Distribution Transformer Handbook

THIRD EDITION

Distribution Transformer Handbook

ADDITIONAL PUBLICATIONS
Alexander Publications offers a variety of books, manuals, and software for electric utilities. For details, visit www.alexanderpublications.com or request your free copy of our latest catalog.

COMMENTS
If you have comments on this handbook, or suggestions how we might make it more valuable for you or your company, please call or write:

Alexander Publications 177
Riverside Avenue #922
Newport Beach, California 92663
Telephone: 1-800-992-3031 or (949)642-0101
Fax: (949)646-4845
E-mail: info@alexanderpublications.com

Third edition
Fourth printing: October 2006
Each printing incorporates minor improvements.

© Alexander Publications 2001. All rights reserved.
I am pleased to introduce our handy reference on distribution transformers for lineworkers. This practical handbook provides quick access to essential information for immediate use, whether in the field or in the shop.

We have tried to select the most commonly required information, then present it in an easy-to-read format, to make this guide a useful and reliable reference document.

Acknowledgements

This handbook is a supplement to other excellent resources on transformers currently available.

Among the materials consulted while preparing this book are:
- ANSI 05.1 Specifications and Dimensions for Wood Poles
- ANSI C57.12.70 Terminal Markings and Connections for Distribution and Power Transformers
- ANSI C57.105 Guide to Three-Phase Transformer Connections
- Distribution Transformer Manual by General Electric
- RUS++ by Alexander Publications
- Transformer Connections by General Electric


We gratefully acknowledge the assistance from each of these sources.

Warnings

Energized transformers and live distribution lines present the risk of electrical shock. All work on this equipment should be performed only by qualified specialists. The connection diagrams, tables, and other data in this handbook are intended to be aids for field personnel. This material does not replace the extensive training necessary to safely work with transformers in service.

This handbook describes work practices which are accepted by most utilities, but some may not apply to you. Always follow your company’s established safety procedures and work practices.

Notice

The publisher does not assume any liability with respect to the use of any information in this publication.

Table of Contents

Chapter 1 Transformer Concepts
- Introduction to Distribution Transformers .................................. 1
- The Transformer ....................................................................... 2 Formulas
- Formulas .................................................................................. 4
- Power Triangle .......................................................................... 5
- Transformer Ratings ................................................................. 6
- Transformer Taps ....................................................................... 8
- Transformer Losses ................................................................. 8
- Transformer Terminal Designations ......................................... 9 Polarity
- Transformer Polarity ................................................................. 9 Wye, Delta
- Configurations ......................................................................... 13
- Completely Self-Protected Transformers .................................. 15
- Completely Self-Protected Transformers .................................. 17
- Feasibility ................................................................................. 18
- Vectors ..................................................................................... 20
- Why 3 for 1.73? ......................................................................... 22 Angular
- Displacement ............................................................................ 23 Parallel
INTRODUCTION TO DISTRIBUTION TRANSFORMERS

Distribution transformers convert the high voltages that economically distribute power, into the lower voltages required by customers.

Distribution transformers are installed overhead on poles, at grade level on pads, and totally underground in vaults. For years, the most widely used transformer has been the single-phase, overhead version, installed either to deliver single-phase service or in a bank of transformers to deliver three-phase service. Padmount transformers are becoming more popular because the higher cost of underground distribution is being offset by increased interest in aesthetics, safety, and system reliability.

Primary (high side) distribution voltage is from 2400 volts to 34,400 volts. Connections to the transformer primary windings are at the top of overhead and underground transformers, and the left panel of padmount transformers.

Secondary (low side) service voltages are typically 120 volts, 208 volts, 240 volts, 277 volts, 347 volts, 480 volts, and 600 volts. Connections to the transformer secondary windings are at the side of overhead and underground transformers, and the right panel of padmount transformers.
THE TRANSFORMER

A transformer consists of a laminated iron core, around which two or more coils of conductors are wound.

When an AC voltage is applied to one coil, current flowing in that coil magnetizes the core – first in one direction, then in the opposite direction. This oscillating magnetic field intersects the second coil, inducing a voltage in it.

The voltage across the secondary terminals causes current to flow through its coil and through any load connected across the secondary terminals. The secondary voltage is determined by the primary voltage and the effective ratio of the number of turns in the primary coil to the number of turns in the secondary coil. The secondary current is the secondary voltage, divided by the load impedance.

Core – The part of the transformer in which the magnetic field oscillates. It is built from thin laminated sheets, each coated with a thin layer of insulation, and cut to form the shape around which the coils are wound. Laminations are used instead of solid cores to reduce core losses.

The ease with which a material can be magnetized is known as its permeability. Iron or a special type of steel is used for transformer cores because these materials have high permeability.

Coil – A coil consists of insulated conductors, wound around the core. The type of insulation depends on the voltage across the coil. The higher voltage (input) coil is the primary, the lower voltage (output) coil is the secondary. The primary coil has many turns of small wire, the secondary coil has fewer turns and its conductors are large wire or strips with rectangular cross-sections.

Turns ratio – The number of turns on the primary coil, divided by the number of turns on the secondary coil.

Effective turns ratio – The relationship between the input and output voltage. Also called: voltage ratio.

Bushing – Porcelain bushings bring the high and low voltage leads from the coils out through the tank, to external connections.

Tank – The enclosure for the core, coils, and transformer oil. The outer surface of the tank dissipates heat generated in the core and coils.

Note: A transformer does not work on DC. DC produces a magnetic flux that flows constantly in one direction, only. Transformation requires a changing magnetic flux.

MOTORS, GENERATORS, AND TRANSFORMERS

• Motors convert electric power, to magnetic flux, to mechanical power.
• Generators convert mechanical power, to magnetic flux, to electric power.
• Transformers convert electric power, to magnetic flux, to electric power in a new form. Unlike motors and generators, transformers are nearly 100% efficient, operate continuously with no maintenance, and have no moving parts. In a transformer, the only “moving part” is the oscillating magnetic flux in the core.

FORMULAS

\[ V_p \cdot I_p = V_s \cdot I_s \]

or: \[ \text{kVA in} = \text{kVA out} \]
This formula is approximate. In practice, small losses in the transformer make kVA out slightly less than kVA in.

Voltages are proportional to the turns ratio:
\[
\frac{V_p}{V_s} = \frac{N_p}{N_s}
\]

Currents are inversely proportional to the turns ratio:
\[
\frac{I_p}{I_s} = \frac{N_s}{N_p}
\]

**POWER TRIANGLE**

Apparent power is the power generated by the utility. Transformers are rated by their ability to deliver apparent power. Watt-hour meters measure active power, which is what most customers are billed for. Reactive power circulates in the wires. It is consumed in alternatively building and collapsing AC magnetic fields in transformers and motor windings – and electrostatic fields in capacitors.

The ratio of active power to apparent power is the power factor of the circuit. Adding capacitors to distribution lines makes the angle between these vectors smaller, bringing the power factor closer to 1. This reduces the total power (kVA) the utility must generate.

**Abbreviations**
- k: kilo, a prefix indicating one thousand.
- VA: volt-ampere. A unit of apparent power.
- VAR: volt-ampere reactive. A unit of reactive power.
- W: watt. A unit of active power.

**TRANSFORMER RATINGS**

Transformers are rated by the amount of apparent power (kVA) they can deliver. The example shown here is for a 10 kVA transformer operating at full load.

\[
\text{Primary: } 7200 \text{ Volts} \times 1.39 \text{ Amperes} = 10 \text{ kVA} \\
\text{Secondary: } 240 \text{ Volts} \times 41.7 \text{ Amperes} = 10 \text{ kVA}
\]

Rated kVA is the full-load capacity for either the primary or the secondary – they are the same.

For example, a 10 kVA transformer could accept any of these primary inputs, and deliver any of these secondary outputs.
Transformers are manufactured in the ratings listed here.

