
CHAPTER 15

DISTRIBUTION TRANSFORMERS

The purpose of a distribution transformer is to reduce the primary voltage of the electric distribution system to the utilization voltage serving the customer. A distribution transformer is a static device constructed with two or more windings used to transfer alternating-current electric power by electromagnetic induction from one circuit to another at the same frequency but with different values of voltage and current.

Figure 15.1 shows distribution transformers in stock at an electric utility company service building. The distribution transformers available for use for various applications, as shown, include pole-type (Figs. 15.2 and 15.3), pad-mounted (Fig. 15.4), vault or network type (Fig. 15.5), and submersible (Fig. 15.6).

The distribution transformer in Fig. 15.2 is self-protected. It is equipped with a lightning arrester, a weak-link or protective-link expulsion-type fuse (installed under oil in the transformer tank), a secondary circuit breaker, and a warning light. The transformer primary bushing conductor is connected to one phase of the three-phase primary circuit through a partial-range current-limiting fuse. The transformer tank is grounded and connected to the



FIGURE 15.1 Electric utility distribution storage yard. Forklift trucks are used to load transformers on line trucks. Storage area is covered with concrete to provide accessibility and protect transformers.



FIGURE 15.2 Typical pole-type distribution transformer installation with the transformer bolted directly to the pole. The unit is equipped with a surge arrester, a low-voltage circuit breaker, and an overload warning light. A partial-range current-limiting fuse is mounted on the primary bushing, connecting it in series with the high-voltage winding to prevent a violent failure of the transformer if an internal fault develops.

primary and secondary common-neutral ground wire. The self-protected transformer contains a core and coils, a primary fuse mounted on the bottom of the primary bushing, a secondary terminal block, and a low-voltage circuit breaker.

Conventional overhead transformers are also available. The key component distinguishing the conventional transformer from the self-protected transformer is the lack of internal fusing in the conventional model. An external fuse/cutout combination is mounted between the distribution primary and the conventional transformer. A conventional unit is depicted in Fig. 15.3.

Pad-mounted transformers are used with underground systems. Three-phase pad-mounted transformers are used for commercial installations, as illustrated in Fig. 15.4, and single-phase pad-mounted transformers are used for underground residential installations, as described and shown in Chap. 34. Vault-type distribution transformers are installed for commercial customers where adequate space is not available for pad-mounted transformers. The vault-type transformer (Fig. 15.5) may be installed in a vault under a sidewalk or in a building. They are often used in underground electric network areas.

Submersible single-phase distribution transformers (Fig. 15.6) are used in some underground systems installed in residential areas, as described in Chap. 34. Corrosion problems and the high cost of installation have minimized the use of submersible transformers.

Distribution Transformer Operation. The basic principle of operation of a transformer is explained in Chap. 1. A schematic drawing of a single-phase distribution transformer appears in Fig. 15.7. The single-phase distribution transformer consists of a primary winding and a secondary winding wound on a laminated steel core. If the load is disconnected from the secondary winding of the transformer and a high voltage is applied to the primary winding of the transformer, a magnetizing current will flow in the primary winding. If we assume the resistance of the primary winding is small, which is usually true, this current is limited by the countervoltage of self-induction induced in the highly inductive primary

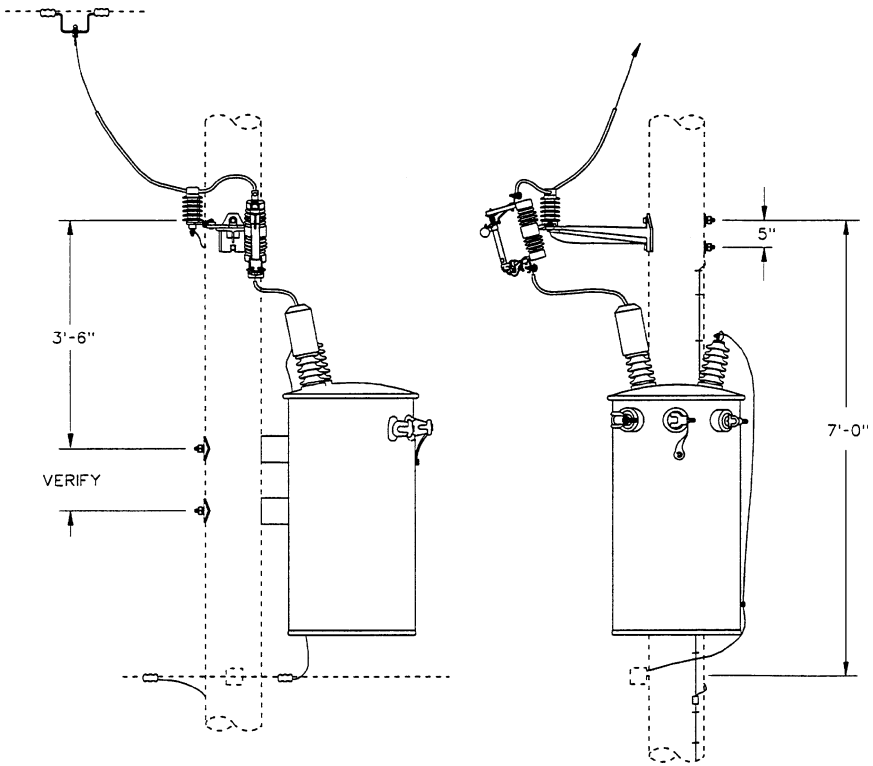


FIGURE 15.3 Two view construction standard detail of a conventional transformer to be installed on the distribution system. Note the fused cutout and lighting arrestor combination external to the transformer. (Courtesy MidAmerican Energy Co.)



FIGURE 15.4 Three-phase pad-mounted transformer installed in shopping center parking lot. Transformer reduces voltage from 13,200Y/7620 to 208Y/120 volts. Primary and secondary terminals of transformer are connected to underground cables. (Courtesy ABB Power T&D Company Inc.)



FIGURE 15.5 Vault-type distribution transformer 1000 kVA, three-phase 13,200 GrdY/7620 to 208Y/120 volts. High-voltage terminals H_1 , H_2 , and H_3 are designed for elbow-type cable connections, and low-voltage terminals X_1 , X_2 , and X_3 are spade-type for bolted connections to cable lugs. (Courtesy ABB Power T&D Company Inc.)



FIGURE 15.6 Submersible distribution transformer strapped to a pallet for shipment. Cables are for low-voltage connections. High-voltage connections are made with elbow cable connectors to bushing inserts installed in wells shown on top of the transformer. (Courtesy ABB Power T&D Company Inc.)

winding. The windings of the transformer are constructed with sufficient turns in each winding to limit the no-load or exciting current and produce a countervoltage approximately equal to the applied voltage. The exciting current magnetizes, or produces a magnetic flux in the steel transformer core. The magnetic flux reverses each half cycle as a result of the alternating voltage applied to the primary winding. The magnetic flux produced cuts the turns of the primary and secondary windings. This action induces a countervoltage in the primary winding and produces a voltage in the secondary winding. The voltages induced in each turn of the primary and secondary winding coils will be approximately equal, and the voltage induced in each winding will be equal to the voltage per turn multiplied by the number of turns.

