Electrical Level 3

Transformers 26307-14

Objectives

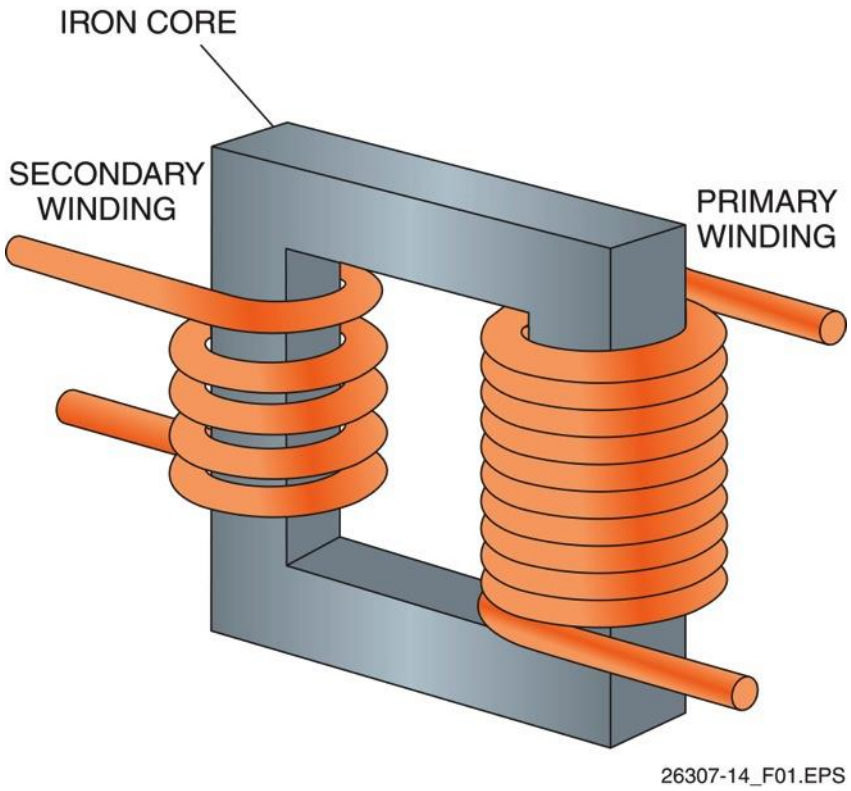
When trainees have completed this lesson, they should be able to do the following:

1. Describe transformer operation.
2. Explain the principle of mutual induction.
3. Describe the operating characteristics of various types of transformers.
4. Connect a multi-tap transformer for the required secondary voltage.
5. Explain *National Electrical Code*® (*NEC*®) requirements governing the installation of transformers.
6. Compute transformer sizes for various applications.
7. Connect a control transformer for a given application.
8. Describe how current transformers are used in conjunction with watt-hour meters.

This is a knowledge-based module; there are no Performance Tasks.

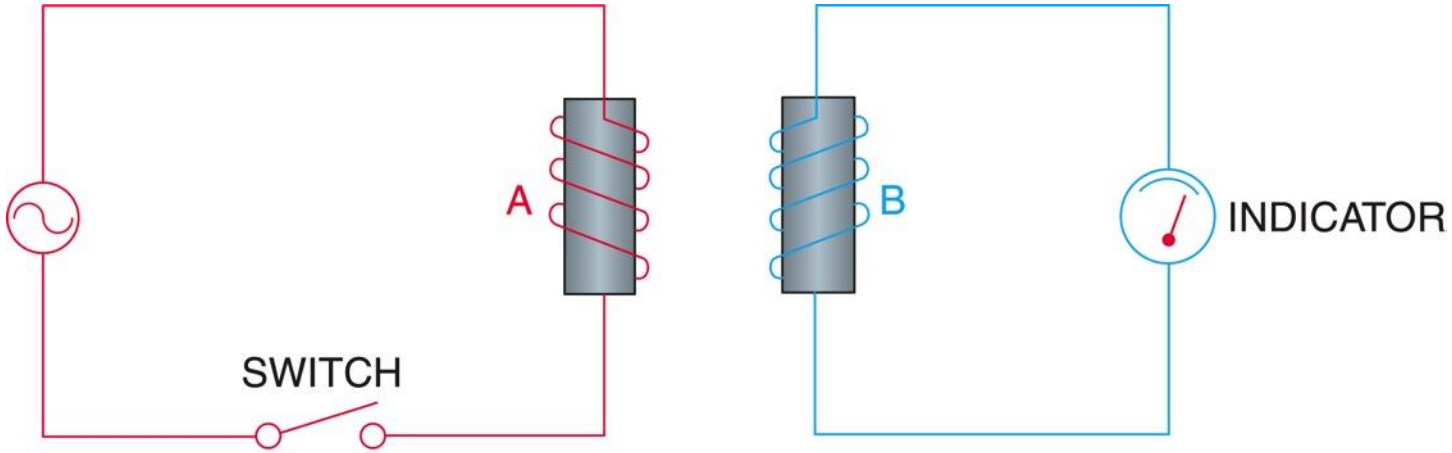
Introduction; Transformer Basics

- Power distribution systems use transformers to step voltage up for more efficient transmission or to step it down for utilization. Transformers are also used to supply control system voltages and to regulate the voltage for other loads.
- A basic transformer consists of two windings on a magnetic core.



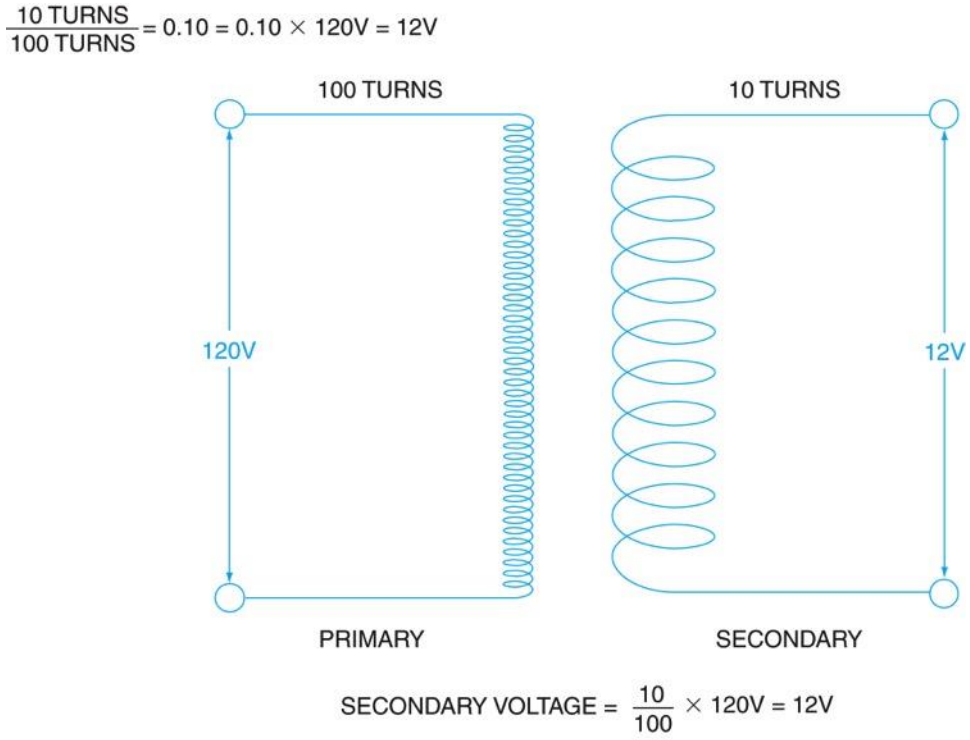
Mutual Induction Circuit

- The energy in a transformer is transferred from one circuit to the other via the process of mutual induction.
- When power is applied to coil A (the primary winding), it creates a magnetic field that cuts across and induces a current in coil B (the secondary winding).



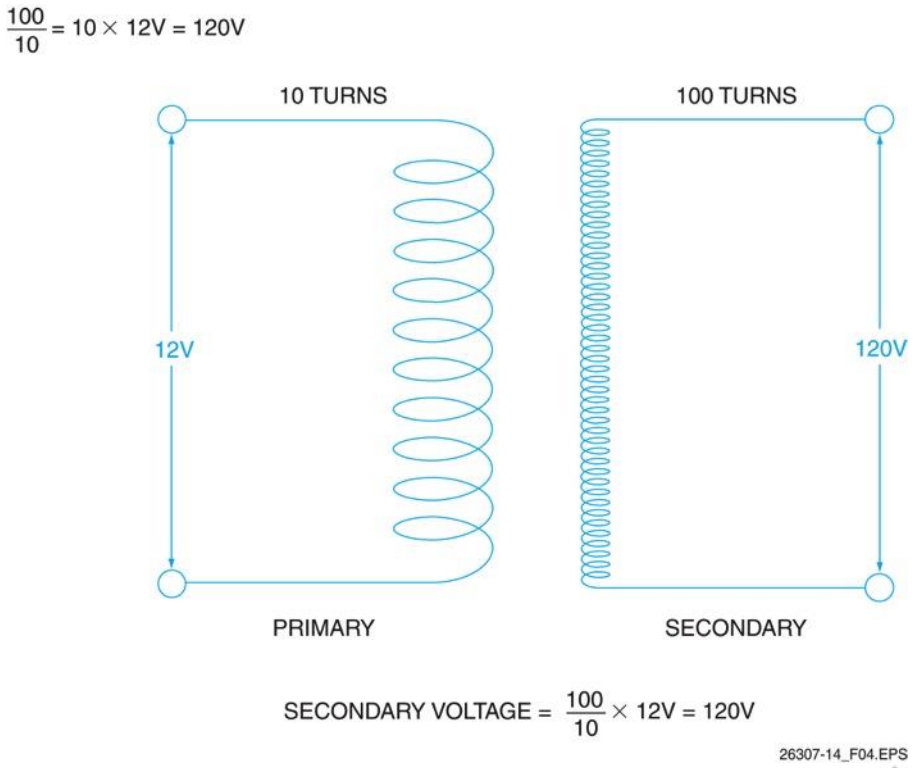
Step-Down Transformer with a 10:1 Turns Ratio

- The induced voltage is dependent on the ratio of the number of turns in the primary winding vs. the number of turns in the secondary winding.
- Since this transformer has more turns in the primary than in the secondary, it is called a step-down transformer.



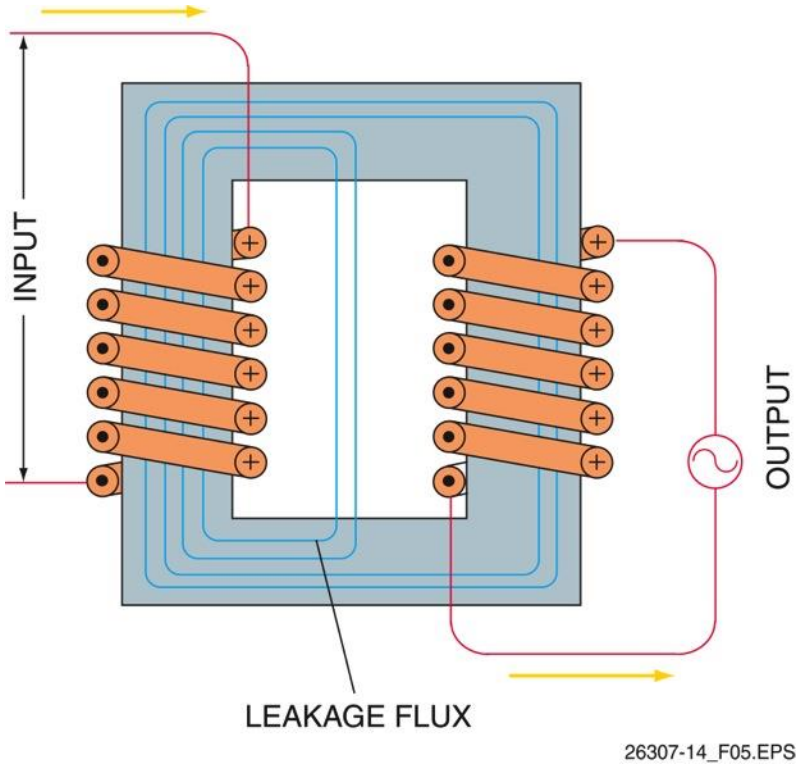
Step-Up Transformer with a 1:10 Turns Ratio

- If there are more turns in the secondary winding than in the primary winding, the output voltage will be higher. This type of transformer is known as a step-up transformer.
- Transformers are rated in volt-amperes (VA) or kilovolt-amperes (kVA).