<table>
<thead>
<tr>
<th>Transformer Concepts</th>
<th>Single-Phase (kVA)</th>
<th>Three-Phase (kVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overhead</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>1.5</td>
<td>15</td>
<td>45</td>
</tr>
<tr>
<td>3.0</td>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>5.0</td>
<td>37.5</td>
<td>333</td>
</tr>
<tr>
<td>7.5</td>
<td>50</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td></td>
</tr>
<tr>
<td><strong>Padmounted</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>10</td>
<td>112.5</td>
</tr>
<tr>
<td>7.5</td>
<td>15</td>
<td>167</td>
</tr>
<tr>
<td>25</td>
<td>250</td>
<td>225</td>
</tr>
<tr>
<td>37.5</td>
<td>300</td>
<td>2500</td>
</tr>
<tr>
<td>50</td>
<td>500</td>
<td>3000</td>
</tr>
<tr>
<td>75</td>
<td>750</td>
<td></td>
</tr>
</tbody>
</table>

**TRANSFORMER SECONDARY CONFIGURATIONS**

Single-phase transformers are manufactured with secondary windings brought out to two, three, or four bushings.

![Diagram of transformer secondary configurations]

**TRANSFORMER TAPS**

Some transformers have taps on their primary windings so lineworkers can adjust the voltages delivered to customers. Typically, five settings are available. By changing the taps, voltages are changed in 2/3 steps.

A common application for tap-changing occurs near the end of a long distribution line where the primary voltage is low, and service voltages delivered to customers are below acceptable limits. Changing the taps on the transformer raises the secondary voltages.

Taps are installed on the high-side (primary) winding. The tap-changing handle is usually located inside the transformer above the oil, and accessed by removing the lid. In some cases, the operating handle is on the outside of the tank. The actual tap-changing contacts are below the oil level. **Caution:** Operate tap changers only when the transformer is de-energized.

**TRANSFORMER LOSSES**

The two main causes of losses in a transformer are iron losses and copper losses.

Iron losses are caused by magnetic hysteresis – the opposition by atoms in the core to being aligned first in one direction and then in the other, by the AC field. Iron losses are also caused by small circles of current that flow, like eddy currents in a pool of water, within the core laminations. Iron losses are called no-load losses because they occur regardless of the loading on the transformer.

Copper losses, also called FR losses, are produced by the resistance in the transformer windings and the currents flowing through them. Total losses within a transformer are typically a small percentage of its kVA rating.

**Transformer Terminal Designations**

For all transformers:
- H designates a primary, or high-side terminal.
- Viewed from the front of the transformer: The primary terminals are numbered left to right. The H bushing is always at the upper left.
- X designates a secondary, or low-side terminal.
- The subscript sequence (Example: X₁, X₂, X₃) indicates progress.
along the coil windings, connected in series. The lowest and highest numbered terminals are across the full winding.

**For single-phase transformers:**
- Viewed from the front of the transformer: Secondary terminals on subtractive transformers are numbered left-to-right. Secondary terminals on additive transformers are numbered right-to-left. This designation makes the phases of H₁ and X₁ coincide.
  
  Note: For details on subtractive and additive transformers, see Polarity, below.

**For three-phase transformers:**
- Neutral terminals are designated by the subscript 0.
  
*Examples: H₀, X₀.*

### POLARITY

Transformer polarity refers to the instantaneous relationship between the oscillating voltage at the primary, and the oscillating voltage at the secondary. There are two possibilities: the voltages are either in-phase, or 180° out-of-phase – it depends on whether the primary and secondary windings are wound in the same direction, or in opposite directions.

Polarity is unimportant when a transformer is installed alone, but is extremely important when transformers are installed in parallel, or as a bank. If one transformer in a bank has a different polarity, the connections to either the primary or the secondary bushings of that transformer must be reversed.

---

**Subtractive Polarity**

In the subtractive transformer shown above, the windings are in the same direction. The upper graph shows the primary voltage and secondary voltage, with both measurements taken left-to-right. The voltages are in-phase. The lower graph shows the voltage difference between the two graphs. The voltage between them is less than the primary voltage, as indicated by the shaded areas. The waveforms subtract. The transformer has subtractive polarity. The secondary bushings are numbered left-to-right.

---

**Additive Polarity**

In the additive transformer shown above, the windings are in opposite directions. The upper graph shows the primary voltage and
secondary voltage, with both measurements taken left-to-right. The voltages are 180° out-of-phase. The lower graph shows the voltage difference between the two graphs. The voltage between them is more than the primary voltage, as indicated by the shaded areas. The waveforms add. The transformer has additive polarity. The secondary bushings are numbered right-to-left. Single-phase transformers below 200 kVA with primary voltage below 8600 volts, usually have additive polarity. All other single-phase transformers usually have subtractive polarity.

12 Distribution Transformer Handbook

These rules apply to all transformers, regardless of polarity:
• H is the left primary bushing.
• What goes into H goes out of X – the voltage at the X bushing is in-phase with the voltage at the H bushing.

POLARITY TEST

Polarity is listed on the transformer nameplate. If in doubt, this test will determine the polarity of a transformer:
1. Connect two adjacent terminals of the high and low voltage windings.
2. Apply a moderate (120 volts) voltage across the high voltage terminals. Do not apply the 120 volts to the secondary terminals. This will induce a lethal voltage across the primary terminals.
3. Measure the voltage across the other high and low voltage terminals.

4. The polarity is additive if the measured voltage is higher than the applied voltage. The polarity is subtractive if the measured voltage is lower than the applied voltage.

WYE, DELTA CONFIGURATIONS

Three transformer windings can be configured as a delta or a wye, to deliver three-phase services.

Delta

One end of a coil is plus and the other end is minus. To make a delta connection, connect unlike markings of each coil together.
Line-to-line voltage is the same as the voltage across a transformer winding. Line current is 1.73 times the current in a transformer winding.

Delta configurations:

Wye
One end of a coil is plus and the other end is minus. To make a wye connection, connect like markings of each coil together. The remaining terminals are the output terminals.

Line-to-line voltage is 1.73 times line-to-neutral voltage (the voltage across a transformer winding). Line current is the same as the current in a transformer winding.

Wye configurations:

---

**TRANSFORMER PROTECTION**

The main enemies of transformers are heat, and high current or voltage.

**Heat Protection**

Transformers can deliver considerably more current than their nameplate indicates, for a short while. The heat-rise from an 80-100% overload can usually be tolerated for an hour or more, before it becomes dangerous.

For cooling, distribution transformers are oil-filled. The oil carries heat away from the core and coils, to the tank wall which dissipates the heat to the surrounding air. Oil around the core and coils heats and rises to the top of the tank, then flows away from the center to the walls of the tank. At the tank walls, the oil cools and sinks to the bottom, and the cycle repeats. To circulate easily, transformer oil has a low viscosity (resistance to flow).

Oil in older transformers may contain PCBs, a chemical whose use is now banned. Use caution when handling this substance.

Heat rise in the tank is accompanied by a rise in pressure in the air space above the oil. Pressure relief valves automatically discharge this pressure to the atmosphere, and pop out to provide a visual indication that they were activated.

**Current Protection**

Fused cutouts protect transformers from excessive currents and short circuits. Cutouts are installed between the primary line and the transformer. The fuse in the cutout must be carefully sized to blow only when abnormal conditions occur.

**Voltage Protection**

Arresters protect transformers from high voltage spikes, such as lightning. If lightning strikes a power pole or line, it seeks the easiest path to ground, which could be through a transformer.

Arresters create a safe, low-resistance path for lightning to get to ground, that bypasses the transformer. Lightning strikes can exceed one million volts, so the connections at the arrestor must be tight, and the ground wire properly sized for surge currents that accompany these high voltages.
COMpletely Self-Protected transformers

The conventional transformer requires externally mounted protection, such as a fuse cutout and arrester. The Completely Self-Protected (CSP) transformer has this protection built-in:

- A high-voltage fuse in series with the primary bushing, for protection in the event of an internal failure in the transformer
- An arrester mounted externally on the tank
- A circuit breaker on the secondary side to protect it from overloads and short circuits

Conflicts can arise between protective devices when a CSP is installed on the same circuit as other protective devices.

CSP transformers should not be used in three-phase four-wire delta banks serving combined three-phase power and single-phase lighting loads.

FERRORESONANCE

Ferroresonance is a special condition which creates a high voltage between the transformer primary winding and ground. This voltage is often more than five times the normal voltage, and sometimes as much as 15 times normal voltage. This high voltage can damage the transformer, the primary cable insulation, and other equipment. When ferroresonance is present, the transformer usually makes a rattling, rumbling, or whining noise which is considerably different from the normal transformer hum.

