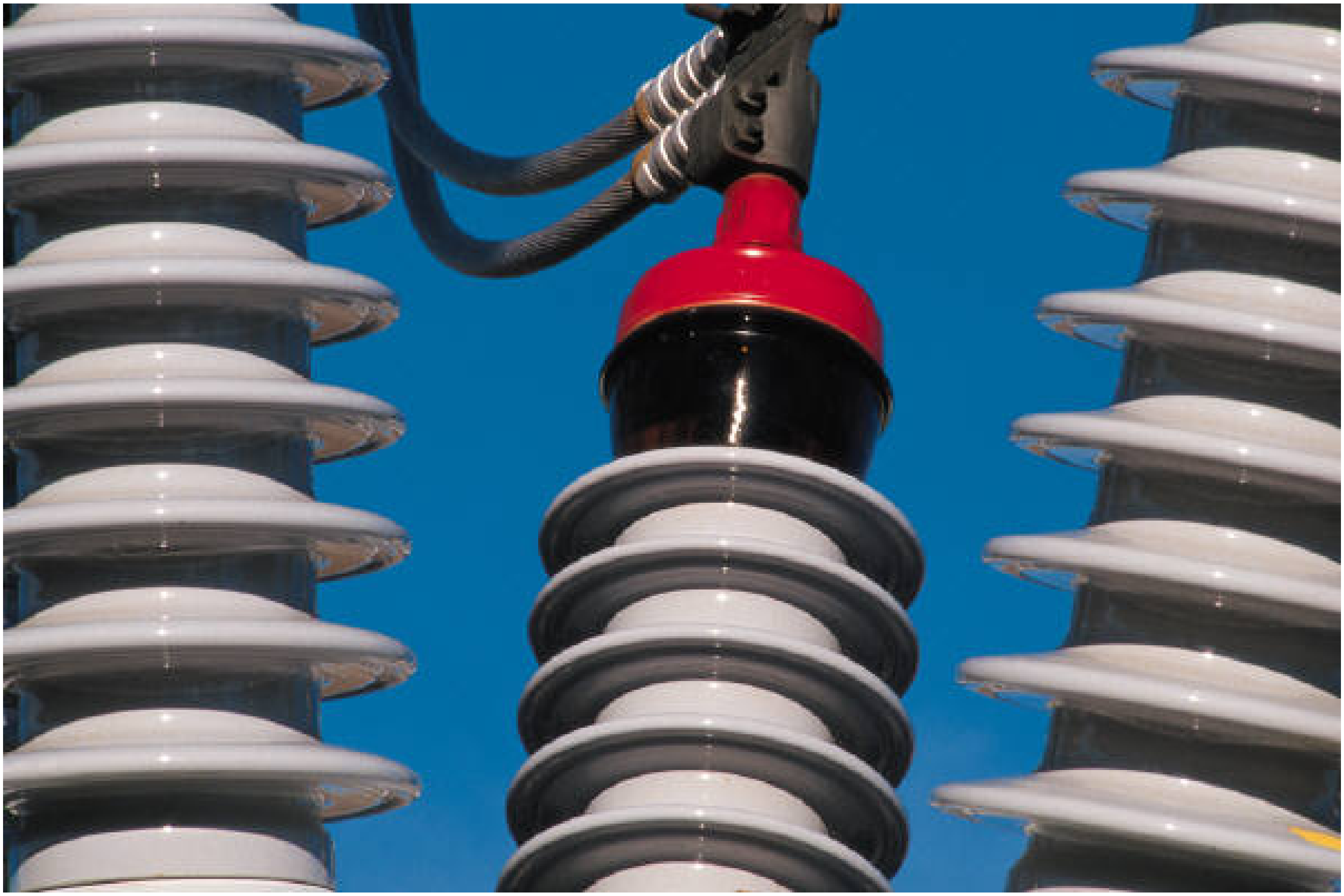
TRANSFORMERS



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CHAPTERS