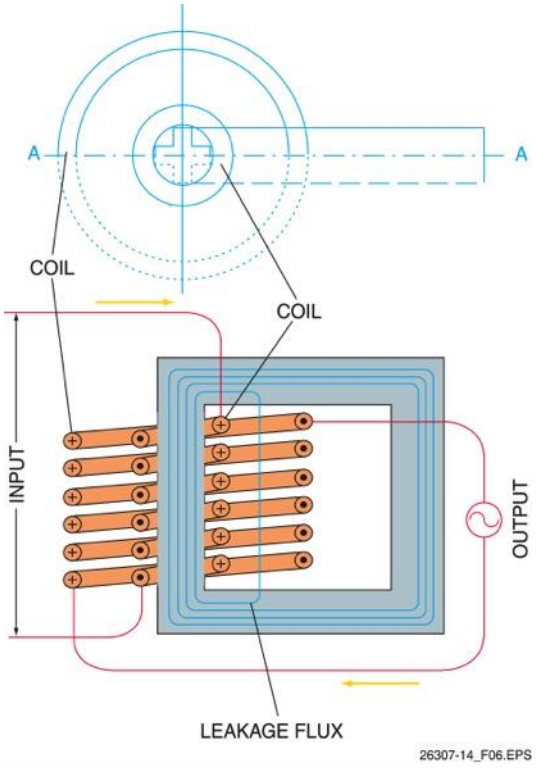
Transformer with High-Leakage Flux

- When a transformer uses physically separated coils, the current flow in the secondary tends to create its own magnetic field in opposition to the original flux field.
- This restricts the flux flow, forcing the excess flux to find another path, typically through the air or the transformer housing/support clamps.



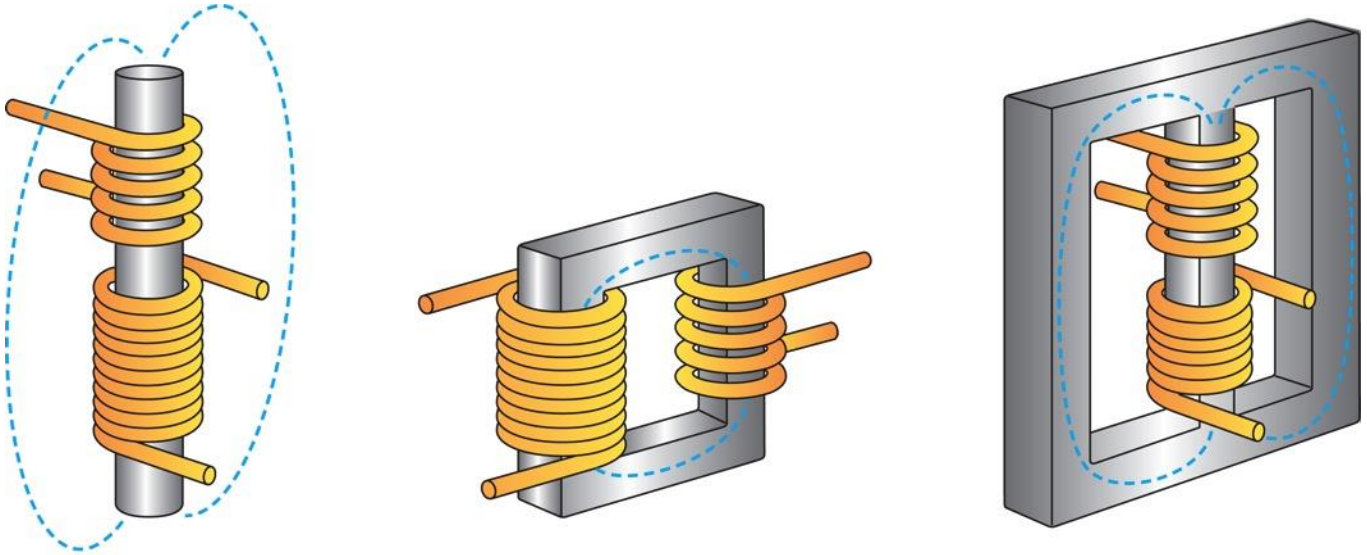
Low-Leakage Transformer

When a transformer uses intertwined coils, the current flow in the secondary is less likely to create a separate magnetic field and the leakage flux is reduced.



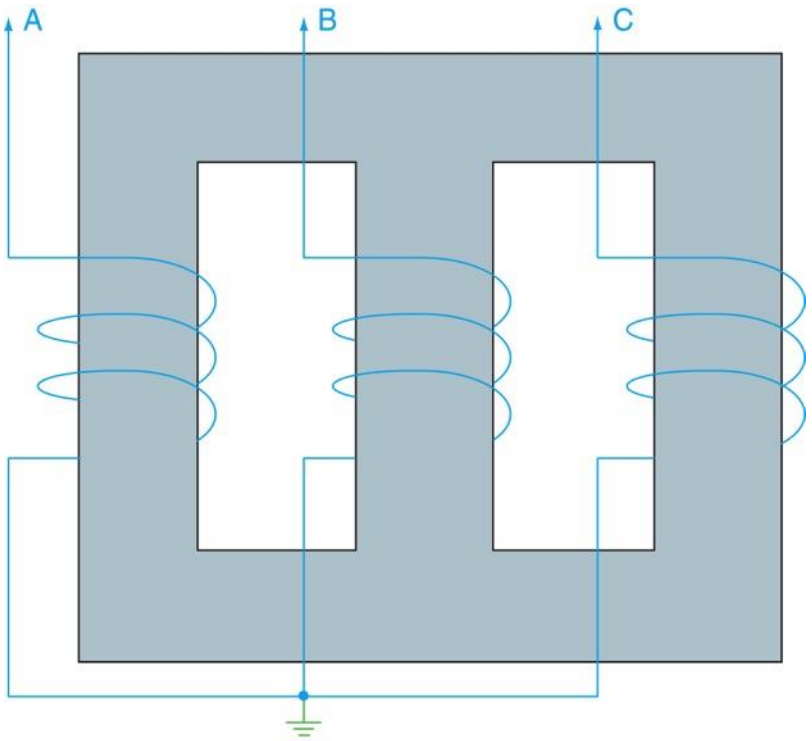
Transformer Construction

- Transformers use iron cores to transfer the magnetic field of the primary winding to the secondary winding.
- There are three basic types of iron core transformers: open core, closed core, and shell core.



Core-Type Transformer Construction

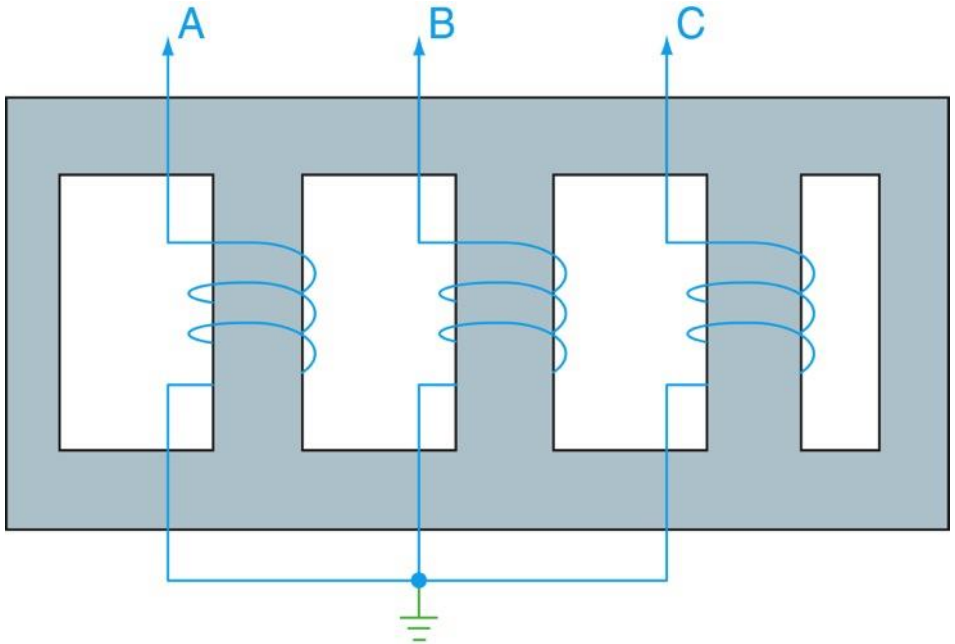
- Core-type transformers are more efficient than open core transformers.
- Core-type transformers are preferred over shell-type transformers for use in dry transformers because they are less expensive, require less space, and provide better cooling.



26307-14_F08.EPS

Shell-Type Transformer Core

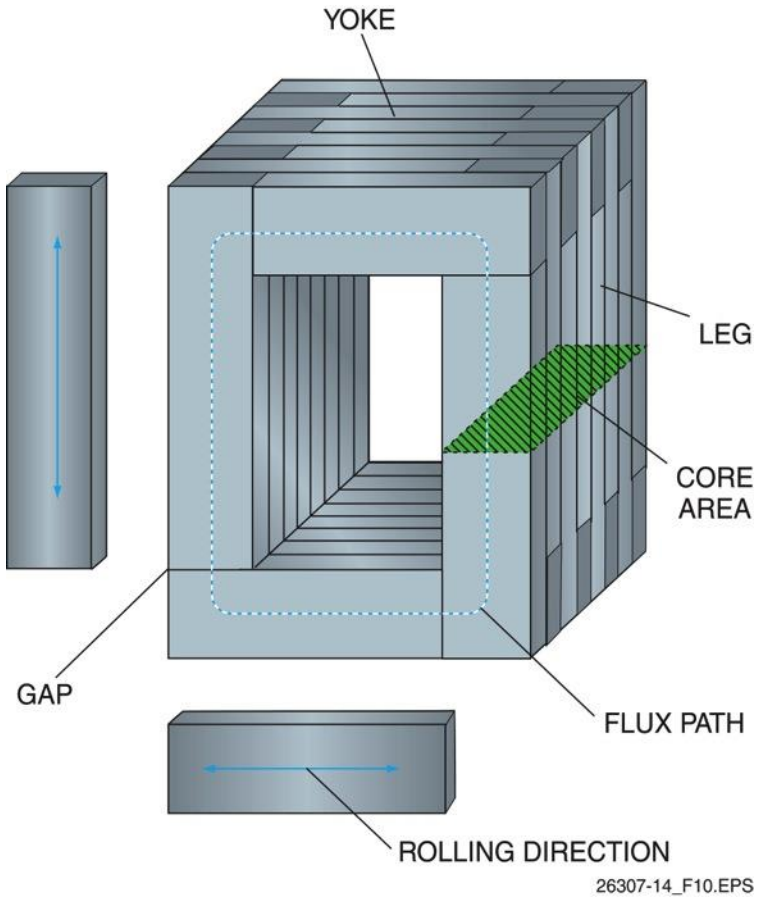
Shell-type transformers improve efficiency by creating parallel paths for the magnetic field. However, they are more expensive and take up more space than other types.