Ferroresonance occurs rarely, and only under these conditions:

- Three-phase systems
- The primary system is ungrounded, the transformer is grounded
- The primary cable feed is long, producing a relatively high capacitance
- The bank has no load, or is lightly loaded (less than 5%)

Underground installations are more susceptible to ferroresonance than overhead installations because underground cables have higher capacitances to ground.

In any AC circuit, when the inductive reactance is equal to the capacitive reactance, a resonant circuit, or “ringing” occurs. Ferroresonance can occur in a distribution system when the inductive reactance of one winding of a three-phase transformer is approximately equal to the phase-to-ground capacitive reactance distributed along the primary cable to that winding. A high voltage appears between the transformer winding and ground, not the usual phase-to-ground voltage. If a transient voltage also occurs at the same time, the voltage between the transformer winding and ground will go even higher.
To decrease the possibility of ferroresonance, field personnel:
• Perform switching operations only at three-phase gang-operated switches
• Perform single-phase switching only when the primary cable length is less than maximum design limits
• Load the transformer bank to greater than 5-10% of the nameplate rating
• Add a resistive load to lower the peak voltage that occurs during ferroresonance
• On floating-wye closed-delta banks, temporarily ground the floating wye point during switching operations.

To decrease the possibility of ferroresonance, design engineers:
• Keep cable lengths from the switching point to the transformer well within design limits
• Convert three-phase closed delta banks to wye-wye connections
• Use a triplex core cable to the transformer

WHY DO TRANSFORMERS HUM?

When a transformer core is magnetized and demagnetized, its core laminations expand and contract. These physical changes to the laminations happen twice during each 60 hertz cycle, on the positive and negative sides of the flux cycle, causing the laminations to vibrate at 120 hertz. The vibrations are conveyed by the cooling oil to the tank wall, where they escape into the air as sound waves.

Transformer hum also occurs at higher harmonics of 120 hertz, but these tones are less audible.

VECTORS

Sine waves can represent AC voltages and currents, but except for the most simple circuits, they make circuit analysis messy and confusing. Vectors are usually used instead of sine waves. The length of the vector (arrow) illustrates the value of the electrical quantity – for example, how many volts. The angle of each vector shows its relation- ship, relative to other vectors in the circuit.

In this diagram, vector A, which rotates around the origin, is shown at 0°. At this starting position, the portion of the vector projected on the vertical axis, is zero. As the vector rotates up to 90°, the portion of the vector projected on the vertical axis increases, to a maximum when the vector is at 90°. The projected value then falls to zero at 180°, become maximum negative at 270°, and returns to zero at 360° or 0°. The process then repeats. Each revolution of the vector describes one cycle of a sine wave. For 60 hertz systems, vectors make 60 revolutions per second.

“VECTOR” OR “PHASOR”?

Technically, vector is a mechanical engineering term that defines the magnitude of a force and its direction. Phasor is an electrical engineering term that defines the magnitude of an electrical quantity and its phase relationship to other electrical quantities.

While phasor would seem to be the correct term to use for transformer applications, vector is more widely used.

Voltages in a three-phase system are illustrated here:

<table>
<thead>
<tr>
<th>Voltage (Volts)</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>90°</td>
<td>1 cycle</td>
</tr>
<tr>
<td>180°</td>
<td>2 cycle</td>
</tr>
<tr>
<td>270°</td>
<td>3 cycle</td>
</tr>
</tbody>
</table>

Vector A is shown at 0°, and the A sine wave on the graph starts by crossing 0, just like the graph on the preceding page.
Vector B starts at 240° and initially projects a negative value on the vertical axis. The B sine wave on the graph also starts at a negative value, and is heading for zero.

All three vectors rotate counterclockwise. The first vector to pass through 0° will be B, followed by C. The phase sequence is ABC counterclockwise.

Why 3, or 1.73?

Why is the line-to-line voltage in wye circuits, 3 or 1.73 times the phase-to-neutral voltage? For example, if the phase-to-neutral voltage measures 120 volts, why is the phase-to-phase voltage 208, not twice 120 volts?

As illustrated on the previous page, each of the three phases passes through maximums and minimums at different times. A vector diagram freezes all phases at one instant in time, and shows the phases as vectors separated by 120°. The length of each vector represents its voltage.

In the diagram below, each phase-to-neutral vector, NA, NB, and NC, is exactly 1 inch long. If we measure from B from C, it is 1.73 inches.

Instead of measuring with a ruler, we could use the theorem for right triangles and prove that the distance between the ends of any two phase-to-phase vectors, is 3 or 1.73 times the length of any phase-to-neutral vector. So, the voltage between any two phases is 1.73 times the voltage between the phase-to-neutral voltages.

Note that the vector drawn from B to C is at 90° (it points up). The A-phase vector is at 0°. Therefore, the phase relationship is: Voltage BC leads voltage NA by 90°.

**ANGLAR DISPLACEMENT**

Angular displacement refers to the phase angle, expressed in degrees, between two voltage vectors. Angular displacement can refer to the relationship between the primary and secondary voltages of a three-phase transformer, or the relationship between two circuits such as two secondaries.

In a three-phase transformer, if the secondary is in-phase with the primary, the angular displacement is 0°. If the voltages are 180° out-of-phase, the angular displacement is 180°. Delta-delta and wye-wye configurations have either 0° or 180° angular displacement—it depends on how the bushings are connected.

Delta-wye and wye-delta configurations have either 30° or a 210° angular displacement. The 30° angular displacement is inherent in all delta-wye and wye-delta configurations. The additional 180° depends on how the bushings are connected.

The diagrams below illustrate angular displacements for combinations of wye and delta transformers.
Vectors for the secondary voltages point in the opposite directions as the vectors for corresponding primary voltages. The angular displacement is 180°.

Compare any corresponding pair of primary and secondary voltage vectors, for example, AB and ab:

In the left diagram, a new vector drawn from the tip of A to the tip of B points approximately west-southwest. Vector ab points directly west. Vector ab lags AB by 30°. The angular displacement is 30°. (Vectors rotate counterclockwise, and AB is ahead of ab by 30°).

In the right diagram, AB points approximately north-northeast. A new vector drawn from the tip of a to the tip of b points approximately east-northeast. The angular displacement is 30°. (AB is ahead of ab by 30°).

Compare any corresponding pair of primary and secondary voltage vectors, for example, AB and ab:

In the left diagram, a new vector drawn from the tip of A to the tip of B points approximately west-southwest. Vector ab points directly east. Vector ab lags AB by 210°. The angular displacement is 210°. (AB is ahead of ab by 210°).

In the right diagram, AB points approximately north-northeast. A new vector drawn from the tip of a to the tip of b points approximately west-southwest. Vector ab lags AB by 210°. The angular displacement is 210°. (AB is ahead of ab by 210°).

**PARALLELING TRANSFORMERS**

When paralleling transformers, always consult your company’s established safety procedures and work practices.

**Single-Phase Paralleling**

To increase the capacity of a single-phase service, a second single-phase transformer may be connected in parallel. Transformers of either additive or subtractive polarity may be paralleled, provided the primary phase sources are the same and the H and X terminals are correspondingly connected. This assures that the secondary
voltages are in-phase.

When single-phase transformers are paralleled, the transformers must meet these conditions:

- Voltage ratings are identical
- Tap settings are identical
- Percent impedances are very nearly the same

Three-Phase Paralleling

Occasionally, three-phase transformer banks are paralleled. This additional condition must be met:

- The voltages on the secondary terminals must be in-phase. One way to determine if the angular displacements match, is to take voltage readings between corresponding pairs of bushings. For details on paralleling three-phase transformers, see pages 57-61.

A wye-wye bank can be paralleled with another wye-wye bank or with a delta-delta bank. These transformers can be wired to have the same angular displacements (either 0° or 180°).

- A wye-delta bank can be paralleled with another wye-delta bank or with a delta-wye bank. These transformers can be wired to have the same angular displacement (either 30° or 210°).

A wye-wye bank and a delta-delta bank cannot be paralleled directly with a wye-delta bank or a delta-wye bank.