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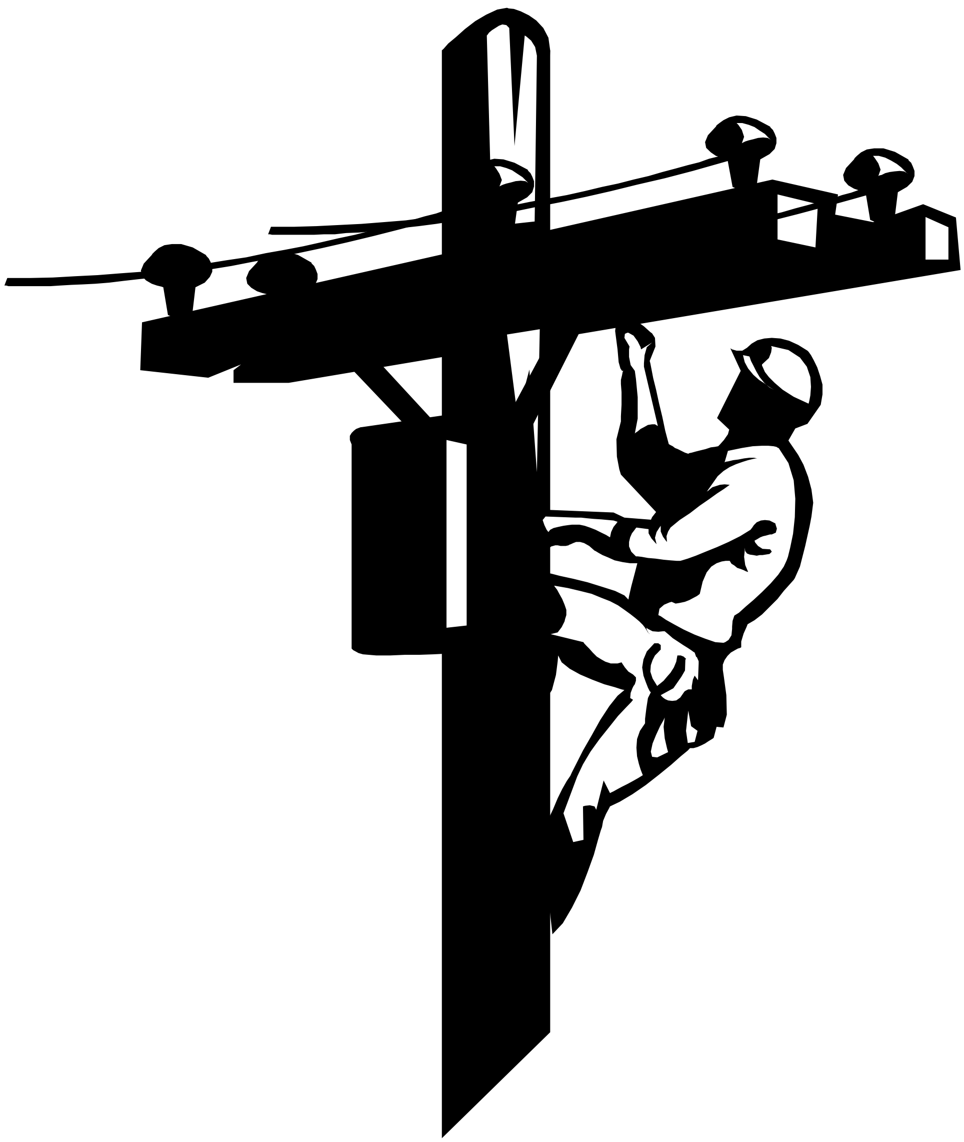
CREDITS