26307-14_F09.EPS

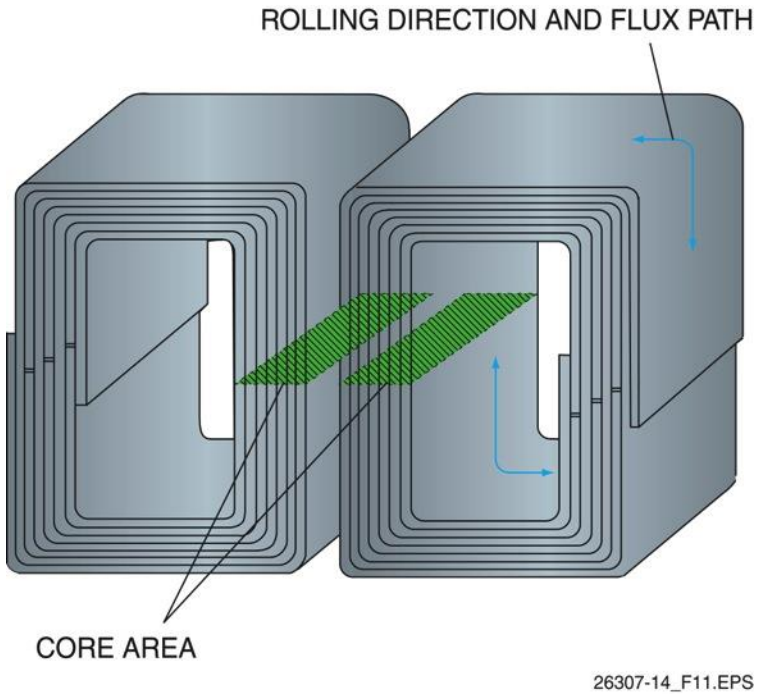
Butt-and-Lap Transformer Core

- Transformer cores can have butt-and-lap, wound, or mitered cores.
- Butt-and-lap cores are built with steel laminations arranged in a brick pattern.



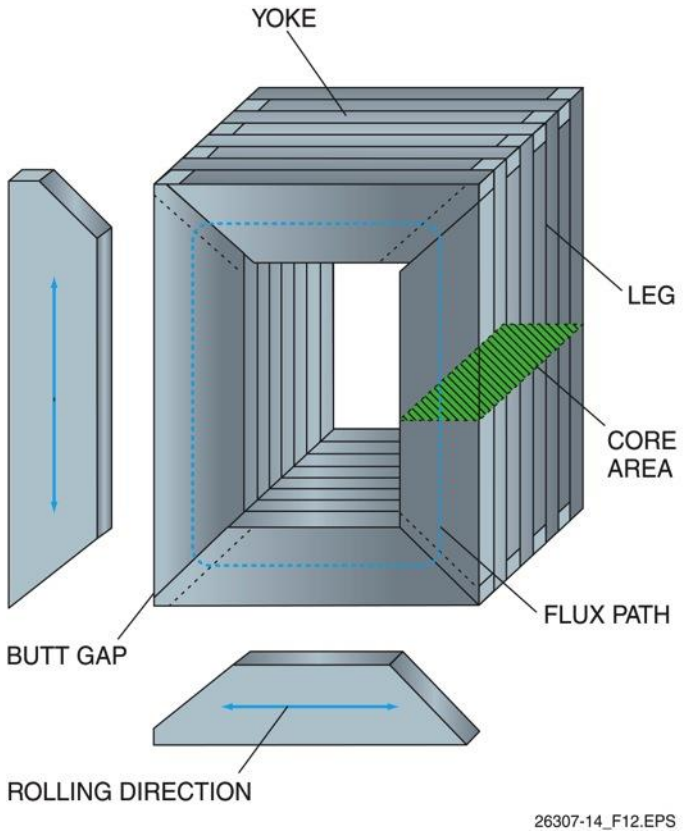
Wound Transformer Coil

- Wound transformer cores are built using concentric rectangular sheets.
- The core loops are cut to different lengths to eliminate gap overlaps.



Mitered Transformer Core

- Mitered-core transformers eliminate all cross grain flux, reducing the core loss and improving exciting current values.
- They also reduce the flux density in the air gap, resulting in reduced sound levels.



Next Session…

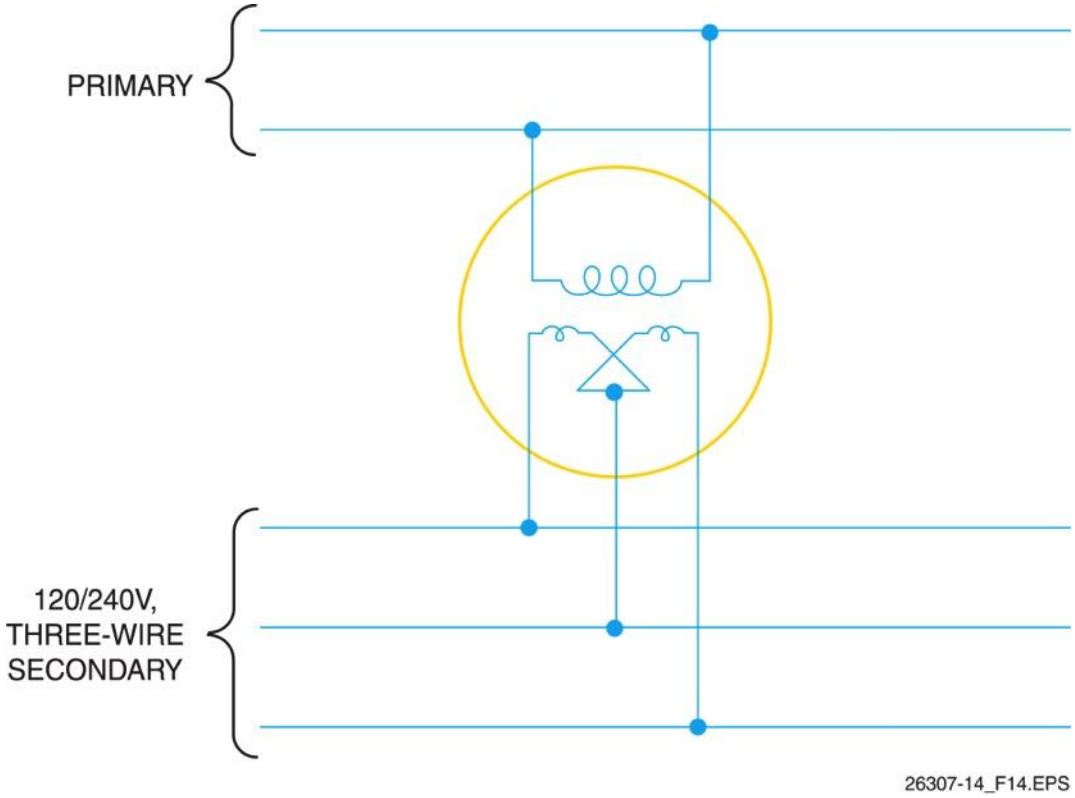
Transformer Taps

- If a load is close to a substation or power plant, the voltage will be higher than normal, and near the end of the line, it will be lower than normal.
- Transformer taps are used to adjust the secondary voltage to maintain a consistent level.

Basic Transformer Connections

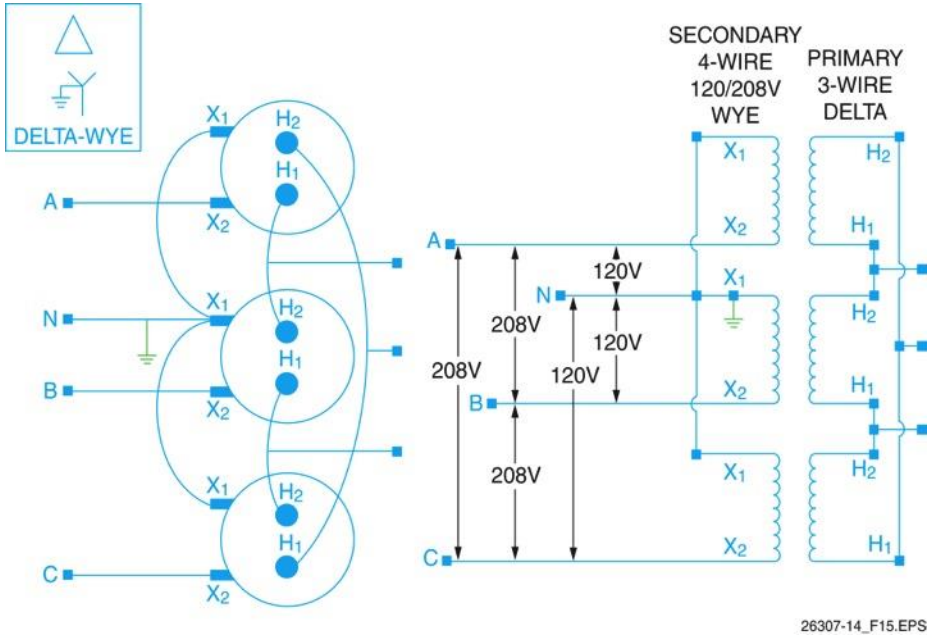
Basic Transformer Connections

Three-wire 120/240V single-phase transformers are used in residential and small commercial applications.



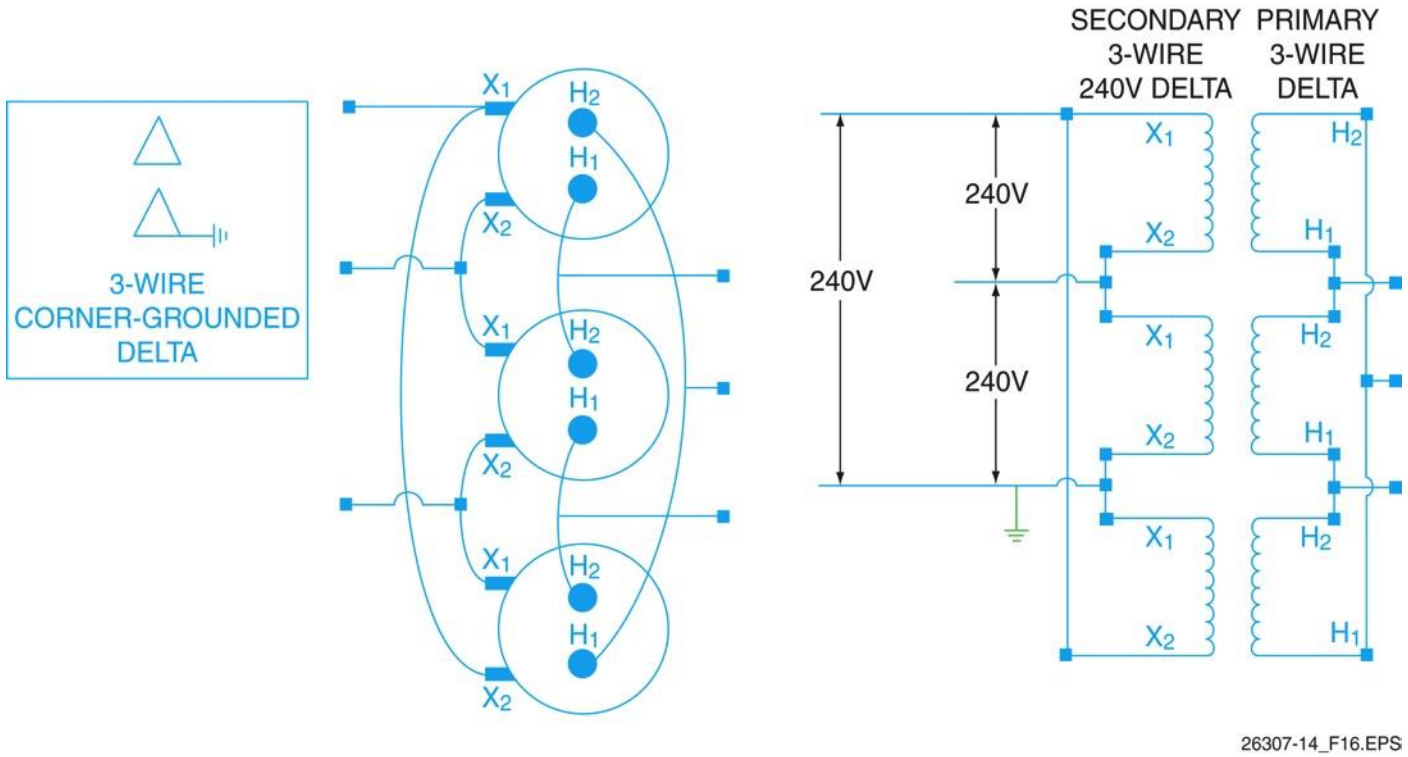
Delta-Wye Transformer System

- Three-phase power systems are selected based on the loads to be supplied, the required voltages, and the likelihood of future expansion.
- One of the most common transformer systems for commercial and industrial power is the delta-wye transformer system. It provides single-phase power at 120V and three-phase power at 208V.