Voltage $V =$ volts per turn \times number of turns N
 Voltage primary winding $= V_p$
 Voltage secondary winding $= V_s$
 Volts per turn $= V_t$

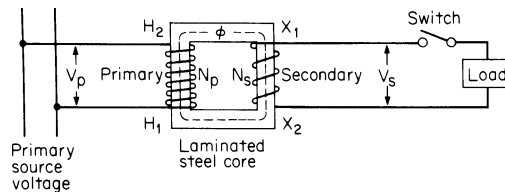


FIGURE 15.7 Schematic drawing of single-phase distribution transformer.

Number of turns of primary winding = N_p
 Number of turns of secondary winding = N_s

Therefore, the voltage of the primary winding is equal to the applied voltage and equal to the number of turns in the primary winding multiplied by the volts per turn.

$$V_p = V_t \times N_p$$

Likewise the voltage of the secondary winding will equal the volts per turn multiplied by the number of turns in the secondary winding.

$$V_s = V_t \times N_s$$

If we use basic algebraic operations and divide both sides of an equation by the same number, we can obtain the following equation:

$$\frac{V_p}{N_p} = \frac{V_t \times N_p}{N_p}$$

$$\frac{V_p}{N_p} = V_t$$

and

$$\frac{V_s}{N_s} = \frac{V_t \times N_s}{N_s}$$

$$\frac{V_s}{N_s} = V_t$$

Quantities equal to the same quantity are equal, so

$$\frac{V_p}{N_p} = \frac{V_s}{N_s}$$

Both of the above quantities are equal to V_t . If we multiply both sides of the equation by the same quantity N_p , we obtain

$$\frac{V_p}{N_p} \times N_p = N_p \times \frac{V_s}{N_s}$$

or

$$V_p = \frac{N_p}{N_s} \times V_s$$

Likewise,

$$V_s = \frac{N_s}{N_p} \times V_p$$

Therefore, if we know the source voltage, or primary voltage, and the number of turns in the primary and secondary windings, we can calculate the secondary voltage. For example, if a distribution transformer has a primary winding with 7620 turns and a secondary winding of 120 turns and the source voltage equals 7620 volts, the secondary voltage equals 120 volts.

$$\begin{aligned}
 V_s &= V_p \times \frac{N_s}{N_p} \\
 &= 7620 \times \frac{120}{7620} \text{volts} \\
 &= 120 \text{volts}
 \end{aligned}$$

When a load is connected to the secondary winding of the transformer, a current I_s will flow in the secondary winding of the transformer. This current is equal to the secondary voltage divided by the impedance of the load Z .

$$I_s = \frac{V_s}{Z}$$

Lenz' law determined that any current that flows as a result of an induced voltage will flow in a direction to oppose the action that causes the voltage to be induced. Therefore, the secondary current, or load current, in the distribution transformer secondary winding will flow in a direction to reduce the magnetizing action of the exciting current or the primary current. This action reduces the magnetic flux in the laminated steel core momentarily and, therefore, reduces the countervoltage in the primary winding. Reducing the countervoltage in the primary winding causes a larger primary current to flow, restoring the magnetic flux in the core to its original value. The losses in a distribution transformer are small, and therefore, for all practical purposes, the voltamperes of the load, or secondary winding, equal the voltamperes of the source, or primary winding.

$$V_p \times I_p = V_s \times I_s$$

If we divide both sides of this equation by the same quantity V_p , we obtain

$$\frac{V_p \times I_p}{V_p} = \frac{V_s \times I_s}{V_p}$$

or

$$I_p = \frac{V_s}{V_p} \times I_s$$

Therefore, if the primary source voltage of a transformer is 7620 volts, the secondary voltage is 120 volts, and the secondary current, as a result of the load impedance, is 10 amps, then the primary current is 0.16 amp.

$$I_p = \frac{120}{7620} \times 10 = 0.16 \text{ amp}$$

A three-phase transformer is basically three single-phase transformers in a single tank in most cases. The windings of the three transformers are normally wound on a single multilegged laminated steel core.

Amorphous Metal. Some distribution transformers are being manufactured with amorphous metal cores. The amorphous metal reduces the core loss in a distribution transformer, thus increasing the transformer efficiency. The core losses of distribution transformers built with an amorphous metal core are approximately 60 percent less than the core losses of distribution transformers with a laminated steel core.

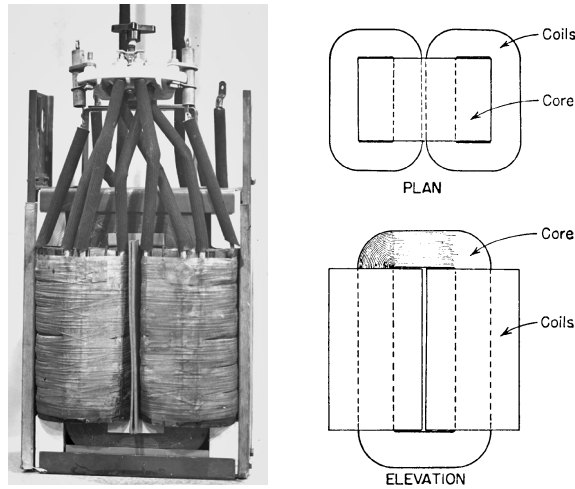


FIGURE 15.8 Views illustrating core-type transformer construction. (Courtesy ABB Power T&D Company Inc.)

Distribution Transformer Construction. Two types of construction are the *core type* and the *shell type*. In the core type, the core is in the form of a rectangular frame with the coils placed on the two vertical sides (Fig. 15.8). The coils are cylindrical and relatively long. They are divided, part of each primary and secondary being on each of the two vertical legs. In the shell type (Fig. 15.9), the core surrounds the coils, instead of the coils surrounding the core. The coils in the shell type are generally flat instead of cylindrical, and the primary and secondary coils are alternated (Fig. 15.10). The core-and-coil assembly of the distribution

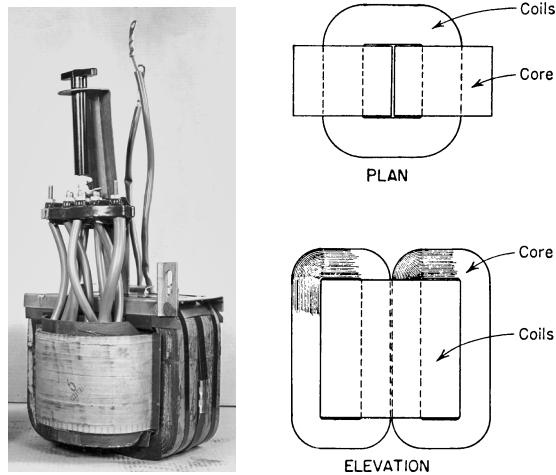


FIGURE 15.9 Views illustrating shell-type transformer construction. (Courtesy ABB Power T&D Company Inc.)

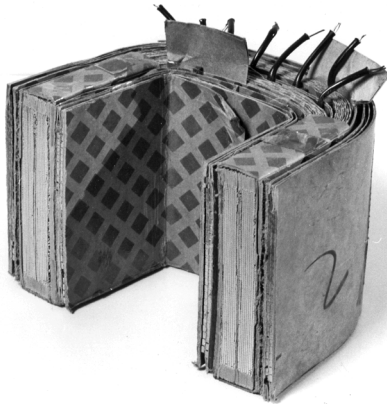


FIGURE 15.10 Windings of a shell-type distribution transformer cut to show cross section of winding conductors. High-voltage winding is located between the secondary winding on the inner and outer surfaces. The high-voltage winding has small conductors and a large number of turns. The secondary winding has large rectangular conductors and a small number of turns. (Courtesy ABB Power T&D Company Inc.)

transformer is completely immersed in insulating oil or other insulating liquids to keep the operating temperatures low and to provide additional insulation for the windings.