1. Southwest Transformer, Bruce Plumlee / Connection Diagram Manual
2. Electrified Oil Production, J.K. Howell and E.E. Hogwood
3. Electrical Engineering Handbook, EASA
4. Wye-Wye Transformer Connections-Friend or Foe? Frank A. Kohlbacher
5. Distribution Transformer Manual, General Electric
6. Notes, Gary E. Allison
7. State of Oklahoma CEU instructor, Leon Allison
8. Oklahoma Gas & Electric, Specifications
9. National Electrical Code 2002
10. IEEE Std. 242-1975: Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems
11. American Electricians' Handbook, 10th Edition
12. National Electrical Code 2002 Handbook

NOTE

- Some credited statements or articles have been abridged or attuned to integrate with specific categories, improve spelling, improve grammar, and/or clarify wording.
- It is recommended that all transformers be connected as shown on the manufacturer's nameplate.
- For physical installation and configuration of highline transformers and related equipment refer to the following publication:
    - United States Department of Agriculture (USDA) Rural Utilities Service (RUS) / RUS Bulletin 1728F-803 (D-803) "Specifications and Drawings for 24.9/14.4 kv Line Construction"
    - United States Department of Agriculture (USDA) Rural Utilities Service (RUS) / RUS Bulletin 1728F-804 (D-804) "Specifications and Drawings for 12.5/7.2 kv Line Construction"

CHAPTER I 3Ø BANKING OF 1Ø TRANSFORMERS



WYE-DELTA CLOSED

YΔ CLOSED / NEUTRAL = PRIM NO-SEC NO

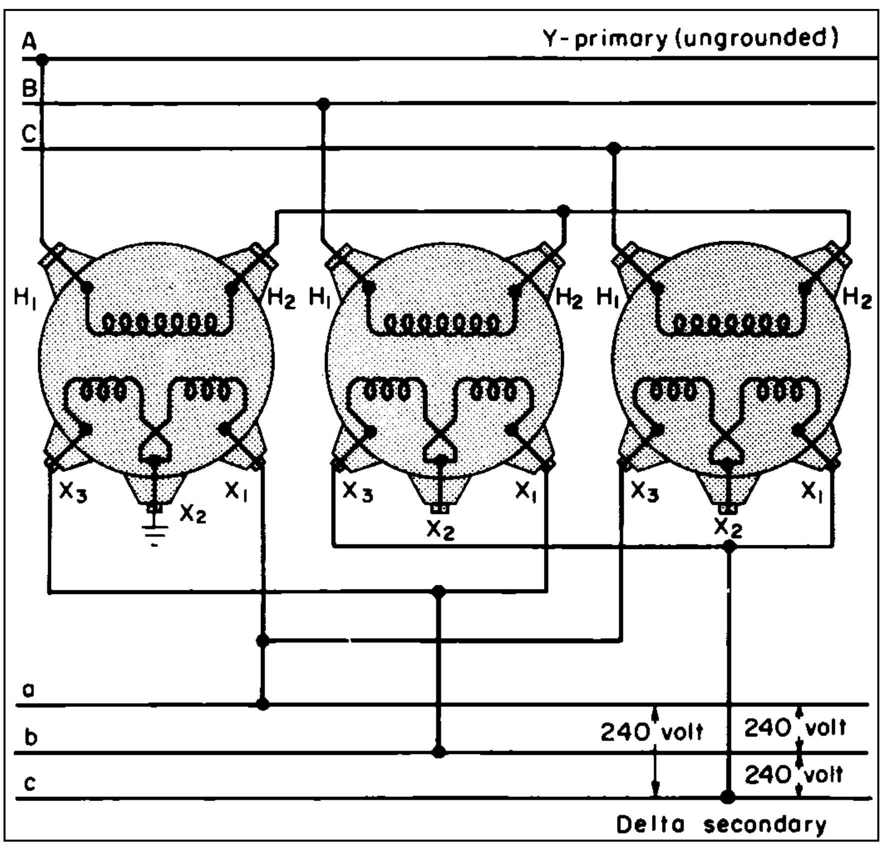
WHERE USED

To supply three-phase loads. No excessive circulating currents when transformers of unequal impedance and ratio are banked. No problem from third harmonic over-voltage or telephone interference. If a ground is required, it may be placed on either an X1 or an X_2 bushing as shown. (5)