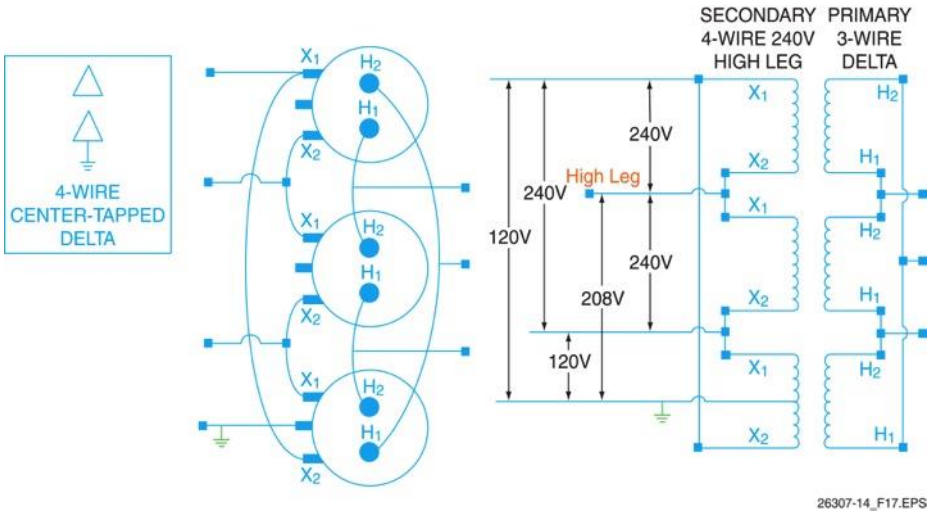
Delta-Connected Secondary

A delta-delta transformer system has its windings connected in series to form a triangle.



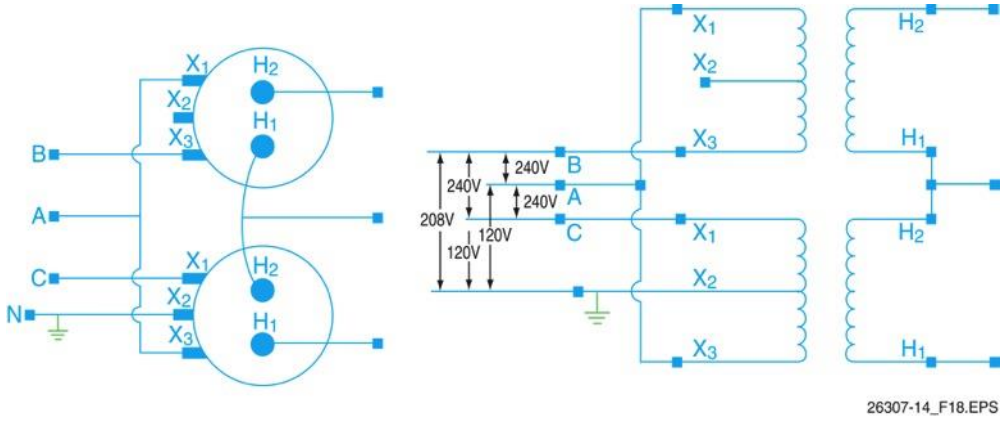
Characteristics of a Center-Tapped, Delta-Connected System

- This system provides 120V between the center-tapped terminal and each ungrounded terminal, and 240V across the full winding of each phase.
- The high leg of a center-tapped delta transformer system provides 208V. Never connect 120V circuits to the high leg.



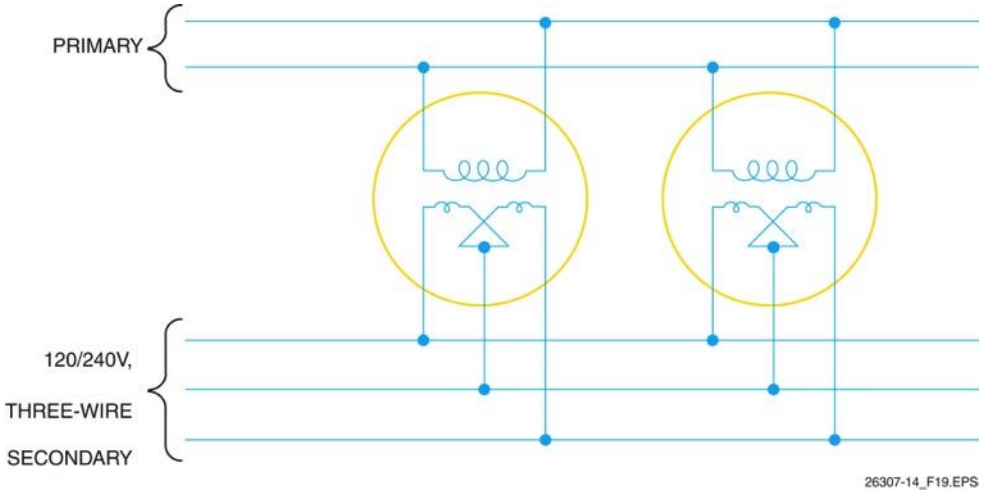
Open Delta System

- If one of the transformers in a three-phase, delta-connected system is damaged, it may be reconnected using only two transformers. This is known as an open delta system.
- An open delta system provides emergency power at 57.7% of the normal full-load capability until the transformer can be replaced.



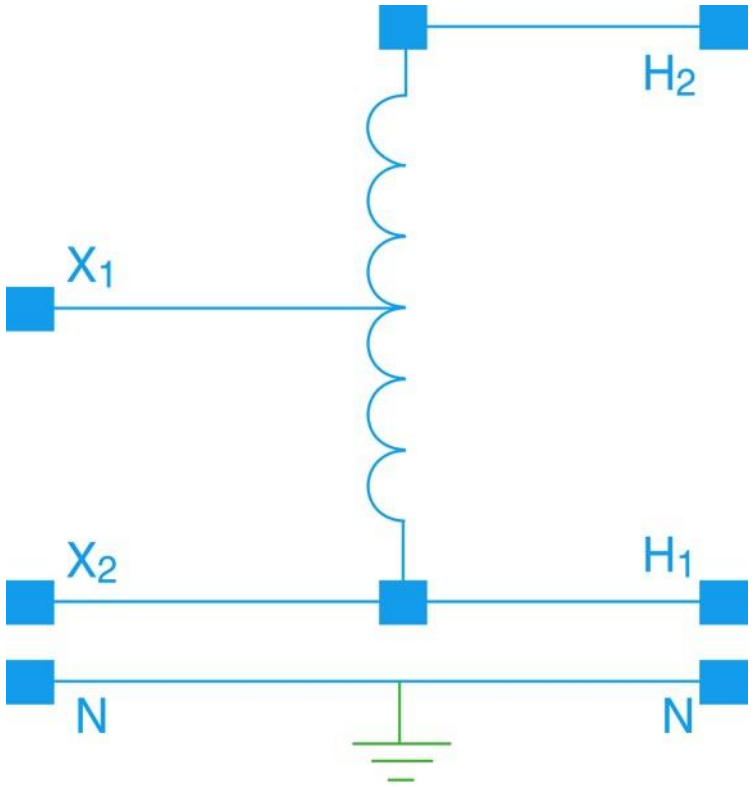
Parallel Operation of Single-Phase Transformers

- Transformers with equivalent windings, voltages, and impedances can be connected in parallel.
- Transformers with different values can cause circulating currents to flow, resulting in overheating and poor efficiency.



Autotransformers

- Transformers in which the primary and secondary circuits have part of a winding in common are known as autotransformers.
- Autotransformers offer many advantages, including better voltage regulation and reduced size, cost, and sound levels.

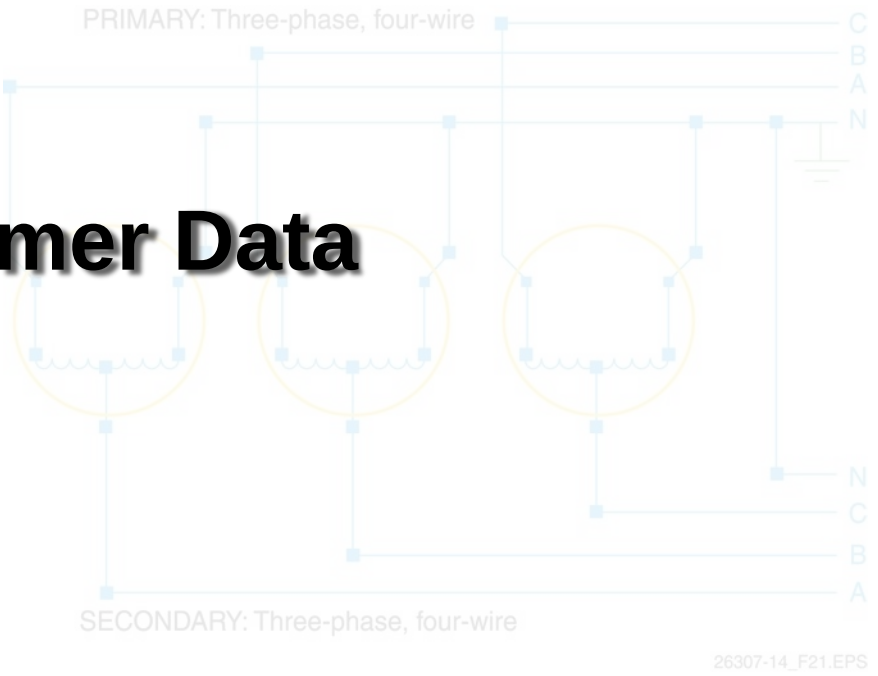


26307-14_F20.EPS

Next Session…

Autotransformers Supplying Power from a Three-Phase, Four-Wire System

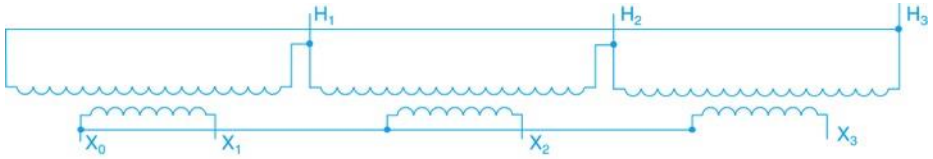
- Autotransformers are commonly used when the ratio of the primary to secondary curre
- In this system, the neutral of the autotransformer must be connected to the system neutral (similar to a wye connection).



