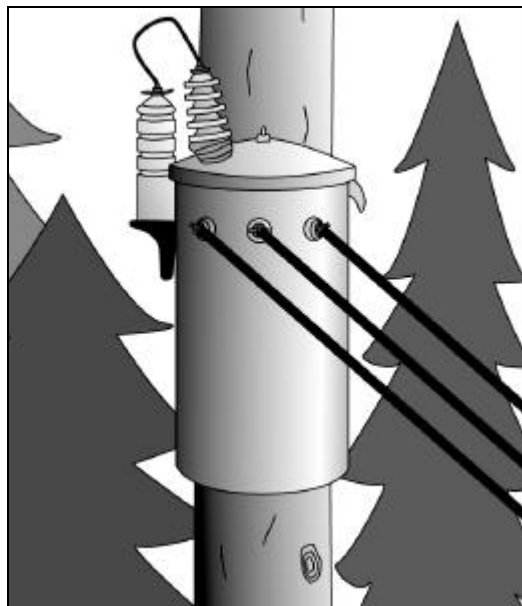


FIGURE 25: TYPICAL POLE TYPE DISTRIBUTION TRANSFORMER

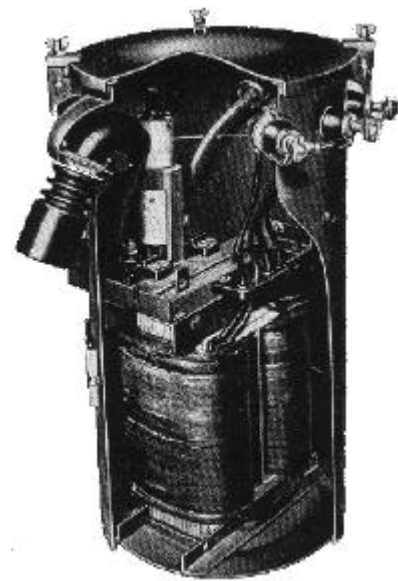


FIGURE 26: CUTAWAY OF POLE TYPE DISTRIBUTION TRANSFORMER

After all these steps, the homeowner has access to 240 and 120 volts for running appliances and lighting.

Auto-Transformer

The *autotransformer* is a special type of power transformer. It consists of a single, continuous winding that is tapped on one side to provide either a step-up or step-down function.

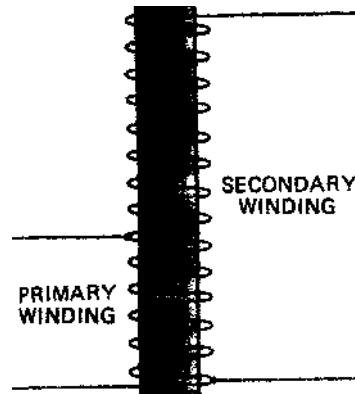


FIGURE 27: STEP-UP AUTOTRANSFORMER

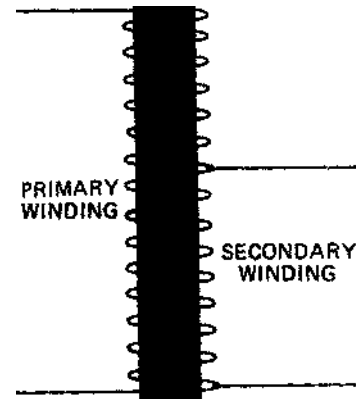


FIGURE 28: STEP-DOWN AUTOTRANSFORMER

This is different from a conventional two-winding transformer, which has the primary and secondary completely insulated from each other, but magnetically linked by a common core. **The autotransformer's windings are both electrically and magnetically interconnected.**

An autotransformer is initially cheaper than a similarly-rated two-winding transformer. It also has better regulation (smaller voltage drops), and greater efficiency. Furthermore, it can be used to obtain the neutral wire of a three-wire 240/120-volt service, just like the secondary of a two-winding transformer.

It is commonly used to transform between two high-voltage circuits, say one at 22,000 volts and the other at 13,800 volts. But, **the autotransformer is considered unsafe for use on ordinary distribution circuits.** This is because the high-voltage primary circuits connected directly to the low-voltage secondary circuit.

TRANSFORMERS

Isolation Transformer

An *isolation transformer* is a very unique transformer. It has a 1:1 turns ratio. Therefore, it does not step voltage up or down. Instead, **it serves as a safety device**. It is used to isolate the grounded conductor of a power line from a chassis or any portion of a circuit load.