WYE-DELTA FOR POWER

Often it is desirable to increase the voltage of a circuit from 2400 to 4160 volts to increase its potential capacity. This diagram shows such a system after it has been changed to 4160 volts. The previously delta-connected distribution transformer primaries are now connected from line to neutral so that no major change in equipment is necessary. The primary neutral should not be grounded or tied into the system neutral since a single-phase ground fault may result in extensive blowing of fuses throughout the system. (3)

DIAGRAM



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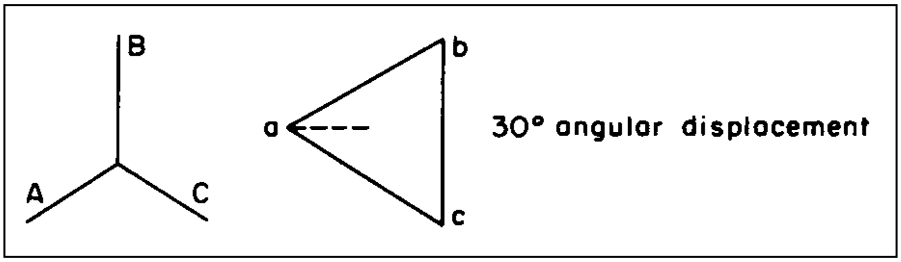


(5)

BANK RATING

Maximum safe bank rating for balanced three-phase loads (when transformer kva's are unequal) is three times the kva of the smallest unit. A disabled transformer renders the bank inoperative. (5)

IMPEDANCE & GROUNDING

The wye-delta connection is one of the most popular connections used today. Transformers are often connected from delta-delta to wye-delta to take advantage of 1.732 times the delta transmission voltage.

In this connection, it is not necessary that the impedance of the three transformers be the same.

This connection should not be used with CSP single-phase transformers since when one breaker opens serious unbalanced secondary voltages may appear.

The wye of this system should not be grounded because then the bank serves as a grounding bank and will supply ground-fault current for a phase-to-ground fault on the primary system. Also for unbalanced three-phase loads on the primary system, the secondary acts as a balance coil; therefore, circulating current may result in an overload. (2)

STATIC DISCHARGE

Potentially present on a non-grounded primary wye connection. A high, excessive voltage results on a 3-phase Y-Δ connection on the secondary line to ground when one leg of the primary is open. The voltage present is static with no power and bleeds off when taken to ground. This static can damage a volt-ohm meter. The static is greater when the secondary feeder is short and lesser when the secondary feeder is long. The static problem is resolved by grounding one phase or the center tap of one transformer on the secondary side, but this usually requires special KWH metering. This static condition is present only when a primary line is open, not the secondary. This static condition can occur on an open (2-transformers) or closed (3-transformers) bank. This static condition can occur with any primary voltage. (6)

FERRORESONANCE

Negative effects of ferroresonance are potentially present on non-grounded primary wye connections. There is more danger at 14,400/24.900 VAC and higher. There is more danger with smaller transformers.

A rule-of-thumb concerning negative ferroresonance effects is that transformers 25 KVA and smaller at 14,400/24,900 are susceptible to damage. 30 KVA and larger transformers are relatively safe from adverse ferroresonance effects at 14,400/24,900. Higher voltages than 14,400/24,900 would necessitate larger transformers than 30 KVA to be considered inherently safe from adverse ferroresonance effects.

On a floating Y-Δ connection, temporarily ground the primary neutral when closing or opening primary fuses to avoid adverse ferroresonance effects. A "chain ground" (a fourth or neutral cutout) should be installed and closed while closing or opening the power cutouts and then re-opened after all of the power cutouts are closed.

Configurations used to avoid ferroresonance are an open Y-Δ with a solidly grounded primary Y or a Y-Y with a solidly grounded primary and secondary Y connection.

Read additional information on ferroresonance in the "Transformer Notes" section.