Transformer Data

Transformer Data

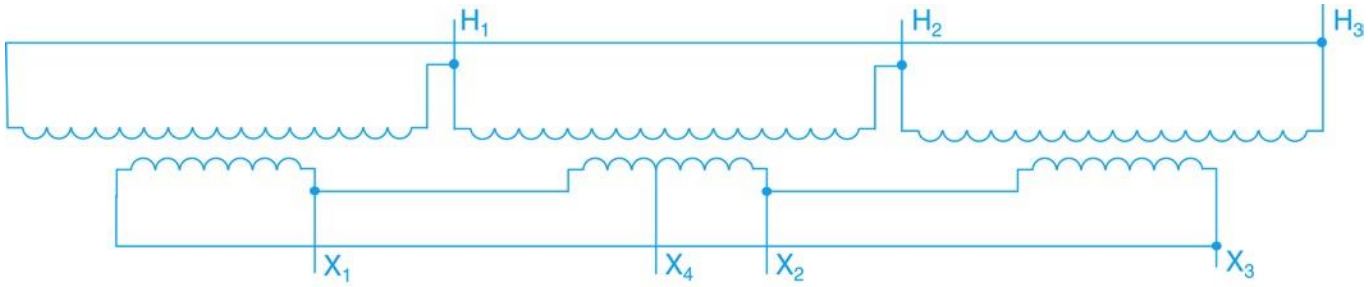
- ***NEC Section 450.11*** requires that transformer nameplates list the kVA, primary/secondary voltages, impedance, frequency, insulation class, and required clearances.
- Most manufacturers also provide a wiring diagram and a connection chart, such as that shown here.



PRIMARY VOLTS	CONNECT PRIMARY LINES TO	CONNECT SECONDARY LINES TO
480V	H_1, H_2, H_3	———
SECONDARY VOLTS		
208V	———	X_1, X_2, X_3
120V SINGLE-PHASE	———	X_1 to X_0 X_2 to X_0 X_3 to X_0

26307-14_F22.EPS

480V Delta to 240V Delta Transformer Connections

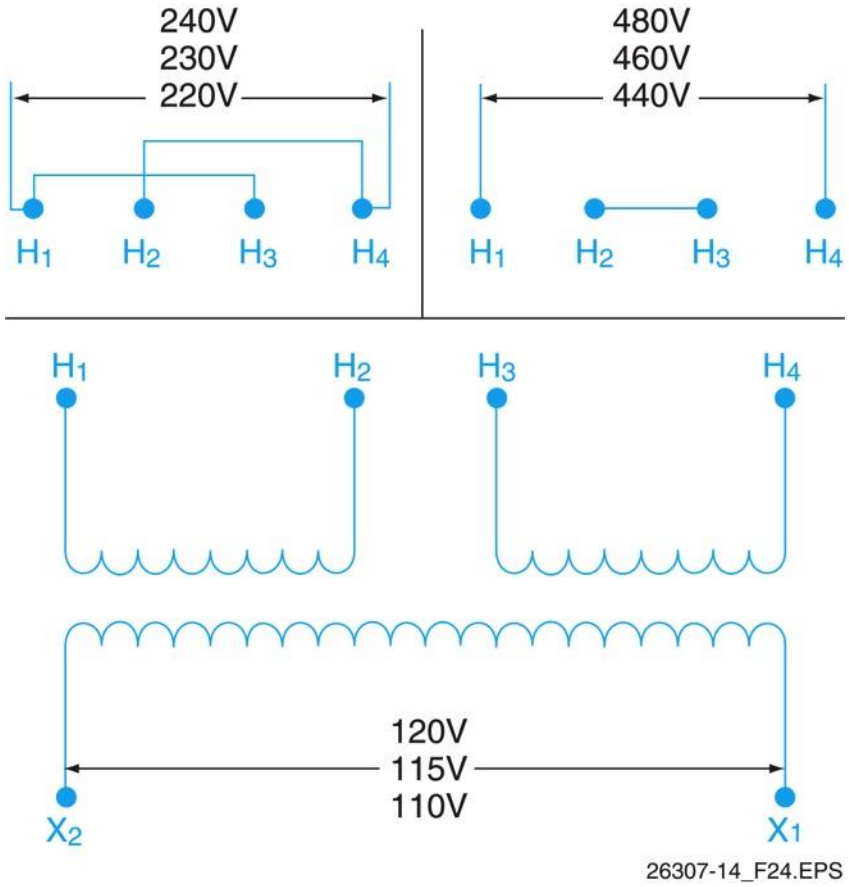


PRIMARY VOLTS	CONNECT PRIMARY LINES TO	CONNECT SECONDARY LINES TO
480V	H_1, H_2, H_3	———
SECONDARY VOLTS		
240V	———	X_1, X_2, X_3
120V	———	X_1, X_4 or X_2, X_4

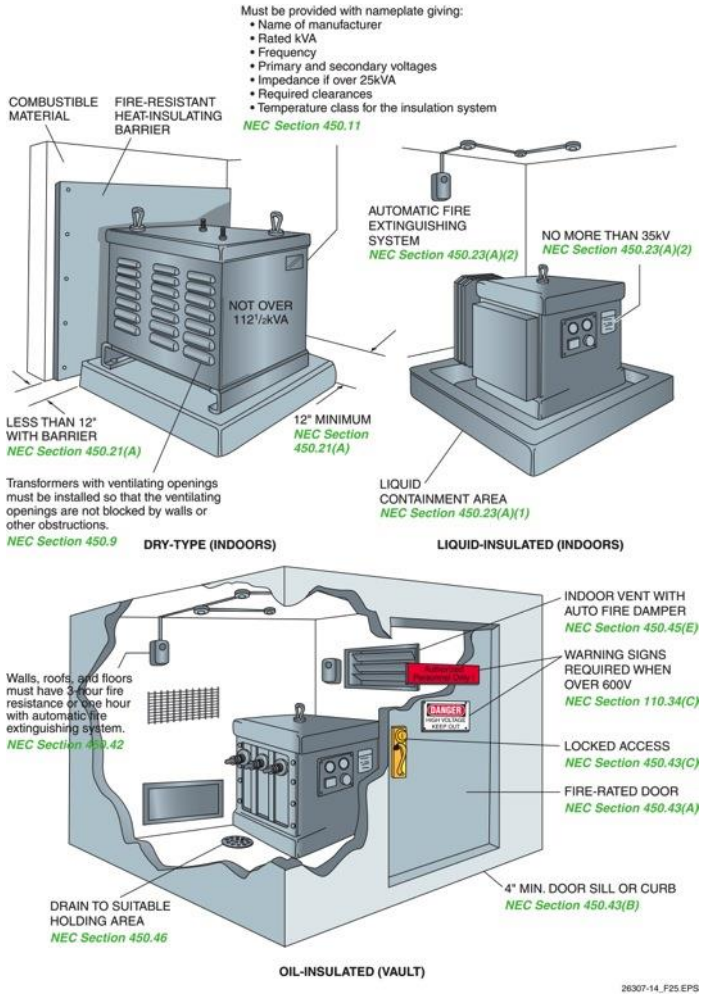
26307-14_F23.EPS

Control Transformers

- Most control transformers are dry-type, step-down transformers with isolated primary and secondary circuits for safety purposes.
- Industrial control transformers are designed to accommodate the momentary inrush current when equipment is energized.



NEC® Requirements

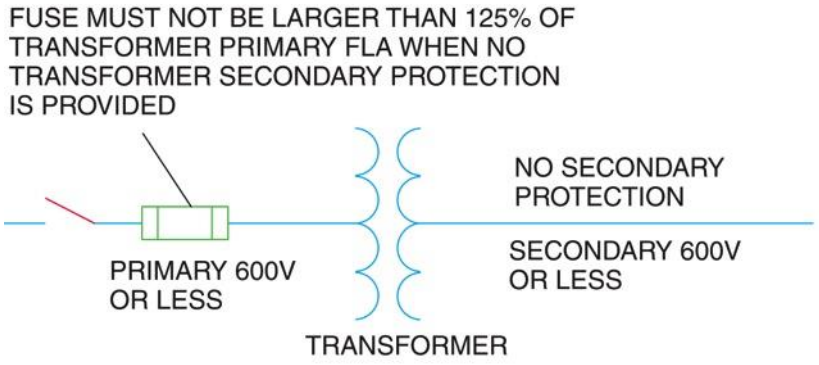


Summary of *NEC*® Transformer Installation and Overcurrent Protection Requirements

Application	*NEC*® Regulation	*NEC*® Reference
Location	Transformers must be readily accessible to qualified personnel for maintenance and inspection.	*NEC Section 450.13*
	Transformers, other than low-voltage Class 2 or Class 3 are required to have a disconnecting means. The disconnect location must be either in sight of the transformer, or in a remote location. Where it is mounted remotely, the disconnect shall be lockable and its location shall be field marked on the transformer.	*NEC Section 450.14*
	Dry-type transformers rated at 112½kVA or less may be located out in the open provided they are separated from combustible material by 12" or a suitable fire/heat barrier.	*NEC Section 450.21(A)*
	Dry-type transformers rated at more than 112½kVA must be installed in a transformer room of fire-resistant construction.	*NEC Section 450.21(B)*
	Dry-type transformers not exceeding 1,000V and 50kVA are not required to be readily accessible and are permitted in fire-resistant hollow spaces of a building under the conditions specified in the *NEC*®.	*NEC Sections 450.13(A) and (B)*
	Dry-type transformers installed outdoors must have a weatherproof enclosure.	*NEC Section 450.22*
	Liquid-filled transformers must be installed as specified in the *NEC*® and usually in vaults when installed indoors.	*NEC Section 450.23*
Overcurrent protection	The primary protection must be rated or set as follows: • 9A or more—125% • Less than 9A—167% • Less than 2A—300%	*NEC Table 450.3(B)*
	If the primary current (line side) is 9A or more, the next higher standard size overcurrent protective device greater than 125% of the primary current is used. For example, if the primary current is 15A, 125% of 15A = 18.75A. The next standard size circuit breaker is 20A. Therefore, this size, 20A, may be used.	
	Conductors on the secondary side of a single-phase transformer with a two-wire secondary may be protected by the primary overcurrent device under certain *NEC*® conditions.	
Transformers used in motor control circuits	Special rules apply to these circuits for the various types of transformers.	*NEC Section 430.72(C)*
Over 1,000V	Special *NEC*® rules apply to transformers operating at over 1,000V.	*NEC Table 450.3(A)*

Transformer Circuit with Primary Fuse Only

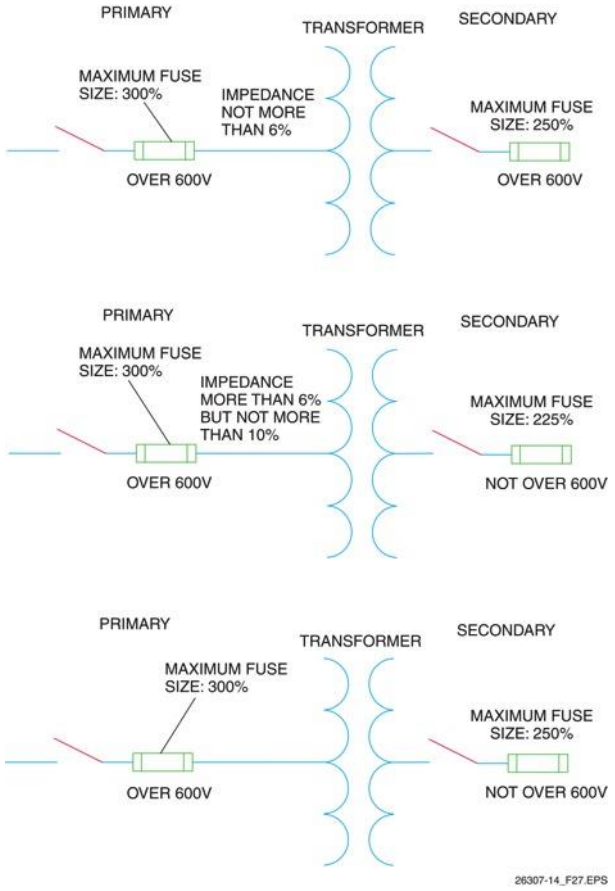
- If secondary fuse protection is not provided, the primary fuses must not be sized larger than 125% of the transformer primary full-load amps (FLA), except as permitted by ***NEC Table 450.3(B).***
- Individual transformer primary fuses are not necessary where the primary fuse provides this protection.