Distribution Transformer Ratings. The capacity of a distribution transformer is determined by the amount of current it can carry continuously at rated voltage without exceeding the design temperature. The transformers are rated in kilovolt-amperes (kVA) since the capacity is limited by the load current which is proportional to the kVA regardless of the power factor. The standard kVA ratings are itemized in Table 15.1.

Distribution Transformer Connections. Single-phase distribution transformers are manufactured with one or two primary bushings. The single-primary-bushing transformers can only be used on grounded wye systems. The two-primary-bushing transformers can be used on three-wire delta systems or four-wire wye systems if they are properly connected. Figure 15.11 illustrates schematically the connections of a single-phase transformer

TABLE 15.1 Standard Ratings of Distribution Transformers, kVA

Overhead type		Pad-mounted type	
Single-phase	Three-phase	Single-phase	Three-phase
5	15	25	75
10	30	37 ¹ / ₂	112 ¹ / ₂
15	45	50	150
25	75	75	225
37 ¹ / ₂	112 ¹ / ₂	100	300
50	150	167	500
75	225		750
100	300		1000
167	500		1500
250			2000
333			2500
500			

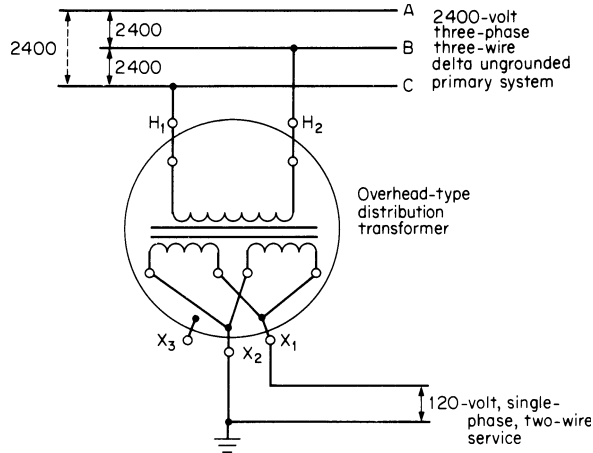


FIGURE 15.11 Single-phase overhead or pole-type distribution transformer connection for 120-volt two-wire secondary service. Transformer secondary coils are connected in parallel.

to a three-phase 2400-volt three-wire ungrounded delta primary voltage system to obtain 120-volt single-phase two-wire secondary service. The connections for similar systems operating at other primary distribution voltages such as 4800, 7200, 13,200, and 34,400 would be identical.

Figure 15.12 illustrates the proper connections for a single-phase transformer to a three-phase three-wire ungrounded delta primary voltage system to obtain 120/240-volt single-phase three-wire service. Normally the wire connected to the center low-voltage bushing will be connected to ground. Grounding the wire connecting to the center bushing limits the

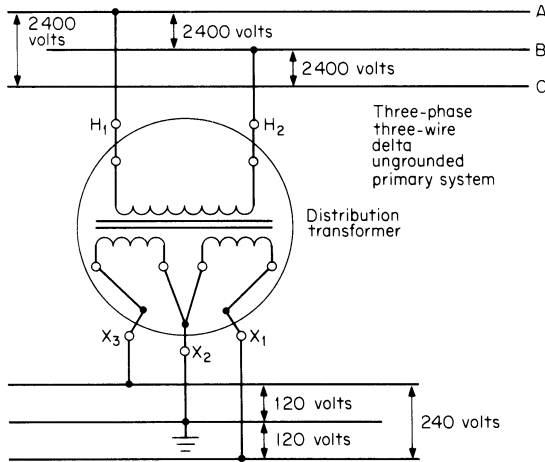


FIGURE 15.12 Single-phase distribution transformer connected to give 120/240-volt three-wire single-phase service. Transformer secondary coils are connected in series.

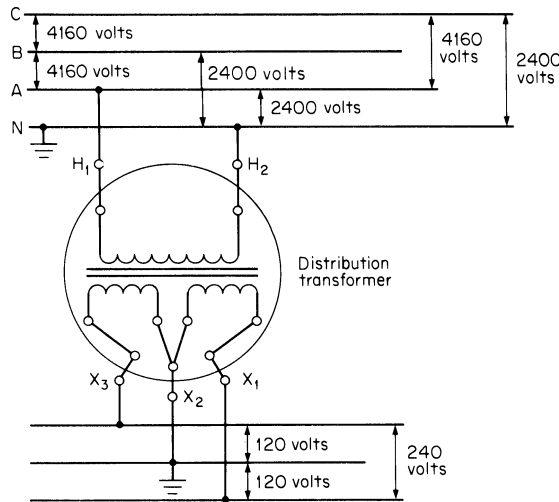


FIGURE 15.13 Single-phase distribution transformer connected to provide 120/240-volt three-wire single-phase service. Primary winding is connected line to neutral or ground.

voltage above ground to 120 volts even though the wires connecting to the outside secondary bushings have 240 volts between them.

Figure 15.13 illustrates schematically the single-phase distribution transformer connections to a three-phase four-wire wye grounded neutral primary system rated 4160Y/2400 volts to obtain 120/240-volt single-phase grounded secondary service. The three-phase four-wire grounded neutral system has voltages between phases equal to the phase or line to neutral voltage multiplied by 1.73. In Fig. 15.13 the primary system line to neutral voltage is 2400 volts, and the voltage between phases is 1.73×2400 , or 4160 volts. This system is designated as a 4160Y/2400-volt system. Other standard three-phase four-wire wye grounded neutral primary system voltages are 8320Y/4800, 12,470Y/7200, 13,200Y/7620, 13,800Y/7970, 22,860Y/13,200, 24,940Y/14,400, and 34,500Y/19,920.

The transformer connections to obtain 120, 120/240, or 240-volt secondary service are normally completed inside the tank of the transformer (Fig. 15.14). The transformer nameplate provides information necessary to complete connections. The voltages should be measured when the transformer is energized, to ensure that the connections are correct before the load is connected to the transformer.

Single-phase pole or overhead-type transformers can be used to obtain three-phase secondary service (Fig. 15.15). There are four normal connections: the delta-delta (Δ - Δ), the wye-wye (Y-Y), the delta-wye (Δ -Y), and the wye-delta (Y- Δ). Figure 15.16 illustrates the proper connections for three single-phase distribution transformers connected to a three-phase three-wire ungrounded delta primary-voltage system to obtain three-phase three-wire delta secondary service. The illustration is for a 2400-volt primary system and 240-volt secondary service. Other similar systems operating at other primary voltages would be connected the same way. Single-phase transformers with secondary windings constructed for voltages of 240/480 could be used to obtain 480-volt three-phase secondary service.