(6)

YΔ CLOSED / NEUTRAL = PRIM NO-SEC YES

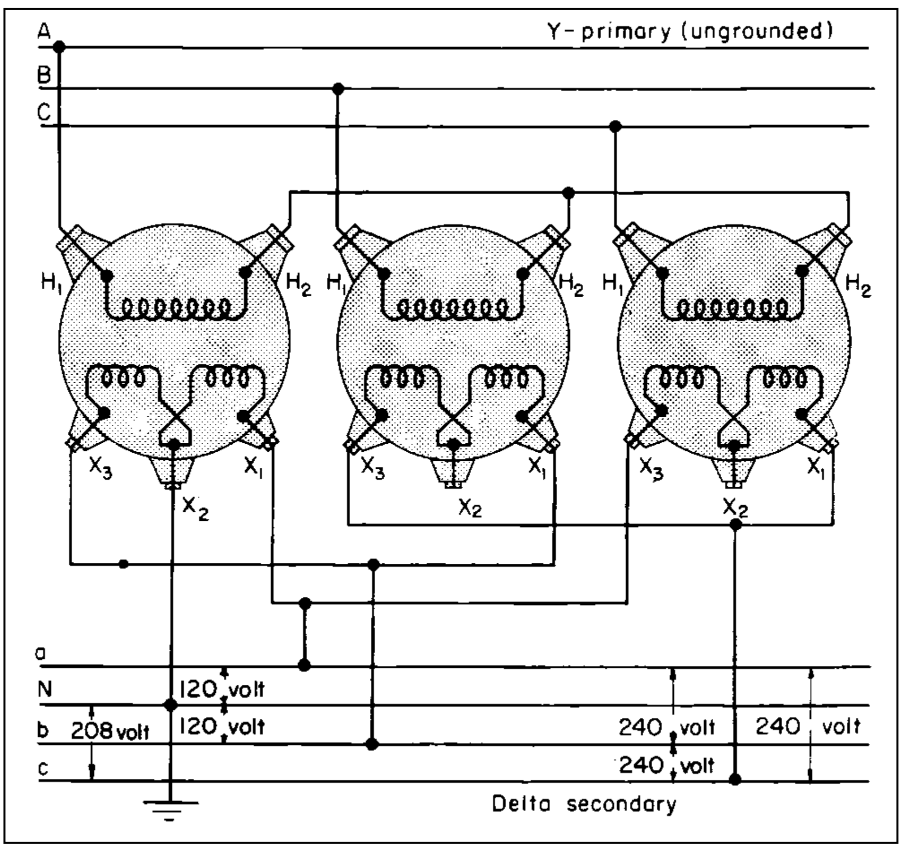
WHERE USED

For supplying three-phase, 240 VAC loads with small amounts of 120/240 VAC, single-phase loads. No excessive circulating currents when transformers of unequal impedance and ratio are banked. No problem from third harmonic overvoltage or telephone interference. (5)

WYE-DELTA FOR LIGHT & POWER

This diagram shows the connections for the Y-Delta bank to supply both light and power. This connection is similar to the delta-delta bank with only the primary connections changed. The primary neutral should not be grounded or tied into the system neutral, since a single-phase ground fault may result in extensive blowing of fuses throughout the system. The single-phase load reduces the available three-phase capacity. This connection requires special watt-hour metering. (3)

DIAGRAM



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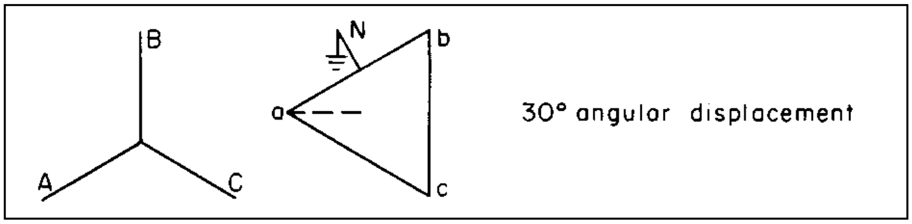