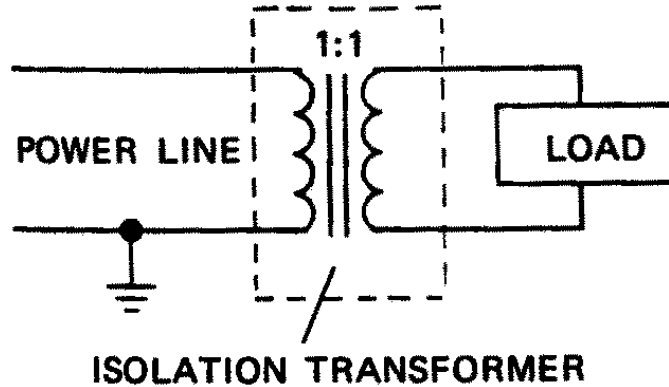


FIGURE 29: HOW AN ISOLATION TRANSFORMER IS USED

Using an isolation transformer does not reduce the danger of shock if contact is made across the transformer's secondary winding.

TRANSFORMERS

Instrument Transformer

For measuring high values of current or voltage, it is desirable to use standard low-range measuring instruments together with specially-constructed instrument transformers, also called accurate ratio transformers.

An accurate ratio transformer does just as the name suggests. It transforms at an accurate ratio to allow an attached instrument to gauge the current or voltage without actually running full power through the instrument. It is required to transform relatively small amounts of power because its only load, called a burden, is the delicate moving elements of an ammeter, voltmeter or wattmeter.

There are two types of instrument transformers:

- Current – Used with an ammeter to measure current in AC voltages.
- Potential – Used with a voltmeter to measure voltage (potential difference) in AC.

Current Transformer

A current transformer has a primary coil of one or more turns of heavy wire. It is always connected in series in the circuit in which current is to be measured. The secondary coil is made up of many turns of fine wire, which must always be connected across the ammeter terminals.

The secondary of a current transformer must never be open-circuited. This is because the primary is not connected to a constant source. There is a wide range of possible primary voltages, because the device can be connected to many types conductors. **The secondary must always be available (closed-circuited) to react with the primary, to prevent the core from becoming completely magnetized. If this happens, the instrument will no longer read accurately.**

A clamp-on ammeter works in a similar way. By opening the clamp and placing it around a current carrying conductor, **the conductor itself acts as a single turn primary**. The secondary and the ammeter are conveniently mounted in the handle of the device. The dial allows a number of current ranges to be gauged accurately.



FIGURE 30: CLAMP-ON AMMETER

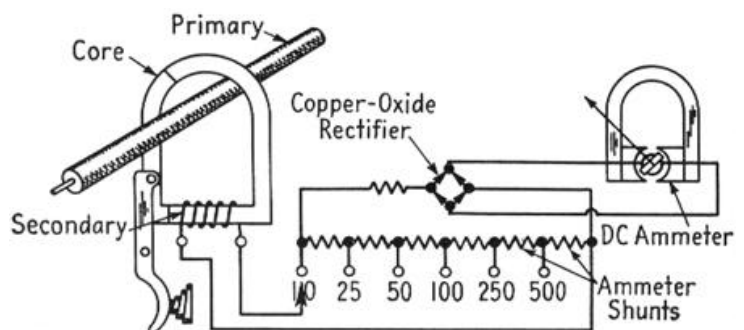


FIGURE 31: WIRING DIAGRAM OF A CLAMP-ON AMMETER

TRANSFORMERS

Potential Transformer

A *potential transformer* is a carefully designed, extremely accurate step-down transformer. It is normally used with a standard 120-volt voltmeter. **By multiplying the reading on the voltmeter (called the *deflection*) by the ratio of transformation, the user can determine the voltage on the high side.** Common transformation ratios are 10:1, 20:1, 40:1, 80:1, 100:1, 120:1, and even higher.