Figure 15.17 illustrates the proper connections for three single-phase distribution transformers connected to a three-phase four-wire grounded neutral wye primary-voltage system to obtain 208Y/120- or 480Y/277-volt secondary service. Figure 15.18 illustrates the

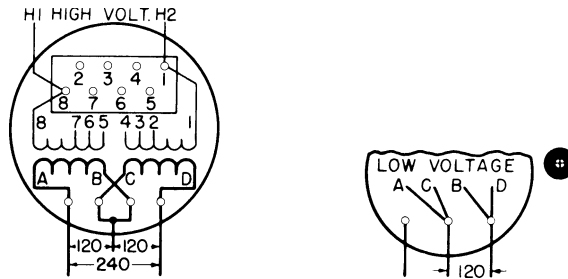


FIGURE 15.14 The left view shows connections for 120/240-volt three-wire service. For 240-volt two-wire service, the neutral bushing conductor is not connected to the jumper between terminals *B* and *C* inside the transformer tank. For 120-volt two-wire service, the connections are made as shown in the right view. All connections are completed inside the transformer tank. (Courtesy ABB Power T&D Company Inc.)

proper connections for three single-phase distribution transformers connected to a three-phase three-wire ungrounded neutral delta primary-voltage system to obtain 208Y/120- or 480Y/277-volt secondary service.

Transformers must be constructed with the proper windings for the primary-voltage system and the desired secondary voltage. Properly manufactured distribution transformers can be connected wye-delta if it is desired to obtain three-wire three-phase secondary voltages from a three-phase four-wire grounded neutral wye primary-voltage system.

The standard secondary system three-phase voltages are 208Y/120, 240, 480Y/277, and 480 volts.

If one of the transformers from a delta-connected bank is removed, the remaining two are said to be open-delta-connected. This can be done, and the remaining two transformers will still transform the voltages in all three phases and supply power to all three phases of the secondary mains. The proper connections, using two transformers, to obtain three-phase



FIGURE 15.15 Cluster-mounted bank of transformers bolted directly to the pole and protected by surge arresters and partial-range current-limiting fuses. The current-limiting fuses are from two different manufacturers, which gives one fuse a different appearance. The transformers are self-protected with an internal weak-link fuse in series with each of the primary windings and a secondary circuit breaker in series with each of the secondary windings. The transformers are connected to a 13,200Y/7620-volt primary circuit and provide 208Y/120-volt three-phase service for the customer.

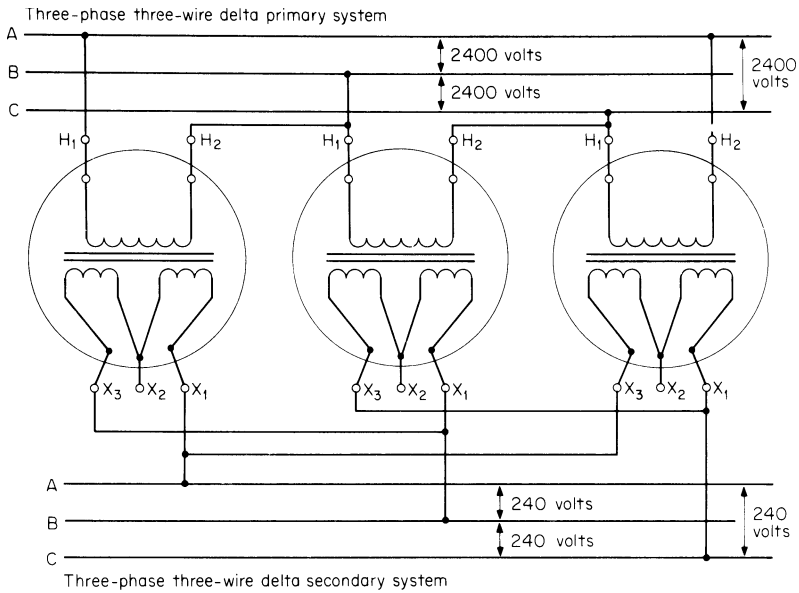


FIGURE 15.16 Three single-phase distribution transformers connected delta-delta (Δ-Δ).

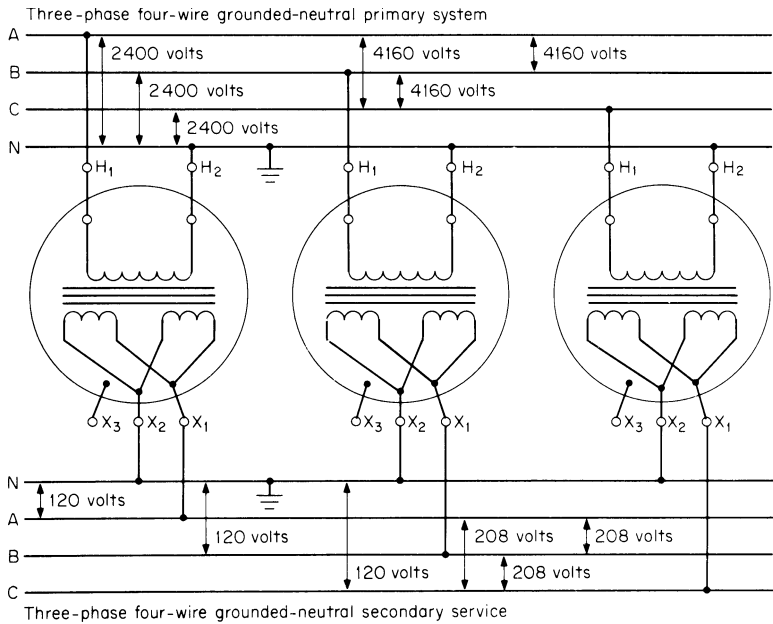


FIGURE 15.17 Three single-phase distribution transformers connected wye-wye (Y-Y). Proper voltage windings would be used with other primary voltages. Secondary windings constructed for 277 volts would provide 480Y/277-volt three-phase secondary service.

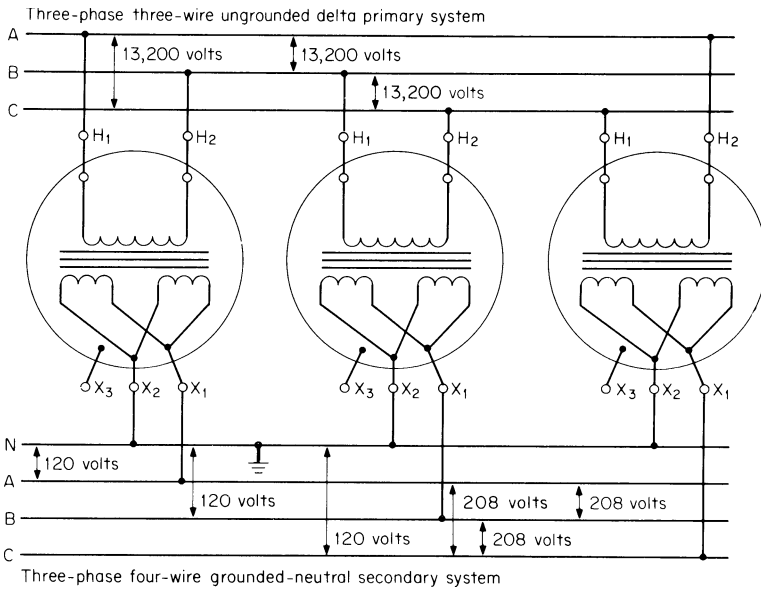


FIGURE 15.18 Three single-phase distribution transformers connected delta-wye (Δ -Y). Windings must be rated for the primary system and the desired secondary voltage.

service, for a delta primary circuit are shown in Fig. 15.19. The capacity of the two transformers is now, however, only 58 percent instead of $66\frac{2}{3}$ percent of what it would appear to be with two transformers.