PRIMARY CURRENT	PRIMARY FUSE RATING
9A or more	125% or next higher standard rating if 125% does not correspond to a standard fuse size
2A to 9A	167% maximum
Less than 2A	300% maximum

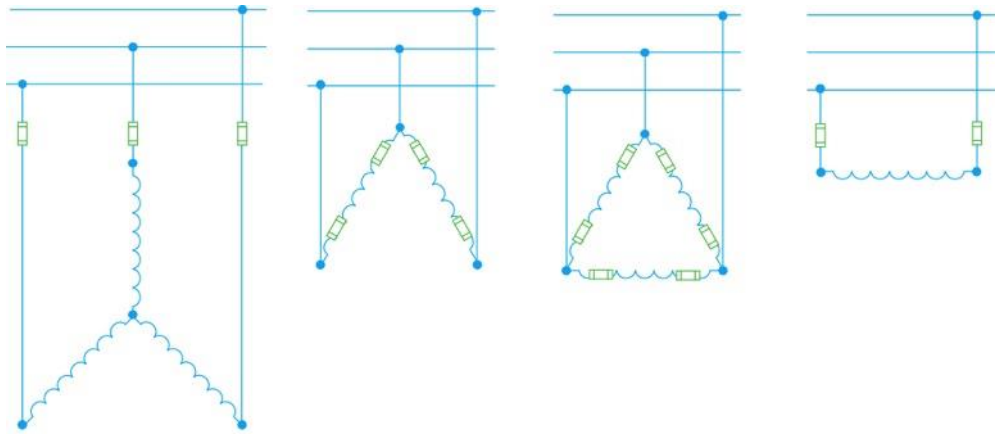
26307-14_F26.EPS

Minimum Overcurrent Protection for Transformers in Supervised Locations



Connections Requiring Fuses to Pass Only the Magnetizing Inrush of One Transformer

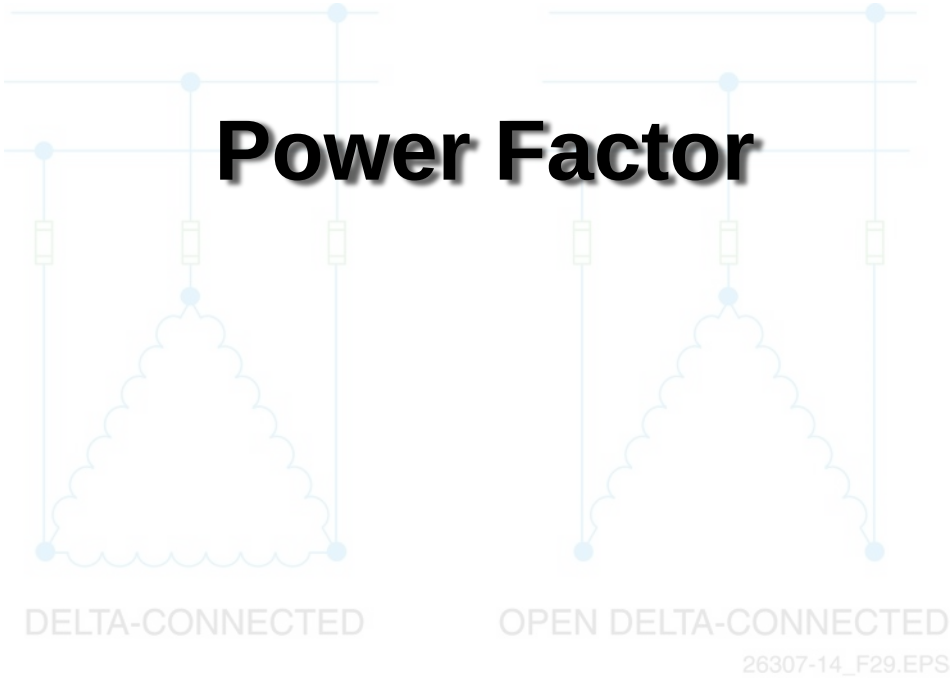
Typical potential transformer connections can be divided into two groups: those that require the fuse to pass the magnetizing inrush of one potential transformer (shown here) and those that require the fuse to pass the magnetizing inrush of more than one potential transformer.



Next Session…

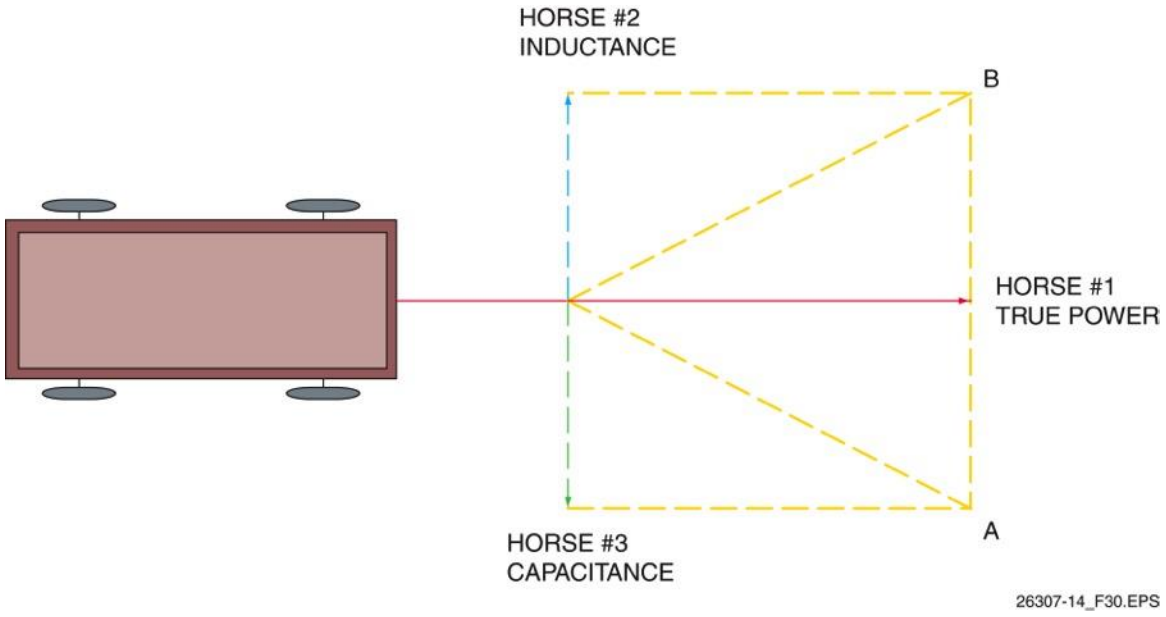
Applications Requiring Fuses to Pass the Magnetizing Inrush of More Than One Transformer

Power Factor



Power Factor

- The power factor of a circuit is the ratio of kilowatts to kilovolt-amperes.
- Inductance and capacitance tend to cancel each other out, resulting in true power as the force that operates a circuit.

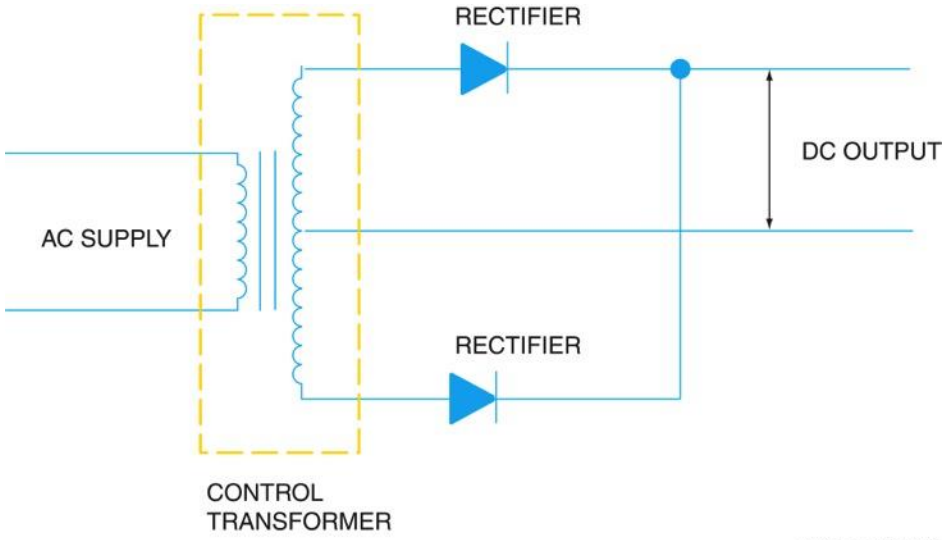


NEC® Capacitor Installation Requirements

Application	*NEC*® Regulation	*NEC*® Reference
Enclosing and guarding	Capacitors must be enclosed, located, or guarded so that persons cannot come into accidental contact or bring conducting materials into accidental contact with exposed energized parts, terminals, or buses associated with them. However, no additional guarding is required for enclosures accessible only to authorized and qualified persons.	*NEC Section 460.2(B)*
Stored charge	Capacitors must be provided with a means of draining the stored charge. The discharge circuit must be either permanently connected to the terminals of the capacitor or capacitor bank or provided with automatic means of connecting it to the terminals of the capacitor bank on removal of voltage from the line. Manual means of switching or connecting the discharge circuit shall not be used.	*NEC Section 460.6*
Capacitors on circuits over 1,000V	Special *NEC*® regulations apply to capacitors operating at over 1,000V.	*NEC Articles 460, Part II and 490*
Conductor ampacity	The ampacity of capacitor circuit conductors must not be less than 135% of the rated current of the capacitor.	*NEC Section 460.8(A)*
Capacitors on motor circuits	The ampacity of conductors that connect a capacitor to the terminals of a motor or to motor circuit conductors shall not be less than one-third the ampacity of the motor circuit conductors and in no case less than 135% of the rated current of the capacitor.	*NEC Section 460.8(A)*
Overcurrent protection	Overcurrent protection is required in each ungrounded conductor unless the capacitor is connected on the load side of a motor running overcurrent device. The setting must be as low as practicable.	*NEC Section 460.8(B)*
Disconnecting means	A disconnecting means is required for a capacitor unless it is connected to the load side of a motor controller. The rating must be not less than 135% of the rated current of the capacitor.	*NEC Section 460.8(C)*
Overcurrent protection for improved power factor	If the power factor is improved, the motor running overcurrent device must be selected based on the reduced current draw, not the full-load current of the motor.	*NEC Section 460.9*
Grounding	Capacitor cases must be grounded except when the system is designed to operate at other than ground potential.	*NEC Section 460.10 and 460.27*

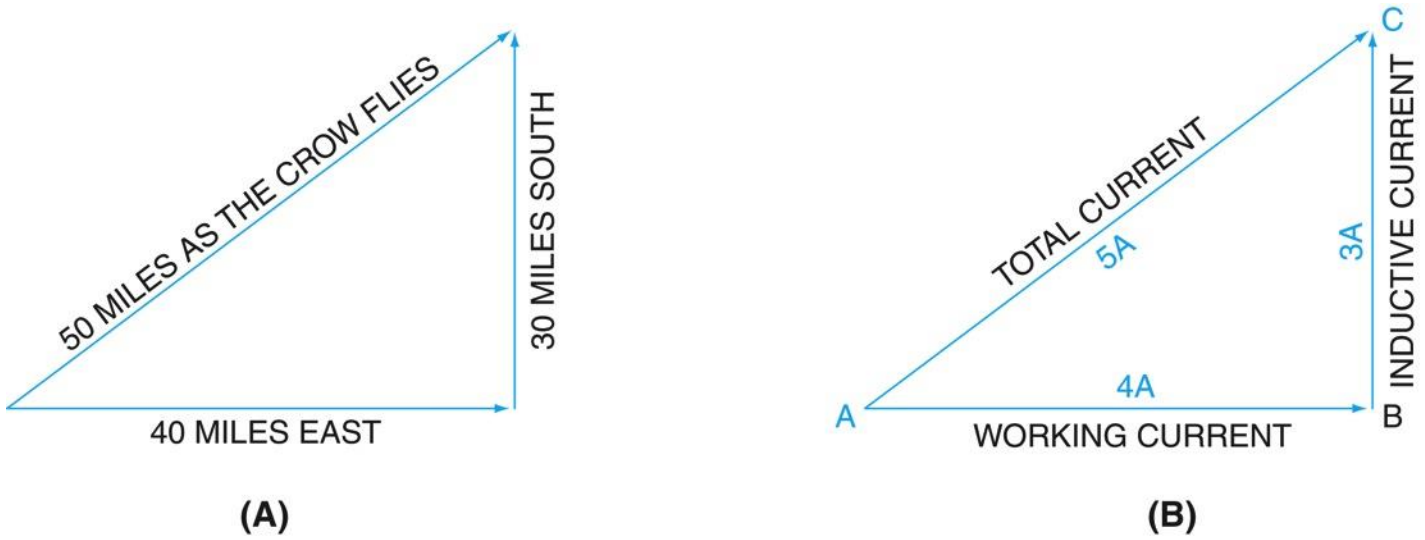
Rectifiers Used in a Control Circuit to Change AC to DC

- Diodes and rectifiers are used to convert or rectify alternating current to direct current.
- A component that is rated below 1A is a diode, while a component rated above 1A is a rectifier.