### INDEX TO THE DIAGRAMS

<table>
<thead>
<tr>
<th>Type Service</th>
<th>Secondary Voltage</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Phase Service</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grounded primary</td>
<td>120/240</td>
<td>30</td>
</tr>
<tr>
<td>Ungrounded primary</td>
<td>120/240</td>
<td>31</td>
</tr>
<tr>
<td>Transformer Bank</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-wire Y, 4-wire Y</td>
<td>120/208, 277/480, 347/600</td>
<td>32</td>
</tr>
<tr>
<td>4-wire Y, 4-wire Y</td>
<td>277/480, 347/600</td>
<td>33</td>
</tr>
<tr>
<td>4-wire Y, 4-wire Y</td>
<td>120/208, 120/240</td>
<td>34</td>
</tr>
<tr>
<td>3-wire Y, 4-wire</td>
<td>120/240/208</td>
<td>35</td>
</tr>
<tr>
<td>3-wire Y, 3-wire</td>
<td>480</td>
<td>36</td>
</tr>
<tr>
<td>3-wire open Y, 3-wire open</td>
<td>480</td>
<td>37</td>
</tr>
<tr>
<td>4-wire open Y, 4-wire open</td>
<td>120/240/208</td>
<td>38</td>
</tr>
<tr>
<td>3-wire , 4-wire Y</td>
<td>120/208, 277/480</td>
<td>39</td>
</tr>
<tr>
<td>3-wire , 4-wire</td>
<td>120/240/208</td>
<td>40</td>
</tr>
<tr>
<td>Three-Phase Transformer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-wire Y, 4-wire wye</td>
<td>120/208</td>
<td>42</td>
</tr>
<tr>
<td>3-wire Y, 4-wire</td>
<td>120/240/208</td>
<td>43</td>
</tr>
<tr>
<td>3-wire , 4-wire</td>
<td>120/240/208</td>
<td>44</td>
</tr>
</tbody>
</table>

### NOTES TO THE CONNECTION DIAGRAMS

- Primary (high voltage) conductors for each diagram are shown above the transformer. Primary phases are indicated by capital letters: A, B, C, N.
- Secondary (low voltage) conductors for each diagram are shown below the transformer. Secondary phases are indicated by lower case letters: a, b, c, n.
- Connection diagrams show single-phase transformers with two primary bushings: H₁ and H₂. Your utility might use single-bushing transformers, with H₁ connected to a primary phase and the other end of the primary winding connected to ground through the transformer case. Note that these diagrams are electrically the same:

```
A       N
H₁      H₂
```

```
x₂       x₁
x₃       x₄
```

### Two-bushing transformer

```
A       N
H₁      H₂
```

http://share.pdfonline.com/fdc380b1f0af4e99a756c8f91a580/Dist.Trans.%20Handbook.htm 14/35
The transformers shown in the diagrams are additive polarity. If a subtractive transformer is used instead, make connections to the same terminal numbers marked in the diagrams. The secondary terminals will be physically located on the transformer tank in the opposite sequence from that shown in the diagrams.

The secondary voltages shown are the voltages each circuit typically delivers. Other outputs are possible, depending the primary voltage and transformers used.

When two-bushing transformers are used in single-phase circuits, normally \( H_1 \) is connected to the primary and \( H_2 \) to ground. However, if there is a clearance problem (trees overhead, restricted climbing space, etc.), for convenience, \( H_1 \) may be connected to ground and \( H_2 \) to the primary.

Transformer cases are shown grounded. This practice is not followed by all utilities. Always follow all your company’s established operating and safety procedures.

For three-phase diagrams:
- Phase sequence is ABC.
- Phases rotate counterclockwise.
- Secondary voltages are labeled with a minus sign (-a, -b, and -c) when the angular displacement for the configuration is 180°, or is 180° plus the 30° angular displacement inherent in all wye-delta and delta-wye configurations.

The diagrams in this handbook illustrate the most popular configurations. Many others are possible. If another configuration is used by your utility, you might sketch it for reference on a blank page at the back of the book.

Note: Send a copy of your sketch to us and we will return to you a computer-precise illustration, ready to paste in your handbook.
Wye-Wye

Three-phase, four-wire wye primary
Three-phase, four-wire wye secondary

Secondary services
120 volts, phase-to-neutral
208 volts, phase-to-phase

0° angular displacement
Three-phase, four-wire wye secondary
0° angular displacement

Three-phase, four-wire wye primary

Secondary services
120 volts: a-to-neutral, b-to-neutral, c-to-neutral
208 volts: a-to-b, b-to-c, c-to-a
120 volts, phase-to-neutral
240 volts, phase-to-phase

180° angular displacement

Three-phase, three-wire wye primary

Secondary services
240 volts, phase-to-phase
120 volts, b-to-neutral, c-to-neutral
208 volts, a-to-neutral

Float the primary neutral

Do not permanently ground

Float the primary neutral and ground, when switching the transformer bank in or out of service.

When concerned about ferroresonance, install a temporary grounding jumper between the floating primary neutral and ground.
**Wye-Delta**

Three-phase, three-wire wye primary

Three-phase, three-wire delta secondary

Secondary services

480 volts, phase-to-phase

Some utilities use this connection with three primary lines and no neutral.

Some utilities ground one corner of the delta secondary.

Caution: With a corner grounded, unintentional grounding of another corner will short a winding.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>A</td>
<td>B</td>
</tr>
</tbody>
</table>

Three-phase, three-wire wye primary

H₁, H₂, H₃, H₁, H₂

x₁, x₂, x₁, x₂, x₁, x₂

-a -b -c

Three-phase, three-wire delta secondary

210° angular displacement

When concerned about ferroresonance, install a temporary grounding jumper between the floating primary neutral and ground, when switching the transformer bank in or out of service.

---

**Open Wye - Open Delta**

Three-phase, four-wire open wye primary

Three-phase, three-wire open delta secondary

Secondary services

480 volts, phase-to-phase

This configuration is relatively inefficient. If it is used as an emergency replacement for a three-transformer bank, these two transformers can deliver only 58% of the original kVA capacity.

---

**Open Wye - Open Delta**

Three-phase, four-wire open wye primary

Three-phase, four-wire open delta secondary

Secondary services

120 volts, a-to-neutral, b-to-neutral

240 volts, a-in-b, b-in-c, a-in-c, 208 volts, c-to-neutral

Field tip to find the 208V leg:

1. Trace from the neutral up to X₁ into T₁
2. Go one-half winding to X₂
3. Go across the common connection into T₂
4. Go across one full winding
5. Go down the riser to the 208V leg

Memorize “1½ windings to 208V”

-a -b -c
Exchange Transformers

Delta-Wye
Three-phase, three-wire delta primary
Three-phase, four-wire wye secondary
Secondary services
120 volts, phase-to-neutral
208 volts, phase-to-phase
277 volts, phase-to-neutral
480 volts phase-to-phase

Delta-Delta
Three-phase, three-wire delta primary
Three-phase, four-wire delta secondary
Secondary services
240 volts, phase-to-phase
120 volts, a-to-neutral, b-to-neutral
208 volts, c-to-neutral
208 V

Distribution Transformer Handbook
Delta-Delta
Three-phase, three-wire delta primary
Three-phase, four-wire delta secondary

Secondary services
240 volts, phase-to-phase
120 volts, a-to-neutral, b-to-neutral
208 volts, c-to-neutral

Delta-Wye
Three-phase, three-wire delta primary
Three-phase, four-wire wye secondary

Secondary services
240 volts, phase-to-phase
120 volts, a-to-neutral, b-to-neutral
208 volts, c-to-neutral

Wye-Wye
Three-phase, four-wire wye primary
Three-phase, four-wire wye secondary

Secondary services
120 volts, phase-to-neutral
208 volts, phase-to-phase

Wye-Delta
Three-phase, three-wire wye primary
Three-phase, four-wire delta secondary

Secondary services
240 volts, phase-to-phase
120 volts, a-to-neutral, b-to-neutral
208 volts, c-to-neutral
LIFTING AND HANDLING TRANSFORMERS

Lift overhead transformers by their lifting lugs only, using a nylon web sling or a rope sling. Sling angles of greater than 45° are preferred. Avoid sling angles of less than 30° because of the high tension in the sling. If the vertical clearance above the transformer is limited, use a spreader bar in place of a sling, and install cover-up on any energized conductors nearby.