The open-delta connection is often used where an increase in load is anticipated. The third unit is added when the load grows to the point at which it exceeds the capacity of the two transformers. Furthermore, if one transformer of a three-phase bank should become defective, the defective transformer can be removed and the remaining two transformers continue to render service to at least part of the load.

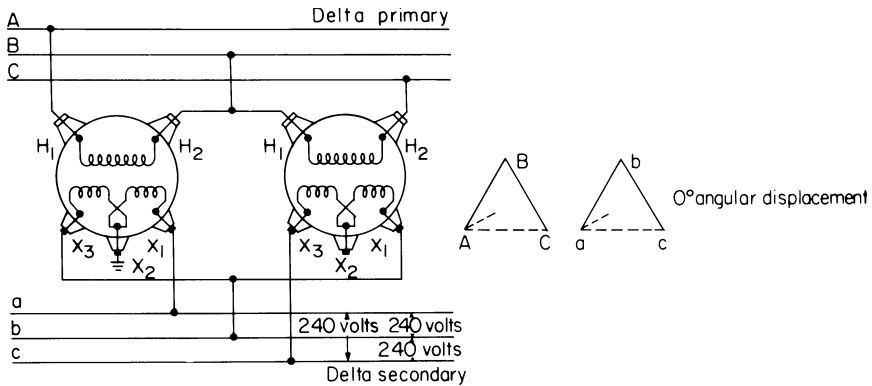


FIGURE 15.19 Two single-phase transformers connected into a bank to transform power from three-phase primary voltage to 240 volts three-phase. Primaries and secondaries are open-delta connected.

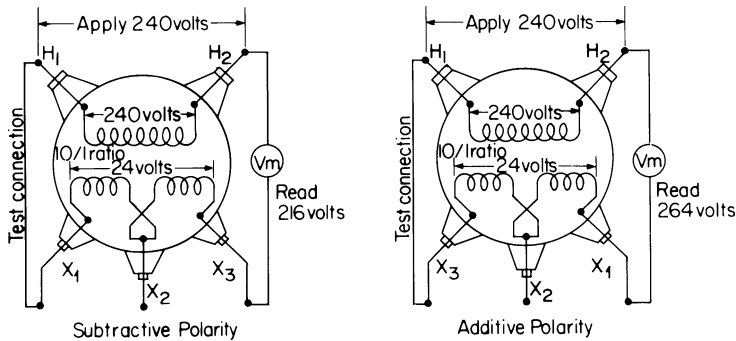


FIGURE 15.20 Polarity tests.

Distribution Transformer Polarity. In connecting transformers in parallel or in a three-phase bank, it is important to know the polarity of the transformer terminals or leads. In building transformers in the factory, the ends of the windings can be so connected to the leads extending out through the case that the flow of current in the secondary terminal with respect to the corresponding primary terminal is in the same direction or in the opposite direction. When the current flows in the same direction in the two adjacent primary and secondary terminals, the polarity of the transformer is said to be *subtractive*, and when current flows in opposite directions, the polarity is said to be *additive*.

Polarity may be further explained as follows: Imagine a single-phase transformer having two high-voltage and three low-voltage external terminals. Connect one high-voltage terminal to the adjacent low-voltage terminal, and apply a test voltage across the two high-voltage terminals. Then if the voltage across the unconnected high-voltage and low-voltage terminal is less than the voltage applied across the high-voltage terminals, the polarity is *subtractive*; while if it is greater than the voltage applied across the high-voltage terminals, the polarity is *additive* (Fig. 15.20).

From the foregoing, it is apparent that when the voltage indicated on the voltmeter is greater than the impressed voltage, it must be the sum of the primary and secondary voltages, and the sense of the two windings must be in opposite directions, as in Fig. 15.21. Likewise, when the voltage read on the voltmeter is less than the impressed voltage, the voltage must be the difference, as illustrated in Fig. 15.22. When the terminal markings are arranged in the same numerical order, H_1H_2 and X_1X_2 or H_2H_1 and X_2X_1 , on each side of the transformer, the polarity of each winding is the same (subtractive). If either is in reverse order, H_2H_1 and X_1X_2 or H_1H_2 and X_2X_1 , their polarities are opposite (additive). The

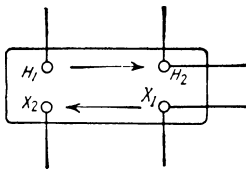


FIGURE 15.21 Sketch showing polarity markings and directions of voltages when polarity is additive.

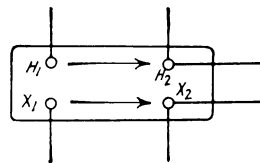


FIGURE 15.22 Sketch showing polarity markings and directions of voltages when polarity is subtractive.

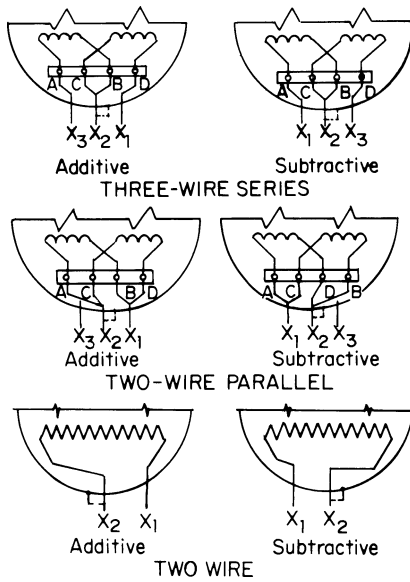


FIGURE 15.23 Standard low-voltage connections for distribution transformer.

nameplate of a transformer should always indicate the polarity of the transformer to which it is attached.

Additive polarity is standard for all single-phase distribution transformers 200 kVA and below having high-voltage ratings of 9000 volts and below.

Subtractive polarity is standard for all single-phase distribution transformers above 200 kVA irrespective of voltage rating.

Subtractive polarity is standard for all single-phase transformers 200 kVA and below having high-voltage ratings above 9000 volts.

Standard low-voltage terminal designations are illustrated in Fig. 15.23.

Paralleling Single-Phase Distribution Transformers. If greater capacity is desired, two transformers of the same or different kVA ratings may be connected in parallel. Single-phase transformers of either additive or subtractive polarity may be paralleled successfully if connected as shown in Fig. 15.24 and if the following conditions are met:

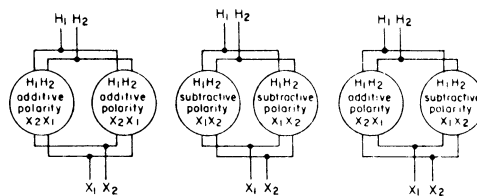


FIGURE 15.24 Schematic diagram showing proper connections for single-phase distribution transformers connected in parallel.

1. Voltage ratings are identical.
2. Tap settings are identical.
3. Percentage of impedance of one is between $92\frac{1}{2}$ and $107\frac{1}{2}$ percent of the other.
4. Frequency ratings are identical.