(5)

BANK RATING

The transformer with the midtap carries 2/3 of the 120/240-volt, single-phase load and 1/3 of the 240-volt, three-phase load. The other two units each carry 1/3 of both the 120/240 and 240-volt loads. (5)

CAUTION

The secondary neutral bushing can be grounded only on one of the three transformers. (5)

IMPEDANCE & GROUNDING

The wye-delta connection is one of the most popular connections used today. Transformers are often connected from delta-delta to wye-delta to take advantage of 1.732 times the delta transmission voltage.

In this connection, it is not necessary that the impedance of the three transformers be the same.

This connection should not be used with CSP single-phase transformers since when one breaker opens; serious unbalanced secondary voltages may appear.

The wye of this system should not be grounded because then the bank serves as a grounding bank and will supply ground-fault current for a phase-to-ground fault on the primary system. Also for unbalanced three-phase loads on the primary system, the secondary acts as a balance coil; therefore, circulating current may result in an overload. (2)

STATIC DISCHARGE

Potentially present on a non-grounded primary wye connection. A high, excessive voltage results on a 3-phase Y-Δ connection on the secondary line to ground when one leg of the primary is open. The voltage present is static with no power and bleeds off when taken to ground. This static can damage a volt-ohm meter. The static is greater when the secondary feeder is short and lesser when the secondary feeder is long. The static problem is resolved by grounding one phase or the center tap of one transformer on the secondary side, but this usually requires special KWH metering. This static condition is present only when a primary line is open, not the secondary. This static condition can occur on an open (2-transformers) or closed (3-transformers) bank. This static condition can occur with any primary voltage. (6)

FERRORESONANCE

Negative effects of ferroresonance are potentially present on non-grounded primary wye connections. There is more danger at 14,400/24.900 VAC and higher. There is more danger with smaller transformers.

A rule of thumb concerning negative ferroresonance effects is that transformers 25 KVA and smaller at 14,400/24,900 are susceptible to damage. 30 KVA and larger transformers are relatively safe from adverse ferroresonance effects at 14,400/24,900. Higher voltages than 14,400/24,900 would necessitate larger transformers than 30 KVA to be considered inherently safe from adverse ferroresonance effects.

On a floating Y-Δ connection, temporarily ground the primary neutral when closing or opening primary fuses to avoid adverse ferroresonance effects. A "chain ground" (a fourth or neutral cutout) should be installed and closed while closing or opening the power cutouts and then re-opened after all of the power cutouts are closed.

Configurations used to avoid ferroresonance are an open Y-Δ with a solidly grounded primary Y or a Y-Y with a solidly grounded primary and secondary Y connection.

Read additional information on ferroresonance in the "Transformer Notes" section.
(6)

HIGH-LEG MARKING

NEC 2002: 110.15 High-Leg Marking.
On a 4-wire, delta-connected system where the midpoint of one phase winding is grounded to supply lighting and similar loads, the conductor or busbar having the higher phase voltage to ground shall be durably and permanently marked by an outer finish that is orange in color or by other effective means. Such identification shall be placed at each point on the system where a connection is made if the grounded conductor is also present.
(9)

NEC 2002 Handbook:
Added for the 2002 Code, this section now contains a requirement that appeared in 384-3(e) of the 1999 NEC. This requirement was moved to Article 110, where the application becomes a more general requirement.

The high leg is common on a 240/120-volt 3-phase, 4-wire delta system. It is typically designated as "B phase." The high-leg marking is required to be the color orange or other similar effective means and is intended to prevent problems due to the lack of complete standardization where metered and non-metered equipment are installed in the same installation. Electricians should always test each phase relative to ground with suitable equipment to determine exactly where the high leg is located in the system. (12)

ARRANGEMENT OF BUSBARS AND CONDUCTORS

NEC 2002: 408.3 / Support and Arrangement of Busbars and Conductors / (E) Phase Arrangement
The phase arrangement on 3-phase buses shall be A, B, C from front to back, top to bottom, or left to right, as viewed from the front of the switchboard or panelboard. The B

phase shall be that phase having the higher voltage to ground on 3-phase, 4-wire, delta-connected systems. Other busbar arrangements shall be permitted for additions to existing installations and shall be marked.