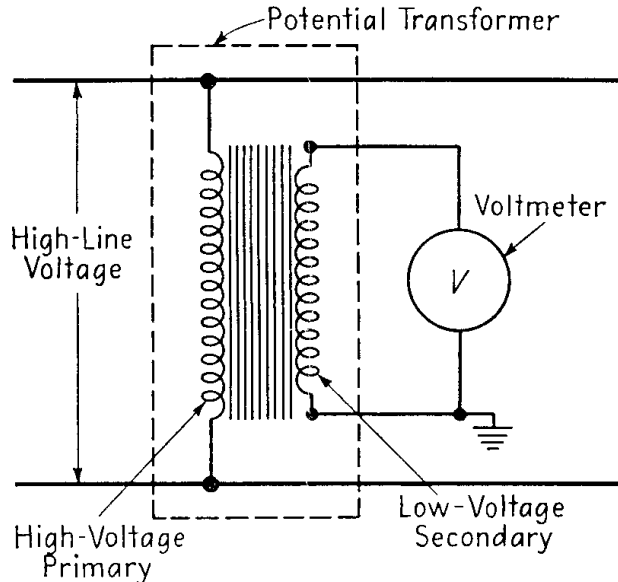


FIGURE 32: WIRING DIAGRAM OF A POTENTIAL TRANSFORMER

In general, a potential transformer is very similar to a standard two-winding transformer, except that it handles a very small amount of power. **Transformers for this service are always the shell type**, because this construction has been proven to provide better accuracy.

For safety, the secondary circuit is extremely well-insulated from the high-voltage primary. It is also grounded. This protects the operator from a shock hazard, in case of accidental contact with the wiring.

REVIEW 2

Answer the following questions without referring to the material just presented. Begin the next section when you are confident that you understand what you've already read.

1. List 3 advantages that three-phase power has over single-phase power

2. A delta-connected secondary has equal voltages across each winding.

TRUE FALSE

3. In your own words, explain why transformers with higher power ratings are usually more efficient.

4. A step-up autotransformer is tapped on the _____ winding.

5. The two main types of instrument transformers are:

PRINCIPLES OF OPERATION AND TERMIN- OLOGY

Coupling Coefficient

This is a good time to introduce several additional principles and common terms associated with transformers. This material will be especially helpful from a practical standpoint by helping to clarify concepts. In addition, a number of the terms are commonly used in the electrical industry. Being familiar with the nomenclature will simplify transformer discussions and selections at your work location

Magnetic coupling between the primary and secondary windings of a transformer was introduced earlier. **Maximum coupling occurs when all the lines of flux from the primary coil cut through the secondary coil.**

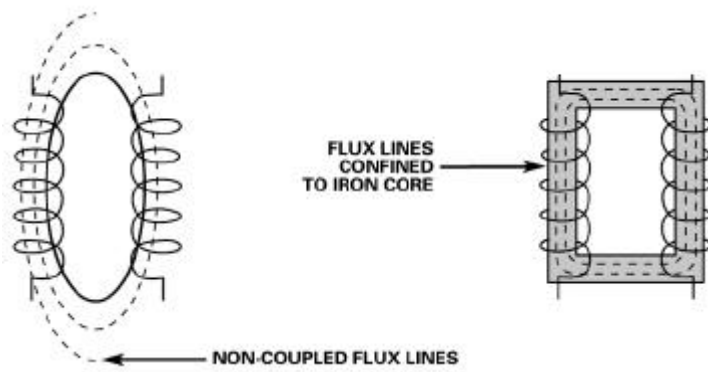


FIGURE 33: COUPLING OF FLUX LINES

Although maximum coupling is desirable for efficiency of operation reasons, it is not always achievable. The amount of coupling that takes place between the two windings is the coefficient of coupling. **Winding both coils on an iron core helps to maximize the coupling coefficient by providing a good, confined path for the lines of flux.**

Transformer Ratings

Transformers are frequently rated in kilovoltamperes (kVA), although there are other rating designations. Very large transformers are often rated in megavoltamperes (MVA), while very small transformers can be rated in voltamperes (VA). **The rating tells you the maximum current that a transformer can deliver to a load without overheating.**

If you know the voltage and the current, the rating can be calculated. If you know the rating and the voltage, the current can be calculated. The rating of a transformer is the same for both the primary and the secondary.

Two formulas are necessary to calculate transformer ratings; one for single-phase loads, and one for three-phase loads.