Distribution Transformer Tapped Windings. Windings of distribution transformers can be manufactured with various taps to broaden the range of primary voltages suitable for a given installation. The standard taps available are on the primary winding of the transformer and are designed to provide variations in the number of winding turns in steps of $2\frac{1}{2}$ percent of the rated voltage. The distribution transformers may be designed with four $2\frac{1}{2}$ percent taps above rated voltage, two $2\frac{1}{2}$ percent taps above and two $2\frac{1}{2}$ percent taps below rated voltage, or four $2\frac{1}{2}$ percent taps below rated voltage. A standard distribution transformer with a primary winding rated 2400 volts and supplied with two $2\frac{1}{2}$ percent taps above and two $2\frac{1}{2}$ percent taps below rated voltage would be constructed with primary winding taps rated 2520, 2460, 2340, and 2280 volts. Tap changers on distribution transformers are designed to be operated while the transformer is deenergized. The operating handle (Fig. 15.25) can be located outside of the tank or inside the tank above the oil level. The transformer nameplate provides information concerning the taps available on the distribution transformer.

Distribution Transformer Standards. The standards are published by American National Standards Institute (ANSI). ANSI Standard C57.12.20 covers "Requirements for Overhead-Type Distribution Transformers, 67000 volts and below; 500 kVA and smaller." ANSI Standard C57.12.25 covers "Requirements for pad-mounted compartmental-type Single Phase Distribution Transformers with Separable Insulated High-Voltage Connectors, High-Voltage, 34,500 GrdY/19,920 Volts and Below; Low-Voltage, 240/120; 167 kVA and Smaller." ANSI Standard C57.12.26 covers "Requirements for Pad-Mounted Compartmental-Type Self-Cooled, Three-Phase Distribution Transformers for Use with Separable Insulated High-Voltage connectors, High-Voltage, 24,940 GrdY/14,400 Volts and Below; 2500 kVA and Smaller."



FIGURE 15.25 No-load changer for distribution transformer. (Courtesy ABB Power T&D Company Inc.)

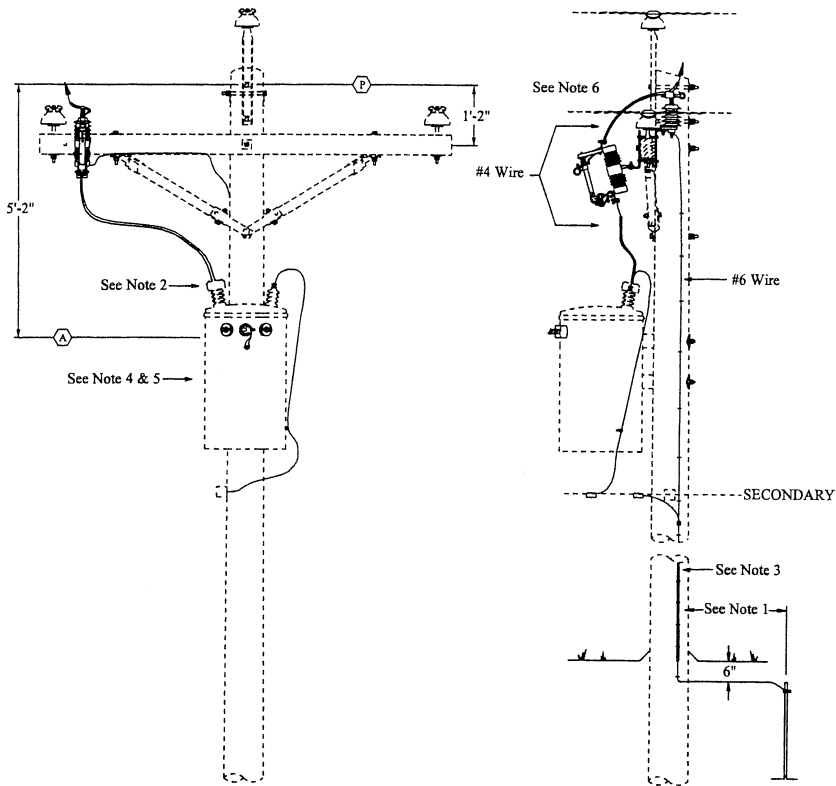


FIGURE 15.26 Diagram of a conventional single-phase, overhead distribution transformer. (Courtesy MidAmerican Energy Co.)

A typical specification for conventional single-phase overhead distribution transformers (Fig. 15.26) would read as follows:

This standard covers the electrical characteristics and mechanical features of single phase, 60 Hz, mineral oil immersed, self-cooled, conventional, overhead type distribution transformers rated: 15, 25, 50, 75, 100, and 167 kVA; with high voltage: 7200/12,470Y, 7620/13,200Y, or 7970/13,800Y volts; and low voltage: 120/240 volts; with no taps. The unit shall be of "conventional" transformer design. There shall be no integral fuse, secondary breaker, or overvoltage protection.

All requirements shall be in accordance with the latest revision of ANSI C57.12.00 and ANSI C57.12.20, except where modified by this standard.

The transformer shall be bar coded in accordance with the proposed EEI "Bar Coding Distribution Transformers: A Proposed EEI Guideline." The manufacturer and serial number shall be bar coded on the nameplate. The serial number, manufacturer, and the Company Item ID (if given) shall be bar coded on a temporary label.

The transformer shall meet interchangeability dimensions for single position mounting as shown in Figs. 1 and 9 of ANSI C57.12.20.

The two primary bushings shall be wet process porcelain cover-mounted. The primary connectors shall be tin-plated bronze of the eye-bolt type. The H1 bushing is to be supplied with a wildlife protector and an eyebolt connector equipped with a covered handknob tightening device. The eyebolt connector shall accept a 5/16 in diameter knurled stud terminal with the

wildlife protector in place. The secondary bushings shall be wet process porcelain or epoxy, mounted on the tank wall. Secondary connectors shall be per ANSI C57.12.20, Section 6.1.2, except terminals on 75 kVA 120/240-volt units shall accommodate up to 1000 kcmil-61 stranded conductor.

The cover of the transformer shall be coated for wildlife protection. The coating shall have a rating of at least 10-kV AC rms. The insulating finish shall be capable of withstanding 10 kV at a 200 volt per sec rate of rise, tested per ASTM D149-87, using electrode type 3 (1/4 in cylindrical rods).

The transformer tank and cover shall be designed to withstand an internal pressure of 20 psig without tank rupture or bushing or cover displacement, and shall withstand an internal pressure of 7 psig without permanent distortion. The transformer tank shall retain its shape when the cover is removed. Support lugs for single-position mounting shall be provided and shall be designed to provide a static-load safety factor of 5. Lifting lugs shall be provided, with location and safety factor as specified in ANSI C57.12.20. The tank and cover finish shall be light gray No. 70 (Munsell 5BG7.0/0.4). The interior shall be coated with a durable protective finish from the top to at least below the top liquid level.

The transformer shall be equipped with a tank ground per ANSI C57.12.20, Paragraph 6.5.4.1 with eyebolt to accept an AWG 6 solid copper ground wire; a tank ground for ground strap connection; and a ground strap, properly sized to carry load and fault current, connected between the secondary neutral terminal and the tank ground. The grounding strap shall be supplied with a connection hole at each end. "J" hook or slotted connection points shall not be allowed.