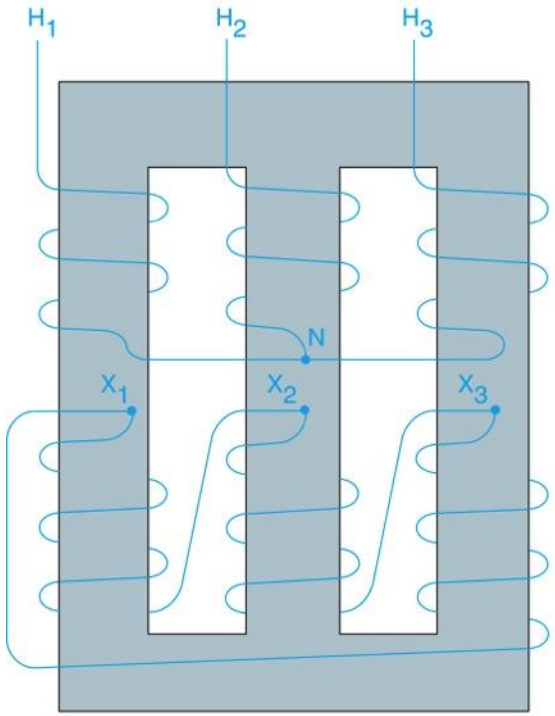


Vectors

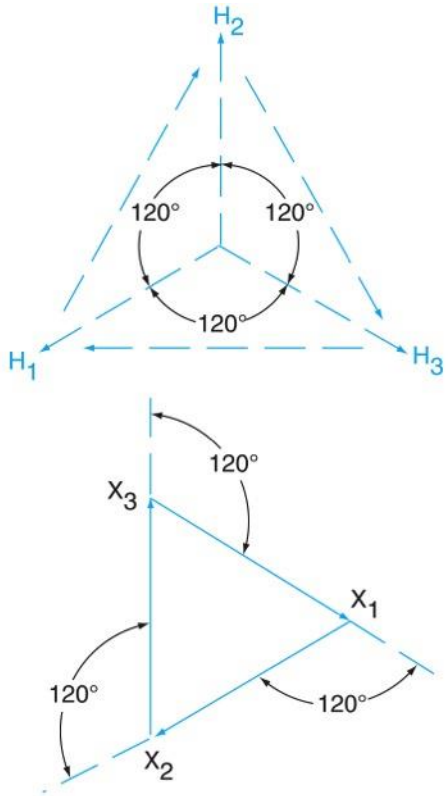
- Phasor diagrams (vectors) are graphic representations of the voltages and currents in transformer windings.
- In this example, the ratio between working and total current is 4:5 and the power factor is 4/5 or 80%.



Windings and Phasor Diagrams of a Three-Phase Transformer



(A)

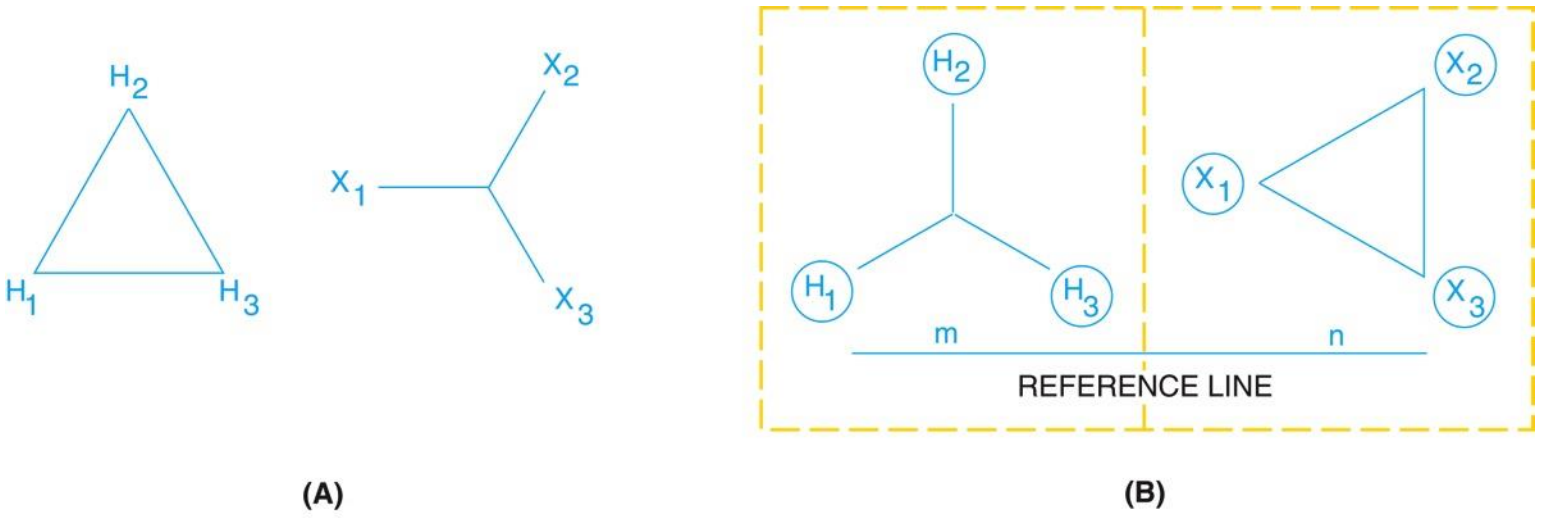


(B)

26307-14_F33.EPS

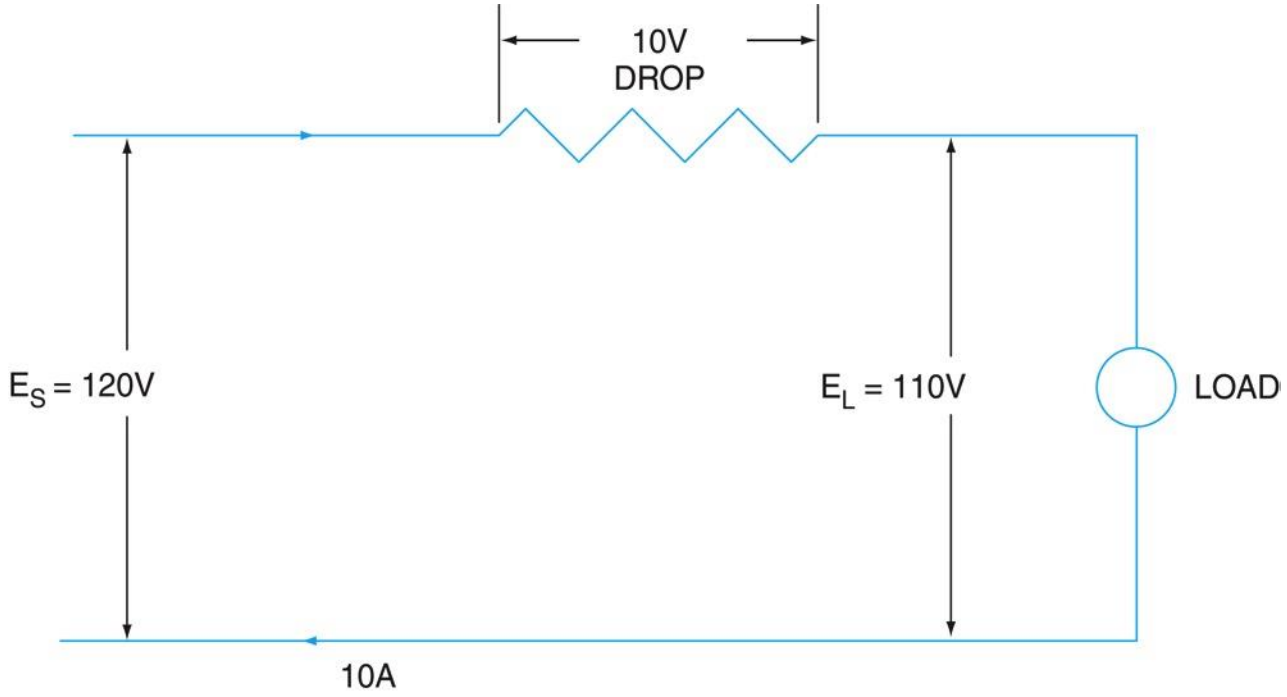
Phasor Diagrams for Three-Phase Transformer Banks in Parallel

Phasor diagrams can be used to determine if three-phase transformers are suitable for connection in parallel.



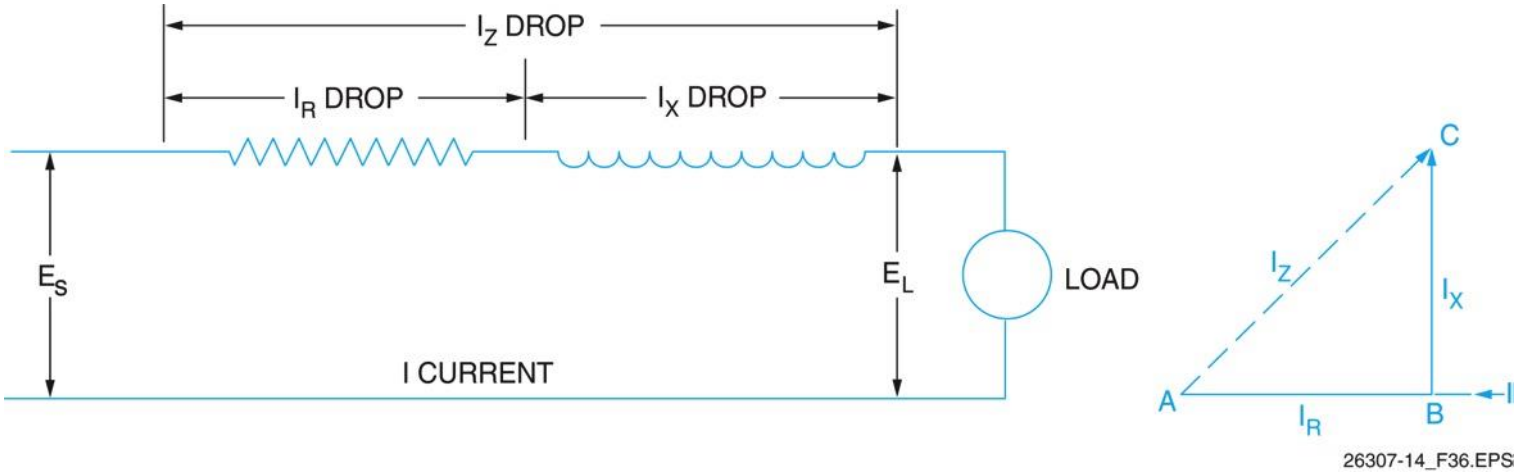
Circuit Containing Resistance Only

In a simple 120V, resistance-only circuit with a 10V voltage drop and 100% power factor, the available voltage is only 110V.