SINGLE-PHASE FORMULA EXAMPLE	THREE-PHASE FORMULA EXAMPLE
Primary Voltage = 240 volts = V	Primary Voltage = 208 volts = V
Primary Current = 5 amperes = I	Primary Current = 100 amperes = I
Primary kVA = $\frac{I \times V}{1000}$	Primary kVA = $\frac{I \times V \times \sqrt{3}}{1000}$
Primary kVA = $\frac{5 \times 240}{1000}$	Primary kVA = $\frac{100 \times 208 \times 1.732}{1000}$
Primary kVA = $\frac{1200}{1000}$	Primary kVA = $\frac{32,025.6}{1000}$
Primary kVA = 1.2 kVA	Primary kVA = 36.026 kVA

FIGURE 34: FORMULAS FOR CALCULATING TRANSFORMER RATINGS

Frequency

A transformer cannot change the frequency of the power supply. If the supply is 60 Hz, the output will also be 60 Hz.

Since transformers are designed for operation at a particular frequency, frequency requirements must be known to make the proper transformer selection. The frequency of the source should be determined, and the frequency of the load should match.

Transformers used in the United States and Canada are usually designed for 60 Hz. A great deal of the rest of the world uses 50 Hz.

TRANSFORMERS

Basic Impulse Level (BIL)

Outdoor electrical distribution systems are subject to lightning surges. Even if the lightning strikes the line some distance from the transformer, voltage surges can travel down the line and into the transformer. Other electrical equipment in the system can also cause voltage surges when they are opened and closed. These surges can be very damaging to electrical equipment.

The basic impulse level (BIL) is a **measure of the ability of the transformer's insulation system to withstand very high-voltage, short-time surges**. The BIL is rated on:

- the kinds of voltage surge stresses the equipment is likely to encounter
- the design of the electrical system
- the voltage protection provided

To familiarize you with BIL, some typical BIL levels are shown with corresponding voltage classes. These do not apply uniformly for all electrical equipment.

VOLTAGE CLASS	CORRESPONDING BIL
600 volt	10 kV
2400 volt	25 kV
15 kV	95 kV
25 kV	125 kV

FIGURE 35: TYPICAL BIL LEVELS

Sound

Although transformers are reliable static devices with no moving parts, they do produce a humming sound. The sound originates in the core. **When the magnetic flux passes through the laminated core, the laminations expand and contract, generating a hum.**

Transformers are designed and constructed in such a manner that the noise is minimized, but not eliminated. The sound level of a transformer is measured in decibels (dB), and determined by tests conducted in accordance with NEMA standards.

Altitude

Air is thinner at higher altitudes, which impacts transformer cooling.

Transformers are designed to operate with a normal temperature rise, at a specific height in feet above sea level. If the operation is to be at a higher altitude, the transformer's nameplate rating must be reduced.

The amount of the reduction depends upon by how much the standard altitude has been exceeded.

Transformer Losses and Efficiency

Most of the energy provided to the primary of a transformer is transferred to the secondary. But, **some energy is lost in the form of heat**. Most of this heat loss is experienced in the wiring or the core.

The lower the losses, the higher the efficiency of the transformer. Losses and efficiency are very important concerns in the selection of a transformer. For example, a transformer with a lower initial cost might not be the best purchasing choice. Another transformer with a higher initial cost, but which is more efficient could prove to be the best purchasing decision in the long run.

A transformer's efficiency is defined as:

$$\text{Efficiency} = \text{Output Power} / \text{Input Power}$$

Put another way, **the output power equals the input power, less the internal losses of the transformer.**

Transformer efficiency can vary by manufacturer, transformer type and transformer size. A 20,000 kVA power transformer, for example, might have an efficiency of 99.4%, while a small 5 kVA transformer might be 94%. You can see how efficiency is an important consideration when applying a transformer.

Copper Loss

One type of loss in transformers is *copper loss*. The copper windings, while a good conductor of electricity, are not perfect conductors. Copper has a certain resistance to current flow, as do all materials.

One of the factors influencing copper loss is heat. Resistance increases with an increase in temperature. To minimize this problem, large electrical power distribution transformers are often cooled by circulation of water, forced air, or oil. Cooling also helps to prevent heat damage to winding insulation. We will discuss heat issues later in this module.