The transformer shall be equipped with neoprene or Buna-N gaskets on all primary and secondary bushings and tank fittings.

A Qualitrol no. 202-032-01 automatic pressure relief device, with operation indication, or approved equivalent; or a cover assembly designed for relief of excess pressure in accordance with ANSI C57.12.20, Section 6.2.7.2, shall be supplied on the transformer.

Final core and coil assembly shall result in a rigid assembly that maintains full mechanical, electrical, and dimensional stability under fault conditions.

The coil insulation system shall consist of electrical kraft paper layer insulation coated on both sides with thermosetting adhesive. Curing of the coils shall cause a permanent bond layer to layer and turn to turn.

The internal primary leads shall have sufficient length to permit cover removal and lead disconnection from the high voltage bushings. These leads shall be adequately anchored to the coil assembly to minimize the risk of damaging the coil connection during cover removal.

The internal secondary leads shall be identified by appropriate markings, embossed or stamped on a visible portion of the secondary lead near the end connected to the bushing. These leads shall have sufficient length to permit series or parallel connection of the secondary windings. If the internal secondary leads are soft aluminum, a hard aluminum-alloy tab shall be welded to the bushing end of the lead for connection to the bushing.

The transformer should be designed so that the voltage regulation shall not exceed 2.5 percent at full load and 0.8 power factor for all transformers covered in this specification.

All transformers shall be filled with Type I insulating oil meeting the following requirements:

- a. All applicable requirements of ASTM D 3487, Paragraph 82a.
- b. Minimum breakdown value of 28 kV per ASTM D 1816, Paragraph 84a using a 0.4 in gap.
- c. The PCB content shall be less than 2 parts per million which shall be noted upon the nameplate of each unit. In addition, the manufacturer shall provide and install a "No PCB" identification on the tank wall, near the bottom of the tank centered below the low-voltage bushings. The decal shall be not less than 1 in by 2 in in size and shall indicate "No PCB's" in blue lettering on a white background, and be sufficiently durable to remain legible for the life of the transformer.

A typical specification for self-protected single-phase overhead distribution transformers (Figs. 15.2 and 15.3) would read as follows:

Distribution transformers; overhead type; single-phase; 25-kVA capacity; 13,200 GrdY/7620-120/240 volts; 95-kV BIL; self-protected, with primary weak-link fuse and secondary circuit

breaker; red overload warning light; oil-insulated, self-cooled (OISC); no taps; 60 Hz; one surge arrester; one primary bushing, with wildlife protector and eyebolt connector equipped with an insulated hand knob-tightening device designed to accept a 5/16-in-diameter knurled stud terminal with wildlife protector in place; tank ground, with eyebolt designed to accept No. 6 solid copper ground wire; a tank ground terminal for a ground strap connection; a ground strap, properly sized to carry load and fault current, connected between the secondary neutral terminal and the tank ground terminal; cover coated to provide 10-kVAC rms protection from wildlife; 65°C rise rating, sky gray in color, Qualitrol No. 202-032-01 Automatic Pressure Relief Device, with operation indication, or approved equivalent; and standard accessories.

The primary weak-link fuse, secondary circuit breaker, and red overload warning light shall be coordinated and compatible with the nameplate ratings.

The arrester shall be a 9/10-kV, direct-connected lead-type distribution class surge arrester (in accordance with the latest revision of ANSI Standard C62.2), with ground lead disconnect, and wildlife protector. The arrester primary lead shall have a minimum length of 24 in with a weatherproof jacket, for connection to the line side of a current-limiting fuse to be installed on the primary bushing in the filed.

All requirements shall be in accordance with the latest revision of ANSI Standard C57.12.20 except where modified by this specification.

The transformer shall be bar coded in accordance with the proposed EEI "Bar Coding Distribution Transformers: A Proposed EEI Guideline." The manufacturer and serial number shall be bar coded on the nameplate. The serial number, manufacturer, and the Company Item ID (if given) shall be bar coded on a temporary label.

The transformer shall meet interchangeability dimensions for single position mounting as shown in Figs. 1 and 9 of ANSI C57.12.20.

All transformers shall be filled with Type I insulating oil meeting the following requirements:

- a. All applicable requirements of ASTM D 3487, Paragraph 82a.
- b. Minimum breakdown value of 28 kV per ASTM D 1816, Paragraph 84a using a 0.4 in gap.
- c. The PCB content shall be less than 2 parts per million which shall be noted upon the nameplate of each unit. In addition, the manufacturer shall provide and install a "No PCB" identification on the tank wall, near the bottom of the tank centered below the low-voltage bushings. The decal shall be not less than 1 in by 2 in in size and shall indicate "No PCB's" in blue lettering on a white background, and be sufficiently durable to remain legible for the life of the transformer.

A typical specification for a single-phase pad-mounted distribution transformer (Figs. 15.27 and 15.28) would read as follows:

Distribution transformers; low profile; dead front; pad-mounted; single-phase; 50-kVA capacity; 13,200 GrdY/7620-120/240 volts; OISC; 95-kV BIL; 60 Hz; 65°C rise rating; and no taps on the primary winding. All requirements shall be in accordance with the latest revisions of ANSI Standard C57.12.25, except where modified by this specification.

The transformer shall be equipped with two primary bolted-on bushing wells rated 8.3 kV and 200 A in accordance with the latest revision of ANSI/IEEE Standard 386. The bushing wells shall be equipped with 8.3/14.4-kV 200-A load break bushing inserts to accommodate load break elbows for sectionalizing cable in a loop-feed primary system.

The secondary terminals are to be equipped with bolted standard copper-threaded studs only.

A ground pad shall be provided on the outer surface of the tank. The low-voltage neutral shall have a fully insulated bushing. A removable ground strap sized for the rating of the transformer shall be provided and connected between the neutral bushing and a ground terminal on the tank of the transformer.

The high-voltage and low-voltage ground pads inside the transformer compartment shall be equipped with eyebolt connectors to accept 1/0 bare copper wire.



FIGURE 15.27 Single-phase, pad-mounted distribution transformer. (Courtesy A. B. Chance Co.)



FIGURE 15.28 Single-phase, pad-mounted distribution transformer with cover open. (Courtesy ABB Power T&D Company Inc.)

The transformer shall be equipped with an RTE Bay-O-Net, or approved equivalent, externally replaceable overload sensing primary fuse for coordinated overload and secondary fault protection coordinated and in series with an 8.3-kV partial-range current-limiting fuse. The current-limiting fuse shall be sized so that it will not operate on secondary short circuits or transformer overloads. The current-limiting fuse shall be installed under oil inside the transformer tank. Each load-sensing and current-limiting fuse device shall be capable of withstanding 15-kV system recovery voltage across an open fuse.

The transformer shall be equipped with an oil drip shield directly below the Bay-O-Net fuse holder to prevent oil dripping on the primary elbows or bushings during removal of the fuse.

The transformer housing shall be designed to be tamper-resistant to prevent unauthorized access.

The transformer shall be bar coded in accordance with the proposed EEI "Bar Coding Distribution Transformers: A Proposed EEI Guideline." The manufacturer and serial number shall be bar coded on the nameplate. The serial number, manufacturer, and the Company Item ID (if given) shall be bar coded on a temporary label.