Do not lift a transformer from beneath a bushing, pressure relief valve, drain plug, or any other attachment not specifically designed for lifting.

Do not move or shift a transformer by grasping the bushings, fins, or plugs. Porcelain bushings can be damaged during handling in ways not visually obvious, then fail when the unit is put into service.

The windings can be damaged if the transformer is dropped.
or severely jolted.
When handling a transformer, take care to not damage the tank
finish. Paint scratches can lead to rust.

NAMEPLATES
Each transformer has a manufacturer’s nameplate with
important technical information.
The nameplate shown here is for an overhead
single-phase transformer.

1. HV – High-voltage (primary) winding. The low number (7200)
is the phase-to-neutral (coil) voltage. The high number (12470)
is the phase-to-phase voltage. This transformer is for
installation in a wye system. Note: On nameplates for
padmount transform- ers and single-bushing overhead
transformers, the low number appears last instead of first.

2. LV – Low-voltage (secondary) winding delivers 120 and
240 volts.

Installing Transformers

3. SER – Serial number, for inventory tracking purposes.

4. HV – High-voltage windings are aluminum with 95 BIL
insulation.

5. LV – Low-voltage windings are aluminum with 30
BIL insulation.

6. 10 60 HZ – Single phase, 60 hertz.

7. Class OA – Oil filled, air cooled without fans.

8. Tap positions on the high-voltage winding.

9. KVA – This transformer is rated 5 kVA.

10. ADD POL. – This transformer has additive polarity. If it is
banked or paralleled, the polarity of the other transformers
must be considered.

11. %Z – Percent impedance. If this transformer is banked or
paralleled, the impedance of the other transformers must be
very close to 1.8%.

12. WT – Weight, for rigging considerations.

13. GAL – Oil capacity.


SAFETY TIPS
These tips are from experienced field lineworkers, but some might
not apply to you. Always follow your company’s operating
procedures and safe work practices.

• Never climb above an energized transformer.

• Watch out for lightning arrestors. Many arrestors look alike but
have different voltage ratings. Check the arrestor yourself,
before installing it.

• Even if someone says the primary or secondary is dead, check
it yourself.
• Don’t use the transformer bracket or bolts to support services. Keep supports separate, for future maintenance.
• Some transformers have two tank grounds: a ground strap from the center bushing of the secondary, and a tank ground to the pole ground wire.
• Use only copper wire on bolt-type transformer lugs. Aluminum wire is soft, and can flow under bolted connections and come loose. Aluminum is OK for spade-type compression connectors.
• Never put two solid wires on the same bolt-type lug. One solid wire with one stranded wire is OK, but two solid wires can loosen and become an intermittent connection.
• If you replace a transformer on a hot day when everybody’s air conditioner is on, the initial current surge will be large. The solution is not to over-fuse. Instead, temporarily reduce the initial load. Go around and open some customers’ main breakers (if you have access to them), or pull some meters.
• Don’t mix conventional transformers with CSPs in the same bank.
• Don’t use CSPs in lighting and power banks.
• When installing bird guards, leave a gap around the bottom for water to drain out. Otherwise, water can build up and leak down through the bushing, into the tank.
• Watch out for transformers with PCB oil. If any oil spills, follow all clean-up procedures, exactly.
• Some transformers have tap changers down in the oil, so you have to put your hands in the oil to change taps. Check first, for PCBs.

After hanging a transformer, check it over before making it hot. Check the nameplate, primary and secondary leads, arrestor, and remove all temporary grounds.
• When closing a cutout, follow these steps:
  1. Check the cutout assembly for cracks and loose connections (very important).
  2. Place yourself directly in front of, and slightly below the cutout.
  3. Use ear, eye, and head protection.
  4. Place the hotstick in the eye of fuse.
  5. Close in one fluid motion, while averting your eyes slightly away from a possible flash.
• Be aware, when closing an open disconnect on a transformer near a substation, the closer you are to a substation, the greater the available fault current.
• When a lighting transformer and a power pot (power transformer) are both feeding a load: Close the lighting transformer first when going on-line, and open the lighting transformer last when going off-line. Sequencing the single-phase and three-phase loads provides better voltage stability and reduces fuse blowing.
• When opening a padmount or totally underground transformer, don’t be on your knees. There might be a snake or lizard in there and you need to be ready to run.
• When opening a padmount transformer, stand on a rubber blanket and wear rubber gloves with sleeves, in case a primary line or elbow has come loose inside the door.
• To avoid mistakes, order transformers by their complete primary voltage rating. Example: “12470 grounded wye 7200” not just a “12470 transformer.”
• Make a habit of doing things the same, every time, so your pole buddy knows what you’re doing – even when he can’t see you. You’ll each know what the other is doing, and will work rings around others who don’t, and do it safer.

Installing Transformers 49

INSTALLATION PROCEDURE FOR OVERHEAD TRANSFORMERS

Follow these steps to install an overhead transformer.

1. Select a pole with these features:
   • Near the center of the electrical load
   • Capable of supporting the weight of the combined equipment
   • Not already occupied by other large equipment
   • Space is available which will not obstruct climbing, and will allow adequate working space

2. Inspect the transformer
   • Nameplate: kVA, primary voltage, secondary voltage, impedance, weight, polarity.
   Note: The primary (high) voltage rating on the nameplate usually shows two voltages: the phase-to-phase voltage and the phase-to-neutral voltage. Example: “7200/12470” means the transformer can be connected across two phases in a 7200-volt delta system, or it can be wye-connected at 7200 volts on a 12470 wye system.
   • Physical condition: Gaskets, bushings, tank, and paint are in good condition. Drain plug is tight. Pressure relief valve (if any) has not activated.

3. Check the transformer for continuity
   • The resistance of the primary winding is nearly a short circuit.
   • The resistance of the secondary winding is nearly a short circuit.
   • The resistance between the primary and secondary windings is an open circuit.

4. For three-phase installations, while the transformer is on the
If paralleling transformers, review pages 26 and 46.3.

Install the neutral and ground connections. See pages 5.21

Connect the primary leads. Do not connect the secondary leads to the service conductors at this time.

Install the transformer, and primary cutout if required.

Energize the transformer. Check the voltages at the

If the voltages are correct, use compression connectors to connect the secondary leads to the service conductors.

If the voltages are not correct, check the windings and the terminal connections. If still not correct, replace the transformer.

For three-phase installations: Check the phase sequence, then label it (ABC or CBA) on the center transformer.

When replacing three-phase transformer banks, to avoid damaging customer motors and other equipment, the phase sequence (the order of successive voltage peaks of a three-phase service) must remain unchanged. Before disconnecting the old secondary, determine the phase sequence using a phase sequence indicator. Then, before re-energizing service, test it again to confirm that the sequence is the same. Note: Be sure to attach the test leads to the test points in the same order.

BACKFEED

Backfeed is a condition in which a transformer is energized from a source other than the distribution feeder. For example, backfeed occurs when electricity flows from a customer’s generator back into the power company’s distribution system. Backfeed can also occur between transformers connected in parallel, and between transformers in certain three-phase banks.

Undetected backfeed can be dangerous to lineworkers and equipment. Even though the transformer has been de-energized at the primary cutout, it is still energized. When working on transformers, consider all possible energizing sources. Always follow your company’s established procedures and safe work practices.

To protect workers from backfeed, some utilities follow this practice:

- Measure the voltages at secondary bushings. All readings should be zero. Then, remove and isolate the secondary conductors at the job site to provide a local, visual confirmation of protection.

### SINGLE-PHASE TRANSFORMER LOADS

#### Full Load Current

This table lists full load current, by transformer kVA rating and voltage, for balanced single-phase transformers.