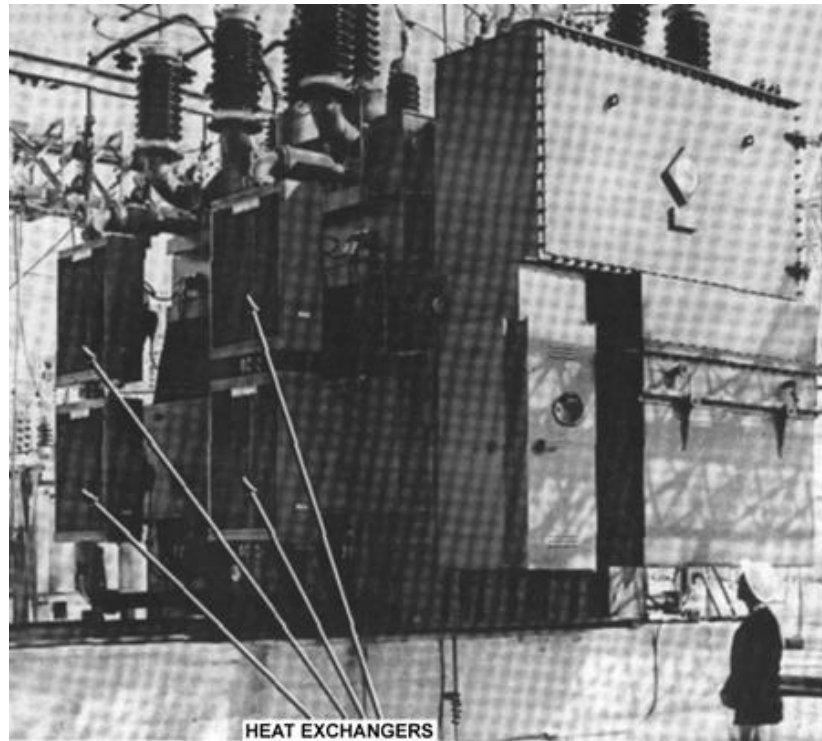


FIGURE 36: HEAT EXCHANGERS USED TO COOL POWER DISTRIBUTION TRANSFORMERS

Heat Dissipation (Cooling)

Heat generated by losses must be removed to prevent deterioration of the transformer's insulation system, and the actual magnetic properties of the core.

The insulation system is made up of the materials wound around the primary and secondary winding coils. A transformer's *insulation system temperature classification* states the maximum temperature permitted in the hottest spot in the winding, at a specified ambient temperature, usually 40°C.

METHODS OF DISSIPATING HEAT

As we briefly mentioned earlier, transformers can use a number of methods to dissipate heat.

The method used depends primarily on the amount of heat that needs to be dissipated, and the application surroundings. This includes indoor vs. outdoor and hazardous vs. non-hazardous installations.

There are two main transformer enclosure types to deal with the problem: oil filled and dry.

Liquid-Filled Transformers

Many transformers are contained in a tightly fitted sheet-metal case or tank of oil. **Oil provides good electrical insulation, and carries heat away from the core and windings by convection.** This type of transformer is referred to as a *liquid-filled transformer*.

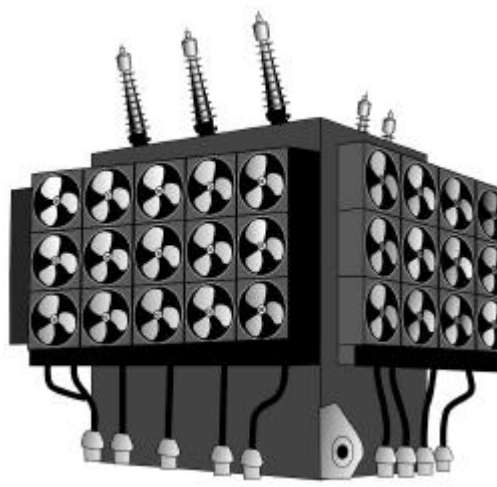


FIGURE 37: LIQUID-FILLER TRANSFORMER WITH BANKS OF COOLING FANS

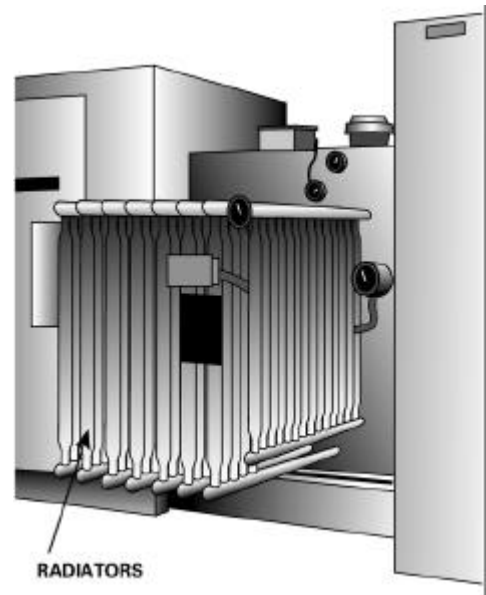


FIGURE 38: LIQUID-FILLER TRANSFORMER WITH RADIATORS

Small transformers might be cooled sufficiently by just allowing the oil to circulate inside the tank. Larger transformers might use fans or radiators to cool the oil. Fans for additional cooling and oil pumps for circulation could be required on even larger transformers.