All transformers shall be filled with Type I insulating oil meeting the following requirements:

- a. All applicable requirements of ASTM D 3487, Paragraph 82a.
- b. Minimum breakdown value of 28 kV per ASTM D 1816, Paragraph 84a using a 0.4 in gap.
- c. The PCB content shall be less than 2 parts per million which shall be noted upon the nameplate of each unit. In addition, the manufacturer shall provide and install a "No PCB" identification on the tank wall, near the bottom of the tank centered below the low-voltage bushings. The decal shall be not less than 1 in by 2 in in size and shall indicate "No PCB's" in blue lettering on a white background, and be sufficiently durable to remain legible for the life of the transformer.

A typical specification for a three-phase pad-mounted distribution transformer (Fig. 15.4) would read as follows:

Distribution transformers; three-phase; dead front; 300-kVA capacity; high-voltage windings rated 13,800 GrdY/7970 volts; low-voltage windings rated 208 GrdY/120 volts; the high-voltage winding shall have four 2¹/₂ percent taps below rated voltage; and the no-load tap-changer switch is to be located in the high-voltage compartment.

All requirements shall be in accordance with the latest revision of ANSI Standard C57.12.26, except where changed by this specification.

The transformer housing shall be designed to be tamper-resistant to prevent unauthorized access in accordance with the latest revision to the Western Underground Committee Guide 2.13, entitled "Security for Padmounted Equipment Enclosures."

The transformer shall have specific dimensions for Type B transformers for loop-feed systems as defined in the latest revision of ANSI Standard C57.12.26. The transformer primary bushing wells and parking stands shall be located as shown in Fig. 6 of the Standard.

The primary and secondary windings of the transformer shall be wound on a five-legged core and connected GrdY-GrdY.

The transformer shall be equipped with six primary bolted-on bushing wells rated 8.3 kV and 200 A in accordance with the latest revision of the ANSI/IEEE Standard 386. The bushing wells shall be equipped with 8.3/14.4-kV 200-A load break bushing inserts to accommodate load break elbows for sectionalizing cables in a loop-feed primary system.

The transformer secondary bushings are to be equipped with copper studs complete with bronze spade terminals.

The low-voltage neutral shall have a fully insulated bushing. A removable ground strap sized for the rating of the transformer shall be provided and connected between the neutral bushing terminal and a ground terminal in the compartment on the tank of the transformer.

The high- and low-voltage compartments shall each have a ground terminal on the transformer tank equipped with an eyebolt connector designed to accept a 1/0 bare copper wire. A ground pad shall be provided on the external surface of the transformer tank.

The high- and low-voltage terminals for the transformer windings shall be separated by a metal barrier.

The transformer shall be equipped with RTE Bay-O-Net, or approved equivalent, externally replaceable overload-sensing primary fuses, for coordinated overload and secondary fault protection, coordinated and in series with 8.3-kV partial-range current-limiting fuses. The current-limiting fuses shall not operate on secondary short circuits or transformer overloads. The current-limiting fuses shall be installed under oil inside the transformer tank. Each load-sensing and current-limiting fuse device shall be capable of withstanding 15-kV system recovery voltage across an open fuse.

The transformer shall be equipped with oil drip shields directly below the Bay-O-Net fuse holders, to prevent oil dripping on the primary elbows or bushings during removal of the fuses.

The transformer tank shall have a removable cover or handhole of the tamper-resistant design.

A Qualitrol no. 202-032-01 automatic pressure relief device with an operation indication, or approved equivalent, shall be supplied on the transformer.

The transformer tank shall be equipped with a 1-in oil drain valve with a built-in oil sampling device.

The transformer shall be bar coded in accordance with the proposed EEI "Bar Coding Distribution Transformers: A Proposed EEI Guideline." The manufacturer and serial number shall be bar coded on the nameplate. The serial number, manufacturer, and the Company Item ID (if given) shall be bar coded on a temporary label.

All transformers shall be filled with Type I insulating oil meeting the following requirements:

- a. All applicable requirements of ASTM D 3487, Paragraph 82a.
- b. Minimum breakdown value of 28 kV per ASTM D 1816, Paragraph 84a using a 0.4 in gap.
- c. The PCB content shall be less than 2 parts per million which shall be noted upon the nameplate of each unit. In addition, the manufacturer shall provide and install a "No PCB" identification on the tank wall, near the bottom of the tank centered below the low-voltage bushings. The decal shall be not less than 1 in by 2 in in size and shall indicate "No PCB's" in blue lettering on a white background, and be sufficiently durable to remain legible for the life of the transformer.

The above specifications can be changed to meet the kVA capacity and voltages required. Changes in the high-voltage requirements also require revisions in the related items to obtain the proper insulation and surge-withstand capabilities.

Safety Precautions for Distribution Transformers. Distribution transformers must be protected from violent explosions. When a distribution transformer is removed from service as a result of an automatic operation of the transformer protective devices, the transformer should be tested to be sure it does not have an internal fault before it is reenergized by a lineman. Linemen have closed a fused cutout on a distribution transformer, which had an internal fault, and have been injured by the explosion and oil fire that resulted. An internal protective link fuse, commonly installed in self-protected distribution transformers, has a limited interrupting rating and cannot be depended on to operate in a manner to prevent catastrophic failure of the transformer. The interrupting rating of a fused cutout, in series with the primary winding of the transformer with or without an internal weak-link fuse, may exceed the available fault current from the electric system and fail to prevent the explosion of the transformer as a result of an internal arcing fault. The operation of the cutout, with an expulsion fuse, may take one-half cycle, permitting internal arcing under oil in the transformer, which can cause a violent explosion and fire.

Current-Limiting Fuses. A current-limiting fuse can be installed in series with the primary winding of a distribution transformer to prevent violent transformer failures as a result of an internal arcing fault. The current-limiting fuse can be installed external to the transformer or inside the tank under oil. The current-limiting fuse is usually installed externally on the bushing of a pole-mounted distribution transformer (Fig. 15.29) and internally under oil in a pad-mounted transformer. The current-limiting fuse installed in series with the primary winding of the distribution transformer must be the proper size to coordinate with the other transformer protective devices. Current-limiting fuses are discussed in Chap. 17, "Fuses."

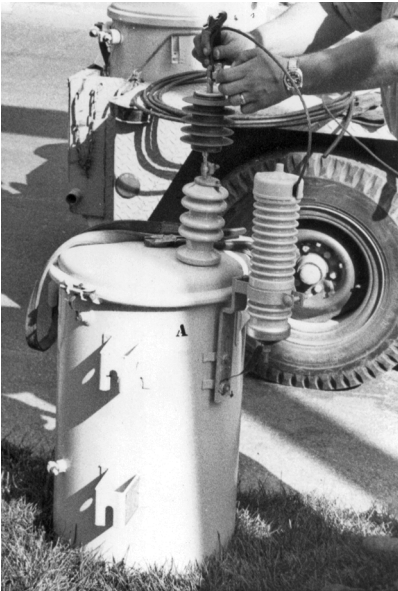


FIGURE 15.29 Lineman is installing a partial-range current-limiting fuse on the terminal on the primary bushing of a self-protected overhead-type distribution transformer. Notice that the wire from the surge arrester is long enough to connect to the top of the fuse. The transformer assembly will be raised and mounted on a pole, in the vicinity, when all the equipment has been installed on the transformer.