<table>
<thead>
<tr>
<th>Trans. Rating (kVA)</th>
<th>Secondary Voltage</th>
<th>Primary Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>120V (Amps)</td>
<td>240V (Amps)</td>
<td>480V (Amps)</td>
</tr>
<tr>
<td>3</td>
<td>25.0</td>
<td>12.5</td>
</tr>
<tr>
<td>5</td>
<td>41.7</td>
<td>20.8</td>
</tr>
<tr>
<td>10</td>
<td>83.3</td>
<td>41.7</td>
</tr>
<tr>
<td>15</td>
<td>125</td>
<td>62.5</td>
</tr>
<tr>
<td>25</td>
<td>208</td>
<td>104</td>
</tr>
<tr>
<td>37.5</td>
<td>313</td>
<td>156</td>
</tr>
<tr>
<td>50</td>
<td>417</td>
<td>208</td>
</tr>
<tr>
<td>75</td>
<td>625</td>
<td>313</td>
</tr>
<tr>
<td>100</td>
<td>833</td>
<td>417</td>
</tr>
<tr>
<td>167</td>
<td>1392</td>
<td>696</td>
</tr>
<tr>
<td>250</td>
<td>2083</td>
<td>1042</td>
</tr>
<tr>
<td>333</td>
<td>2775</td>
<td>1338</td>
</tr>
<tr>
<td>500</td>
<td>4167</td>
<td>2083</td>
</tr>
</tbody>
</table>

Full load current = kVA \times circuit voltage

**Rule of Thumb:** For balanced loads, when a single-phase transformer is fully loaded, the current is:

**Voltage** | **Current**
---|---
120V | 8.3 \times kVA rating of the transformer
240V | 4.2 \times kVA rating of the transformer
480V | 2.1 \times kVA rating of the transformer

**Example:** A 25 kVA, 240-volt transformer supplies balanced 120-volt loads. When this transformer is loaded to 100% of its nameplate rating, each phase will carry approximately: 4.2 \times 25 = 105 amps.
1. Measure the current in the two line conductors.
2. Add the amps together.
3. Multiply by 120.
4. Move the decimal point three places to the left.

**Example:** If the readings are 55A and 60A:

\[
\begin{align*}
55A + 60A &= 115A \\
115 \times 120 &= 13800 \\
\text{The load is 13.8 kVA}
\end{align*}
\]

**Complete Calculation**

Calculate the load on each half of the transformer separately, then add them together to determine the full load.

\[
\text{Current (amps)} \times \text{Voltage (volts)} = \text{kVA}
\]

**Example:** The readings on a 25 kVA transformer are 30A and 160A:

\[
\begin{align*}
30 \times 120 &= 3600 \\
160 \times 120 &= 19200 \\
\text{Total load in kVA} &= 3.6 + 19.2 \\
&= 22.8 \text{ kVA}
\end{align*}
\]

The total load is within the transformer rating, but one secondary winding exceeds 12.5 kVA and is severely overloaded.

**THREE-PHASE TRANSFORMER LOADS**

<table>
<thead>
<tr>
<th>Transformer Rating (kVA)</th>
<th>Secondary Voltage 208V (Amps)</th>
<th>240V (Amps)</th>
<th>347V (Amps)</th>
<th>480V (Amps)</th>
<th>600V (Amps)</th>
<th>4160V (Amps)</th>
<th>12,470V (Amps)</th>
<th>24,900V (Amps)</th>
<th>34,500V (Amps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>83.3</td>
<td>72.2</td>
<td>49.9</td>
<td>36.1</td>
<td>28.9</td>
<td>4.16</td>
<td>1.39</td>
<td>0.70</td>
<td>0.50</td>
</tr>
<tr>
<td>45</td>
<td>125</td>
<td>108</td>
<td>74.9</td>
<td>54.1</td>
<td>43.3</td>
<td>6.24</td>
<td>2.08</td>
<td>1.04</td>
<td>0.75</td>
</tr>
<tr>
<td>75</td>
<td>208</td>
<td>180</td>
<td>124</td>
<td>90.2</td>
<td>72.2</td>
<td>10.4</td>
<td>3.47</td>
<td>1.74</td>
<td>1.26</td>
</tr>
<tr>
<td>112.5</td>
<td>312</td>
<td>271</td>
<td>187</td>
<td>135</td>
<td>108</td>
<td>15.6</td>
<td>5.20</td>
<td>2.61</td>
<td>1.88</td>
</tr>
<tr>
<td>150</td>
<td>416</td>
<td>361</td>
<td>250</td>
<td>180</td>
<td>144</td>
<td>20.8</td>
<td>6.94</td>
<td>3.48</td>
<td>2.51</td>
</tr>
<tr>
<td>225</td>
<td>625</td>
<td>541</td>
<td>374</td>
<td>271</td>
<td>217</td>
<td>31.2</td>
<td>10.4</td>
<td>5.22</td>
<td>3.77</td>
</tr>
<tr>
<td>300</td>
<td>833</td>
<td>722</td>
<td>499</td>
<td>361</td>
<td>289</td>
<td>41.6</td>
<td>13.9</td>
<td>6.96</td>
<td>5.02</td>
</tr>
<tr>
<td>500</td>
<td>1388</td>
<td>1203</td>
<td>832</td>
<td>601</td>
<td>481</td>
<td>69.4</td>
<td>23.2</td>
<td>11.6</td>
<td>8.37</td>
</tr>
<tr>
<td>750</td>
<td>2082</td>
<td>1804</td>
<td>1248</td>
<td>902</td>
<td>722</td>
<td>104</td>
<td>34.7</td>
<td>17.4</td>
<td>12.6</td>
</tr>
<tr>
<td>1000</td>
<td>2776</td>
<td>2406</td>
<td>1664</td>
<td>1203</td>
<td>962</td>
<td>139</td>
<td>46.3</td>
<td>23.2</td>
<td>16.8</td>
</tr>
<tr>
<td>1500</td>
<td>4164</td>
<td>3608</td>
<td>2496</td>
<td>1804</td>
<td>1443</td>
<td>208</td>
<td>69.5</td>
<td>34.8</td>
<td>25.1</td>
</tr>
<tr>
<td>2000</td>
<td>5552</td>
<td>4811</td>
<td>3328</td>
<td>2406</td>
<td>1925</td>
<td>278</td>
<td>92.6</td>
<td>46.4</td>
<td>33.5</td>
</tr>
<tr>
<td><strong>Total load in kVA</strong></td>
<td><strong>3.6</strong></td>
<td><strong>19.2</strong></td>
<td><strong>22.8</strong></td>
<td><strong>12.5</strong></td>
<td><strong>13.8</strong></td>
<td><strong>20</strong></td>
<td><strong>17.4</strong></td>
<td><strong>12.6</strong></td>
<td><strong>16.8</strong></td>
</tr>
</tbody>
</table>

**LOAD CHECKS ON DELTA, WYE BANKS**

**For a delta-connected bank:**

In a delta connection, the current outside the delta is the resultant of the currents of two windings.

\[
\text{winding current times 1.73 = line current} \\
\text{line current divided by 1.73 = winding current}
\]

\[
\begin{align*}
\text{In (amps)} \times 1.73 &= \text{Out (amps)} \\
\text{Out (amps)} &= \frac{\text{In (amps)}}{1.73}
\end{align*}
\]

For bank load calculations, the current readings can be taken either inside or outside the delta:

\[
\text{Total bank load in kVA} = \frac{\text{average current (outside)}}{1.73} \times 1000
\]

For an individual transformer load calculation, take the current reading inside the delta.
Individual transformer load in kVA = \( \text{current} \times \text{voltage} \)

To calculate the total bank load in kVA using this method, calculate the load for each transformer, then add the three kVA loads together.

**For a wye-connected bank:**

To calculate the kVA load for a three-phase wye bank, calculate the load for each transformer, then add the three kVA loads together.

\[
\text{Transformer load A in kVA} = \frac{1}{3} \times \text{I} \times \text{E} \\
\text{Transformer load B in kVA} = \frac{1}{3} \times \text{I} \times \text{E} \\
\text{Transformer load C in kVA} = \frac{1}{3} \times \text{I} \times \text{E} \\
\]

Total bank load in kVA = Load A + Load B + Load C

This method allows you to determine if any individual transformer is overloaded.

**Alternate method**

\[
\text{Total bank load in kVA} = \frac{(\text{average I}) \times (\text{E}_{\text{line to line}})}{1.73} \\
\]

**For an open wye, open delta bank:**

To calculate the kVA load for an open wye, open delta bank, calculate the load for each transformer, then add the two kVA loads together.

\[
\text{Individual transformer load in kVA} = \text{I} \times \text{E} \\
\]

Note: This bank is 87% efficient. For example, if the transformers are rated at 100 kVA each, each could deliver 87 kVA plus an overload factor, and the total capacity of the bank would be 174 kVA.