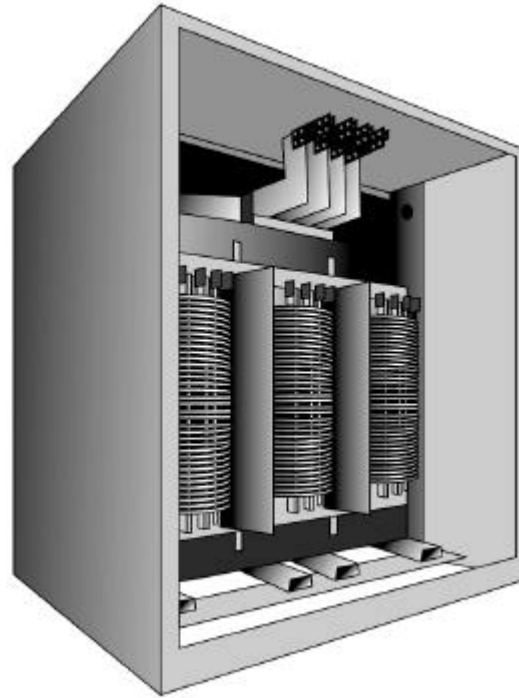
In addition to oil, other cooling liquids are used, such as silicone. Silicone might be used in an application where oil is not suitable, such as where flammability is an issue.

Sealing the transformer case or tank is important, especially in the case of an oil-filled unit. Any penetrating moisture can reduce the insulating quality of the oil. Also, oxygen can cause oil decomposition, resulting in sludge.

TRANSFORMERS

Dry Type Ventilated Transformers

A transformer designed to operate in air is called a *dry type transformer*. The design does not require the assistance of a liquid to dissipate excess heat. **Natural or fan-assisted circulation through ventilation openings is all that is required to meet temperature classification requirements.**



VENTILATED DRY TYPE TRANSFORMER WITH
FRONT COVERS REMOVED SHOWING CORE
AND COILS MOUNTED INSIDE

FIGURE 39: DRY TYPE TRANSFORMER

Since a liquid is not used, a tank is not required. However, dry type transformers are contained in some type of an enclosure.

You may hear the phrase core and coils when dealing with dry type transformers. This refers to the inside parts of a dry type transformer, primarily the core and windings, mounted on a base as one unit, without an enclosure. A core and coils unit could be considered by a customer intending to include it as part of an assembled enclosure being supplied by the customer.

Dry Type Specialty Transformers

A variety of specialty dry type transformers exist. **Typically not ventilated, this type of transformer usually has a small rating, and is capable of moving excessive heat away from the core and coils naturally**, without the need for ventilation openings or other heat dissipation means.

In most designs, this is accomplished by surrounding the core and coils with special material mixtures which absorb the heat and provide a solid seal. This type transformer is ideal for hazardous locations, and is usually referred to as an encapsulated transformer.



FIGURE 40: SMALL SPECIAL APPLICATION ENCAPSULATED DRY TYPE TRANSFORMER

HELPING THE CUSTOMER

We have covered a wide range of transformer fundamentals in this module. This information will help you in matching a transformer to an application.

Conduct a short interview with the customer to determine their needs. This list of questions is not all-inclusive for every transformer, but it will certainly get you started in the right direction.

- What is the intended use of the transformer?
With this question, you can usually select a transformer type from those covered in this module.
 - Power – supplies power to distribution systems
 - Distribution - supplies low voltage power to homes, offices and facilities
 - Autotransformer - transform between two high-voltage circuits
 - Isolation - isolate the grounded conductor of a power line from the chassis
 - Instrument – steps down high values of current or voltage to lower levels for meter reading
 - Current – measuring current
 - Potential – measuring voltage
- Do you need the transformer to step up or step down the voltage?
- What is the incoming power?
- What is the required outgoing power?
- What turns ratio is required?
- What rating (VA, kVA, MVA) is required?
- Will the transformer be used with single-phase or three-phase power?
- For three-phase, delta or wye connection in the primary? In the secondary?
- What is the frequency of the electrical system?
- What, if any, voltage taps will be needed?
- In what sort of environment will the transformer be placed?
With this question and some follow-up questions, you can usually choose an enclosure type for the transformer.
 - High voltage? Usually an oil-filled
 - Low voltage? Usually a dry type
 - Indoor or outdoor environment? Could be oil filled
 - Caustic? Maybe an encapsulated dry type
 - Is flammability an issue? Maybe dry or silicone filled

Armed with this information, you should be able to consult your product catalog and make a good product recommendation.