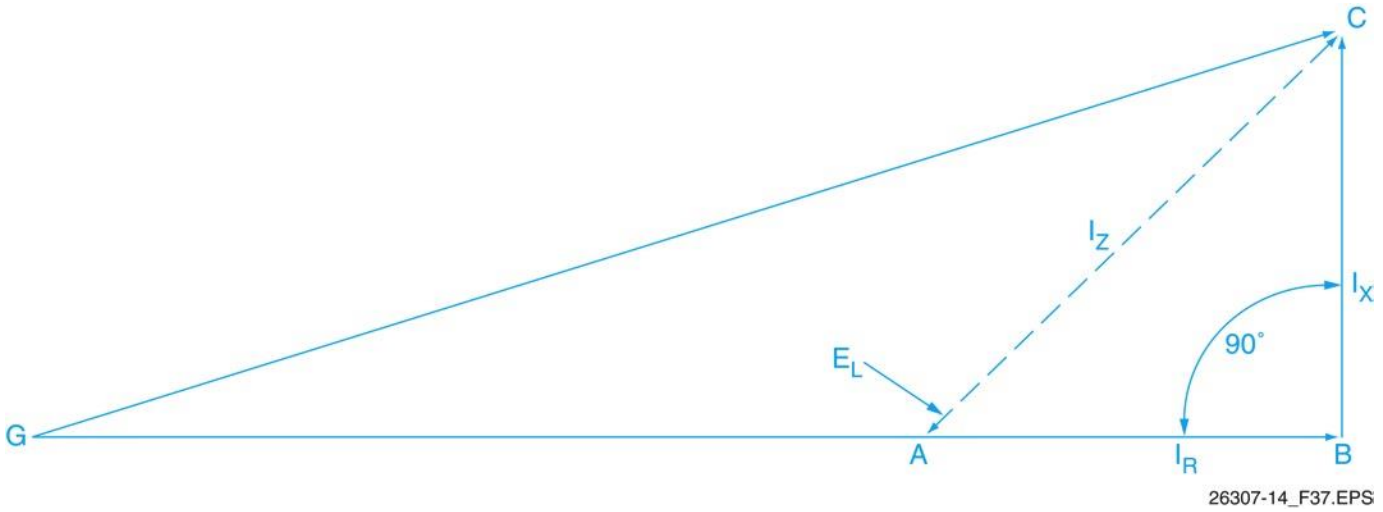
Electrical Circuit with Both Resistance and Inductance

When inductance is introduced into the circuit, the load voltage will equal the voltage drops through R and X, but they cannot be added and must be calculated using a vector diagram.



Effect of Voltage Drop in an AC Circuit

- The load voltage E_L is less than the source voltage G-C due to the voltage drop in line A-C.
- Due to the effect of reactance in the circuit, this voltage drop cannot be subtracted and must be calculated using a vector diagram.

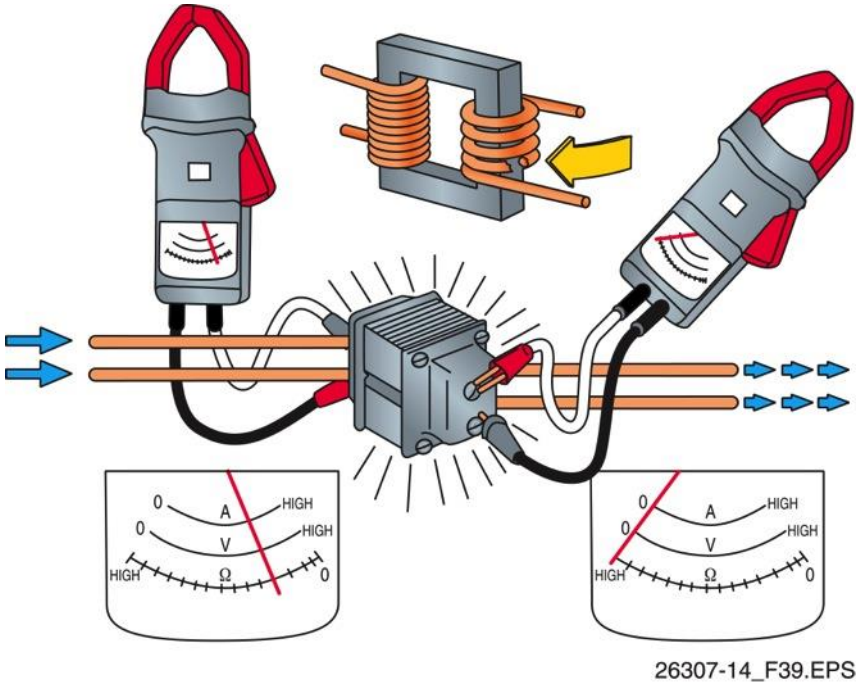


Next Session…

Troubleshooting; Transformer Maintenance

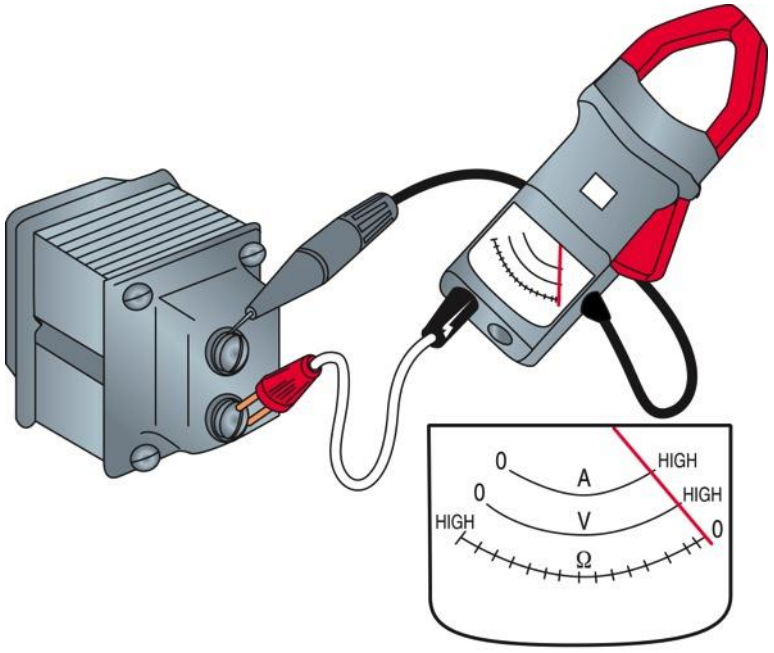
Troubleshooting; Transformer Maintenance

- Common transformer problems include open circuits, shorted turns, complete shorts, and grounded windings.
- An open circuit in a transformer is indicated by a voltage measurement at the input terminals but zero voltage at the output terminals.



Checking for an Open Winding with a Continuity Test Using a VOM

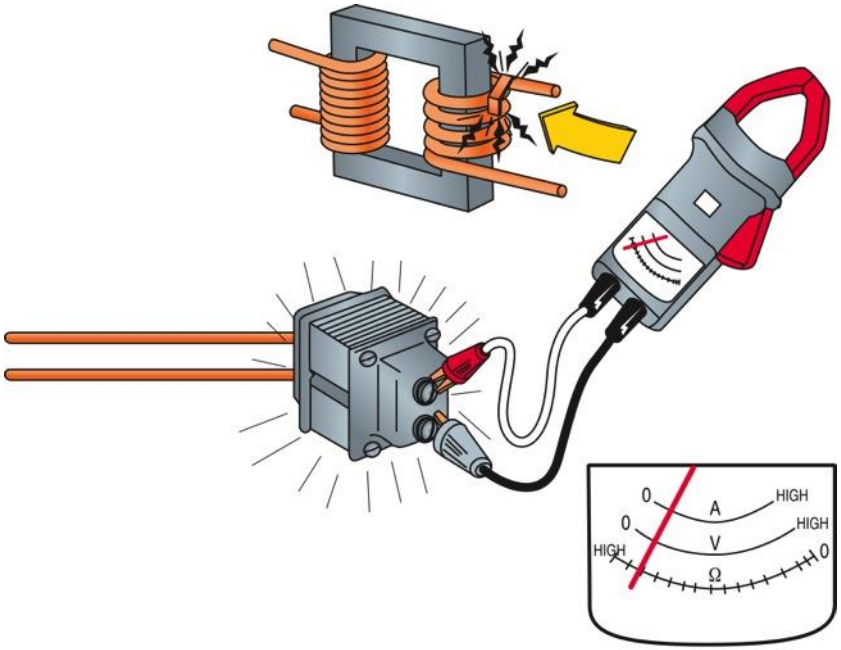
- After determining that no voltage is present on the output terminals, lock out and tag the circuit and perform a continuity test to verify an open winding.
- An open winding will be indicated by a resistance reading of infinity using the ohmmeter function of a VOM.



26307-14_F40.EPS

Transformers That Overheat Usually Have a Partial Short in the Windings

- A partial short in one of the transformer windings will result in overheating and a voltage drop across the secondary.
- A transformer turns ratio tester or a VOM can be used to test for partially shorted windings. The output voltage will be lower than expected.

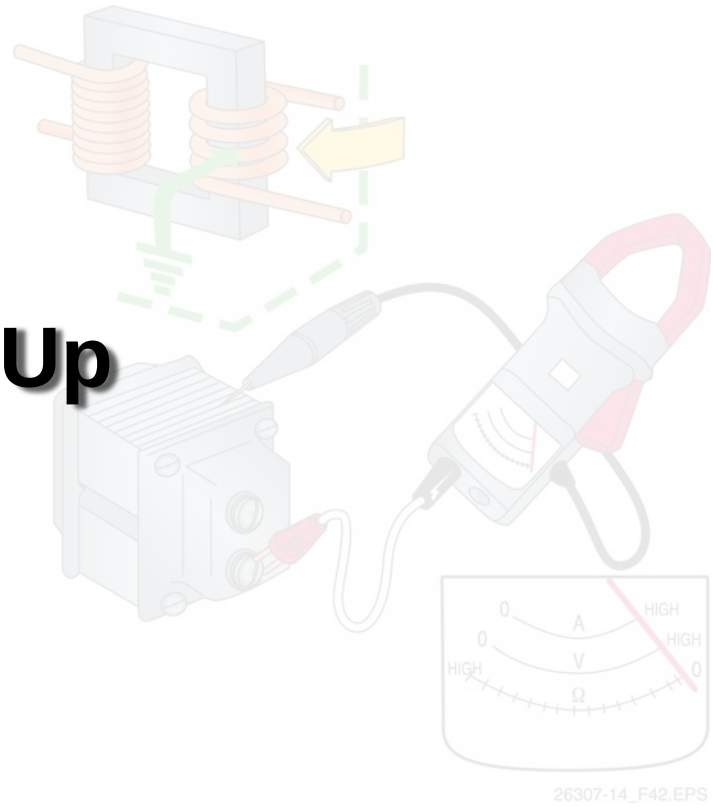


26307-14_F41.EPS

Next Session…

Testing a Transformer for a Ground Fault by Measuring Resistance Using a VOM

- Transformer overloads will cause eventual insulation failure, leading to exposed conductors and a grounded winding. Symptoms include overheating and a burning smell.
- A megger can be used to test the insulation resistance. Note that only qualified and trained individuals may operate this equipment.



Wrap Up

Wrap Up

3-2-1

3 – Write 3 important things learned during class

2 – Write 2 questions you have about the material

1 – Write 1 thought you had about the material

Next Session…

MODULE EXAM

Review the complete module to prepare for the module exam. Complete the Module Review as a study aid.