Note: If an open wye, open delta bank was originally a bank of three equally sized transformers, and was converted to an open wye, open delta by removing one transformer and grounding the open wye midpoint, the remaining bank of two transformers has a capacity of only 58% (two-thirds of 87%) of the original bank. A load check must be taken to avoid excessive overload and possible burn-out.

**MAKE OR BREAK PARALLEL CIRCUITS AT TRANSFORMER BANKS**

### Make a Parallel Circuit

To connect a new transformer bank in parallel with an existing secondary:

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Check the physical installation to see that it is correct and complete.</td>
</tr>
<tr>
<td>2.</td>
<td>Secure the secondary conductors in the clear.</td>
</tr>
<tr>
<td>3.</td>
<td>Energize the bank.</td>
</tr>
<tr>
<td>4.</td>
<td>Proceed with the steps on page 58 or page 60.</td>
</tr>
</tbody>
</table>

### Break a Parallel Circuit

To break parallel at a transformer bank:

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Be sure the remaining bank can carry the load without excessive overload.</td>
</tr>
<tr>
<td>2.</td>
<td>Disconnect the secondary phase conductors and secure them in the clear. Caution: Secondary phases are still energized.</td>
</tr>
<tr>
<td>3.</td>
<td>Open the disconnects. Remove any risers.</td>
</tr>
</tbody>
</table>

It is now safe to work on the transformer bank.
neutrals. The circuits could be secondaries or primaries. Either circuit at the left can be paralleled with either circuit at the right. The neutral is dashed to indicate the connection could be through the earth or a conductor.

Typical circuits with a field neutral.

Equipment required: Voltmeter (if paralleling secondaries) or phasing stick (if paralleling primaries) rated for twice the phase-to-phase voltage, or higher.

Follow these steps when phasing and paralleling installations with a field neutral.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Measure each circuit for normal phase-to-phase voltages and phase-to-neutral voltages.</td>
</tr>
<tr>
<td>2.</td>
<td>If the secondary is being paralleled to maintain temporary customer service while another transformer bank is being rebuilt, take load checks to be sure the bank remaining in service will not be overloaded excessively.</td>
</tr>
<tr>
<td>3.</td>
<td>If there is not a continuous system neutral, measure for voltage between the neutrals of the two circuits.</td>
</tr>
<tr>
<td>4.</td>
<td>If no voltage exists, or if a small voltage exists (5% or less), you may connect the two neutrals.</td>
</tr>
</tbody>
</table>

Installing Transformers

Note: Make a sketch of the circuits, showing the proper connections. Then proceed.

5. Measure the voltage from A to a phase on circuit #2 that gives a near-zero voltage reading (5% or less). This is A. Check the voltage from A to B and from A to C. These should read normal phase-to-phase voltages.  
   Note: On delta-connected, combination lighting and power banks, if you do not get the above readings, you have a transformer mid-tapped that is connected to different phases in each bank. An outage will be required on one bank to correct this condition. The primary or secondary connections may be altered to provide uniformity between the two banks.  
   Note: When paralleling wye or delta banks, the phase angle must be the same. Phase angle differences between banks will be indicated by higher than required voltages during tests.  
   Caution: When replacing a bank, the original phase sequence must be maintained to avoid damage to customer equipment.  

6. Measure the voltage from B to a phase in circuit #2 that gives a near-zero reading. This is B. Check voltages from B to A and from B to C. These should read normal phase-to-phase voltages.  

7. Measure the voltage from C to a phase in circuit #2 that gives a near-zero reading. This is C. Check voltages from C to A and from C to B. These should read normal phase voltages.  

8. It is now safe to connect A to A, B to B, and C to C.  
   Note: When taking these readings, small voltage differences may exist between the two circuits because of unequal loads; service lines with different lengths, conductor sizes, and voltage drops; and unequal transformer impedances.

Phasing and Paralleling Circuits Without a Field Neutral

This illustration shows typical delta and wye circuits without field neutrals. The circuits could be secondaries or primaries. Either circuit at the left can be paralleled with either circuit at the right.

Typical circuits without a field neutral.

Equipment required: Voltmeter (if paralleling secondaries) or phasing stick (if paralleling primaries) rated for twice the phase-to-phase voltage, or higher.

Follow these steps when phasing and paralleling installations without a field neutral.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Measure each circuit for normal phase-to-phase voltages and phase-to-neutral voltage. If there is no neutral, such as on a delta system, measure phase-to-ground to determine if there are any unintentional ground faults. If there are, do not proceed with paralleling until the ground faults are cleared.</td>
</tr>
</tbody>
</table>
2. If the secondary is being paralleled to maintain temporary customer service while another transformer bank is being rebuilt, take load checks to be sure the bank remaining in service will not be overloaded excessively. 

Note: Make a sketch of the circuits, showing the proper connections. Then proceed.

3. Measure the voltage from A₁ to a phase on circuit #2 that gives a near-zero voltage reading, or the lowest indeterminate voltage reading (anywhere from zero to phase voltage). This might be A₂. Connect A₁ and A₂.

Note: If a voltage greater than phase-to-phase voltage is found on any of the following measurements, repeat Step 3 – you have connected A₁ to B₁ or to C₁. If, after three attempts at Steps 3 and 4 you cannot find near-zero readings, a phase angle difference exists and the circuits will not parallel.

Caution: When replacing a bank, the original phase sequence must be maintained to avoid damage to customer equipment.

4. Measure the voltage from B₁ to a phase in circuit #2 that gives a near-zero reading. This is B₂. Check voltages from B₂ to A₁ and from B₂ to C₁. These should read normal phase voltages.

5. Measure the voltage from C₁ to a phase in circuit #2 that gives a near-zero reading. This is C₂. Check voltages from C₂ to A₁ and from C₂ to B₁. These should read normal phase voltages.

6. It is now safe to connect A₁ to A₂, B₁ to B₂, and C₁ to C₂.

Note: When taking these readings, small voltage differences may exist between the two circuits because of unequal loads; service lines with different lengths, conductor sizes, and voltage drops; and unequal transformer impedances.

---

**MINIMUM POLE CLASS GUIDELINES**

These tables present guidelines only. Stronger poles than those specified here may be required depending on the pole location, other equipment on the pole, and conductor weights and tensions.

For pole-mounted, single-phase transformers:

<table>
<thead>
<tr>
<th>Rating (kVA)</th>
<th>Approx. Weight (lbs)</th>
<th>40 ft.</th>
<th>45 ft.</th>
<th>50 ft.</th>
<th>55 ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>230-340</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>25</td>
<td>350-475</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>37.5</td>
<td>575-600</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>50</td>
<td>700-710</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>75</td>
<td>875-960</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>100</td>
<td>1010-1145</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>167</td>
<td>1500</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

For pole-mounted, three-phase transformer banks:

<table>
<thead>
<tr>
<th>Rating (kVA)</th>
<th>Approx. Weight (lbs)</th>
<th>40 ft.</th>
<th>45 ft.</th>
<th>50 ft.</th>
<th>55 ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>790-1120</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>75</td>
<td>1150-1525</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>112.5</td>
<td>1525-1900</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>150</td>
<td>2200-2230</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>225</td>
<td>2275-2980</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>H1</td>
</tr>
<tr>
<td>300</td>
<td>3130-3435</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>H1</td>
</tr>
<tr>
<td>500</td>
<td>4600</td>
<td>1</td>
<td>H1</td>
<td>H2</td>
<td>H3</td>
</tr>
</tbody>
</table>

---

**STRENGTH OF WOOD POLES**

http://share.pdfonline.com/fdc380b1f0a4f4b4e9a756c8f891a580/Dist.Trans.%20Handbook.htm
The following table lists the horizontal force that common pole classes must exceed, without failing at the groundline. The force is applied two feet from the top of the pole.