REVIEW 3

Answer the following questions without referring to the material just presented.

1. Calculate the rating of a single-phase transformer's primary. The primary has a voltage of 1200 volts and a current of 10 amps.

_____ kVA

2. A transformer cannot change the frequency of the power supply. If the supply is 60 Hz, the output will also be 60 Hz.

TRUE FALSE

3. In your own words, define the term "basic impulse level."

4. Calculate the efficiency of a transformer which takes in 20 kVA at the primary and puts out 19 kVA at the secondary.

_____ %

5. In your own words, explain why sealing the tank of an oil-filled transformer is important.

TRANSFORMERS

GLOSSARY

Accurate Ratio Transformer	A small transformer which transforms at an accurate ratio to allow an attached instrument to gauge the current or voltage without actually running full power through the instrument.
Ammeter	An instrument used to measure current.
Autotransformer	A special type of power transformer, consisting of a single, continuous winding that is tapped on one side to provide either a step-up or step-down function.
Basic Impulse Level	A measure of the ability of a transformer's insulation system to withstand very high-voltage, short-time surges
Burden	Term applied to the tiny load that an instrument's delicate moving elements places on an accurate-ratio transformer.
Coefficient of Coupling	The amount of coupling that takes place between the two windings in a transformer. This amount should ideally be 100%, but this is not achievable in the real world.
Coils	See "Winding."
Copper Loss	The energy wasted as heat in the copper windings, as copper is not a perfect conductor of electricity.
Core	A component of a transformer. The iron or steel core provides a controlled path for the magnetic flux generated in the transformer by the current flowing through the windings
Core and Coils	A non-enclosed, dry type transformer, mounted on a base as one unit.
Core Type	A type of core where the windings surround the laminated iron core.
Current Transformer	A type of instrument transformer used to measure current.
Deflection	Literally, the amount of movement the indicator of an instrument makes when sensing. Also called the reading of the instrument.
Distribution Transformer	A transformer used to supply relatively small amounts of power to residences. It is used at the end of the electrical utility's delivery system. Often mounted on a pole.

TRANSFORMERS

Delta	A three-phase transformer connection where the phases are connected in a manner which resembles the Greek letter Delta, “Δ.”
Dry Type Transformer	A transformer designed to operate in air. The design does not require the assistance of a liquid to dissipate excess heat. Natural or fan-assisted circulation through ventilation openings is all that is required to meet temperature classification requirements.
Eddy Current	Induced voltage in the core as a result of transformer operation. The currents move through the core in circular paths.
Eddy-Current Loss	The energy wasted by eddy currents creating heat in the core, as this does not aid in the induction process.
Efficiency	A rating of the percentage of input power transmitted through the transformer. This number will never be 100% in the real world due to copper losses, eddy-current losses and other inefficiencies.
Encapsulated Transformer	A specialty dry type transformer, sealed in an enclosure. It is capable of moving excessive heat away from the core and coils without ventilation openings or other heat dissipation means.
Full Capacity Above Normal Tap	A special voltage tap used to account for voltage fluctuations on the input side. Allows for fine-tuning the output voltage when the input voltage is higher than expected.
Full Capacity Below Normal Tap	A special voltage tap used to account for voltage fluctuations on the input side. Allows for fine-tuning the output voltage when the input voltage is lower than expected.
Input	The voltage source coming into the transformer through the primary winding.
Instrument Transformer	A small transformer which transforms at an accurate ratio to allow an attached instrument to gauge the current or voltage without actually running full power through the instrument.
Insulation System Temperature Classification	A statement of the maximum temperature permitted in the hottest spot in the winding, at a specified ambient temperature, usually 40°C. Exceeding this figure will likely result in an insulation failure.

TRANSFORMERS

Isolation Transformer	A transformer with a 1:1 turns ratio. It does not step voltage up or down. It serves as a safety device, isolating the grounded conductor of a power line from a chassis or any portion of a circuit load.
Liquid-Filled Transformer	A type of transformer cooled by mounting it in a sealed tank filled with liquid. The liquid is normally oil, but silicone and other liquids may also be used.
Magnetic Coupling	The method by which one circuit is linked to another circuit by a common magnetic field.
Magnetic Flux	Lines of magnetic force surrounding a magnet or electromagnet.
NEMA	Abbreviation for National Electrical Manufacturers Association. An organization of manufacturers of electrical products
Output	The transformed voltage exiting the transformer through the secondary winding, and going out to the load.
Potential Transformer	A type of instrument transformer used to measure voltage.
Power Transformer	A transformer used primarily to couple electrical energy from a power supply line to a circuit system.
Primary Side	The side of the transformer where the power to be changed comes from.
Primary Winding	Turns of wire on the core, used to connect the input to the core.
Rectifier Transformer	A type of power transformer used with solid state circuits.
Secondary Side	The side of the transformer where the power is sent to the equipment it needs to power. Depending upon the requirement of the load, the power was either increased or decreased from the primary voltage.
Secondary Winding	Turns of wire on the core, used to connect the output to the core.
Shell Type	A type of core where the core the windings.

TRANSFORMERS

Step-Up Transformer	A transformer in which the output voltage is higher than the input voltage. The secondary winding has more turns of wire than the primary winding.
Step-Down Transformer	A transformer in which the output voltage is lower than the input voltage. The secondary winding has fewer turns of wire than the primary winding.
Three-Phase Transformer	A transformer used to transform power provided by a three-phase power system.
Transformer	A device that transfers electrical energy from one electric circuit to another, without changing the frequency, by the principles of electromagnetic induction. The energy transfer usually takes place with a change of voltage.
Transformer Bank	An arrangement of three single-phase transformers, configured to transform three-phase power.
Turns	The number of times the wire of a winding actually goes around the core.
Turns Ratio	A comparison of the number of turns in the primary versus the number of turns in the secondary. Directly related to the voltage ratio.
Voltage Ratio	A comparison of the voltage entering the primary versus the voltage exiting the secondary. Directly related to the turns ratio.
Voltage Tap	An additional connection to a winding, which permits use of only a specific part of the winding. This allows the same winding to handle multiple voltage levels.
Voltmeter	An instrument used to measure voltage.
Wattmeter	An instrument used to measure wattage.
Winding	Turns of wire around the core of the transformer. Connects the core to either the input, in the case of the primary winding, or the output, in the case of the secondary winding.
Wye	A three-phase transformer connection where the phases are connected in a manner which resembles the letter "Y." Often called a "star connection."

TRANSFORMERS

REVIEW 1 ANSWERS

1. Answer should basically say, "A transformer is a device that transfers electrical energy from one electric circuit to another, without changing the frequency, by the principles of electromagnetic induction. The energy transfer usually takes place with a change of voltage."
2. Answer should basically say, "The transformer core is used to provide a controlled path for the magnetic flux generated in the transformer."
3. 20
4. False
5. 2
6. Voltage taps

REVIEW 2 ANSWERS

1. Any three of the following:
 - Powers large industrial loads more efficiently than single-phase.
 - Single-phase electricity is available from a three-phase system.
 - Three conductors of a three-phase system can provide significantly more power than the two conductors of a single-phase system.
 - Allows heavy industrial equipment to operate more smoothly and efficiently.
 - Can be transmitted over long distances with smaller conductor sizes.
2. True
3. Answer should basically say, "Because of the larger wire gauge used in the windings, and the larger cross-sectional area of the core."
4. Primary
5. Current, potential

REVIEW 3 ANSWERS

1. 12
2. True
3. Answer should basically say, "The basic impulse level (BIL) is a measure of the ability of the transformer's insulation system to withstand very high-voltage, short-time surges."
4. 95%
5. Answer should basically say, "Any penetrating moisture can reduce the insulating quality of the oil. Also, oxygen can cause oil decomposition, resulting in sludge."

Cutler-Hammer

Milwaukee, Wisconsin U.S.A.

Publication No. TR.36.01.T.E
February 1999
Printed in U.S.A. (GSP)



101 Basics Series and 201 Advanced Series are trademarks of Cutler-Hammer University, Cutler-Hammer and Eaton Corp.
©1999, Eaton Corp.