<table>
<thead>
<tr>
<th>Pole Class</th>
<th>Horizontal Force (lbs)</th>
<th>Min. Circumference at Top (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H5</td>
<td>10,000</td>
<td>37</td>
</tr>
<tr>
<td>H4</td>
<td>8,700</td>
<td>35</td>
</tr>
<tr>
<td>H3</td>
<td>7,500</td>
<td>33</td>
</tr>
<tr>
<td>H2</td>
<td>6,400</td>
<td>31</td>
</tr>
<tr>
<td>H1</td>
<td>5,400</td>
<td>29</td>
</tr>
<tr>
<td>1</td>
<td>4,500</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>3,700</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>3,000</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>2,400</td>
<td>21</td>
</tr>
<tr>
<td>5</td>
<td>1,900</td>
<td>19</td>
</tr>
</tbody>
</table>

WOOD POLE SETTING DEPTHS
This table lists generally accepted minimum pole setting depths for various conditions. The general rule for the embedment depth of a pole is 10% of the length of the pole, plus 2 feet. Two common exceptions are 30 and 35 feet, which are 10% plus 2-1/2 feet.

<table>
<thead>
<tr>
<th>Length of Pole (ft)</th>
<th>In Soil (ft)</th>
<th>In Poor Soil (ft)</th>
<th>In Solid Rock (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>5</td>
<td>6-1/2</td>
<td>3-1/2</td>
</tr>
<tr>
<td>30</td>
<td>5-1/2</td>
<td>7</td>
<td>3-1/2</td>
</tr>
<tr>
<td>35</td>
<td>6</td>
<td>7-1/2</td>
<td>4</td>
</tr>
<tr>
<td>40</td>
<td>6-1/2</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>45</td>
<td>6-1/2</td>
<td>8-1/2</td>
<td>4</td>
</tr>
<tr>
<td>50</td>
<td>7</td>
<td>9</td>
<td>4-1/2</td>
</tr>
<tr>
<td>55</td>
<td>7-1/2</td>
<td>9-1/2</td>
<td>5</td>
</tr>
<tr>
<td>60</td>
<td>8</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>65</td>
<td>8-1/2</td>
<td>10-1/2</td>
<td>5-1/2</td>
</tr>
</tbody>
</table>

GROUNDING TRANSFORMERS
Each distribution transformer is grounded to an electrode in the earth near the base of the pole or the pad. The ground provides a path for return current in the event of a fault.

“Ground” means the complete path from the connection at the transformer, to the grounding conductor, to the grounding electrode in the earth.

The transformer ground is in addition to grounds on the system neutral. During normal operations:

- Current does flow in the system neutral
- Current does not flow in the transformer ground

Usually, transformers are grounded by means of the lug provided on the transformer case for that purpose.

Do not remove a transformer ground unless the transformer fuse(s) are open.

When grounding an overhead transformer, run the grounding conductor from the tank ground to the neutral, then from the neutral down the pole on the same side as the neutral conductor and opposite the climbing space. On three-transformer banks, the tank grounding lugs are interconnected, then connected to the neutral.

The grounding conductor is a minimum wire size of #4 copper.

Use compression connectors for all connections to the pole ground conductor or the system neutral. Don’t use bolted connectors or hot taps. Don’t press more than one conductor under the same connector – each conductor has its own connection to the pole ground or the neutral.
The grounding electrode is a driven ground rod, or a ground plate. If conditions are poor, two electrodes in parallel, may be required. Conditions which affect the ability of the electrode to dissipate surges:

- Soil type. Examples: Clay soil has high conductivity, which is good. Gravel has low conductivity, which is bad.
- Soil condition. Damp is good, contact with the water table is very good, high salt contact is good, frozen soil is bad.
- Surface area of the ground rod or plate. The larger the surface area, the better.
- Material of the ground rod or plate. Copper is better than steel. Copper-clad steel is better than steel alone.
- Resistance of clamps and connections.

Note: The integrity of in-ground connections can deteriorate over time.

Recommendation: Keep the primary neutral separate and distinct from the many other connections at the secondary rack. Failure to keep the primary neutral separate introduces the high risk of inadvertently cutting the primary neutral while the transformer is energized. This will result in a primary voltage across the cut.
Grounding Single-Phase Two-Bushing Transformers, Neutral in Primary Position

Recommendation: Keep the primary neutral separate and distinct from the many other connections at the secondary rack. Failure to keep the primary neutral separate introduces the high risk of inadvertently cutting the primary neutral while the transformer is energized. This will result in a primary voltage across the cut.

Installing Transformers

Grounding Three-Phase Wye-Wye Banks, Single-Bushing Transformers, Neutral in Common Position

Drive the top of the ground rod flush with or below grade level.
A continuous ground around the transformer protects personnel by reducing step and touch potentials.

Installing Transformers

FUSING TRANSFORMERS

The transformer fuses listed in these charts are typical for grounded wye systems, and might not apply to you. Always follow your company’s fusing practices.

When fusing a single-phase transformer in a three-phase bank, select the fuse according to the size of the individual transformer:

<table>
<thead>
<tr>
<th>Transformer Size (kVA)</th>
<th>System Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2,400 V</td>
</tr>
<tr>
<td>3</td>
<td>2H</td>
</tr>
<tr>
<td>5</td>
<td>2H</td>
</tr>
<tr>
<td>7.5</td>
<td>2H</td>
</tr>
<tr>
<td>10</td>
<td>6T</td>
</tr>
<tr>
<td>15</td>
<td>10T</td>
</tr>
<tr>
<td>25</td>
<td>15T</td>
</tr>
<tr>
<td>37.5</td>
<td>25T</td>
</tr>
<tr>
<td>50</td>
<td>25T</td>
</tr>
<tr>
<td>75</td>
<td>50T</td>
</tr>
<tr>
<td>100</td>
<td>50T</td>
</tr>
<tr>
<td>150</td>
<td>100T</td>
</tr>
<tr>
<td>167</td>
<td>100T</td>
</tr>
<tr>
<td>200</td>
<td>200T</td>
</tr>
<tr>
<td>250</td>
<td>—</td>
</tr>
</tbody>
</table>

For single-phase padmount transformers (Bay-O-Net fuses):

<table>
<thead>
<tr>
<th>Transformer Size (kVA)</th>
<th>System Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2,400 V</td>
</tr>
<tr>
<td>10</td>
<td>C10</td>
</tr>
<tr>
<td>15</td>
<td>C10</td>
</tr>
<tr>
<td>25</td>
<td>C10</td>
</tr>
<tr>
<td>37.5</td>
<td>C10</td>
</tr>
<tr>
<td>50</td>
<td>C12</td>
</tr>
<tr>
<td>75</td>
<td>C14</td>
</tr>
<tr>
<td>100</td>
<td>C14</td>
</tr>
<tr>
<td>167</td>
<td>C14</td>
</tr>
</tbody>
</table>

After a Bay-O-Net fuse has blown:
1. De-energize the primary cable serving the transformer.
2. Re-fuse the transformer.
3. Re-energize the transformer from a remote location. For example: one vault or transformer away.

Note: Don’t use a Bay-O-Net fuse to energize a transformer after a suspected failure.
SAFETY CLEARANCES AROUND PADMOUNT TRANSFORMERS

Clearances from padmount transformers to structures are measured from the nearest metal portion of the transformer, to the structure or any overhang.

The clearance from a building is 3 feet if the building has non-combustible walls (brick, concrete, steel, or stone), 10 feet if the building has combustible walls (including stucco).

The clearances shown below and on the next page apply to any oil-filled equipment.

WORK CLEARANCES AROUND PADMOUNT, UNDERGROUND TRANSFORMERS

A minimum clearance of 10 feet of clear, level, unobstructed working space is required in front of a padmount transformer, to allow use of hot sticks.
Totally underground transformer work clearances.

Guard posts are required where a padmount transformer is exposed to vehicular traffic, and where minimum clearances around equipment cannot be met. If several guard posts are used, locate them no more than 5 feet apart. For extra visibility, paint the posts traffic yellow. In some situations a 6-inch diameter post is required, not the 4-inch post illustrated here.

THE MYSTERY OF TRANSFORMATIONS

Distribution transformers use magnetic force to convert electric power from one form into a new and more valuable form. But no one actually sees electricity or magnetism – we are aware of them only through their effects. In our daily lives, we occasionally have experiences which prove transforming. We can’t see the forces behind these wonderful events either, but we surely notice their powerful effects.

Whether transformations are electrical or spiritual, there is something mysterious about them. While we don’t fully understand how they function, we are delighted that they do.