Exception: Equipment within the same single section or multisection switchboard or panelboard as the meter on 3-phase, 4-wire, delta-connected systems shall be permitted to have the same phase configuration as the metering equipment.

FPN: See 110.15 for requirements on marking the busbar or phase conductor having the higher voltage to ground where supplied from a 4-wire, delta-connected system. (9)

NEC 2002 Handbook:
The high leg is common on a 240/120-volt, 3-phase, 4-wire delta system. It is typically designated as “B phase.” Section 110.15 requires the high-leg marking to be the color orange or other similar effective means of identification. Electricians should always test each phase to ground with suitable equipment in order to know exactly where this high leg is located in the system.

The exception to 408.3(E) permits the phase leg having the higher voltage to ground to be located at the right-hand position (C phase), making it unnecessary to transpose the panelboard or switchboard busbar arrangement ahead of and beyond a metering compartment. The exception recognizes the fact that metering compartments have been standardized with the high leg at the right position (C phase) rather than in the center on B phase.

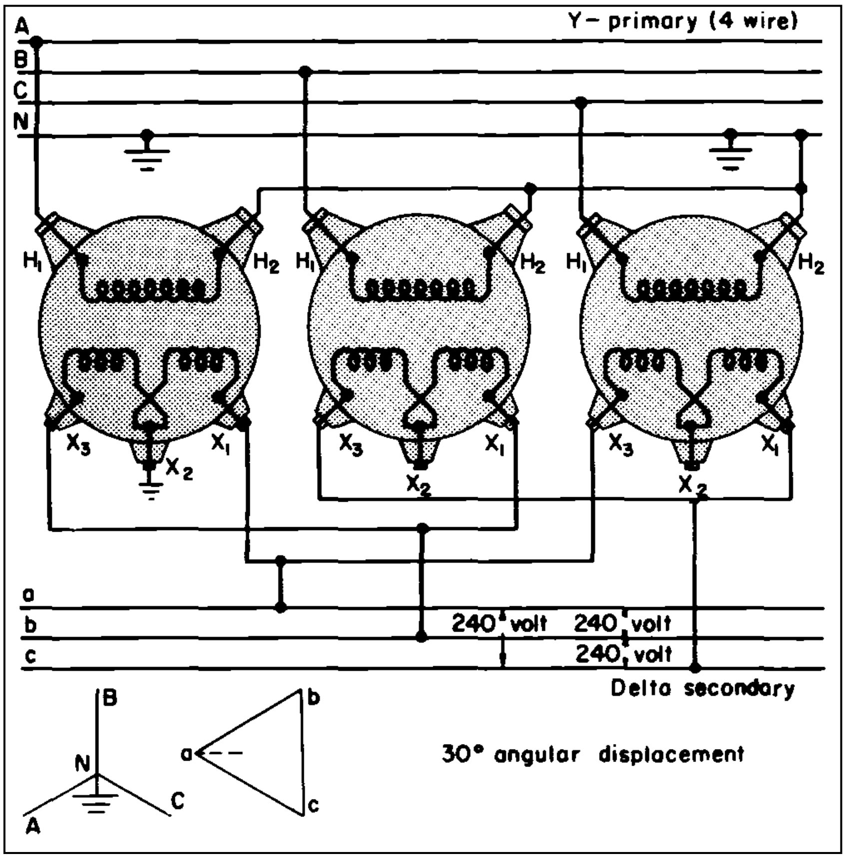
See also 110.15, 215.8, and 230.56 for further information on identifying conductors with the higher voltage to ground. Other busbar arrangements for making additions to existing installations are permitted by 408.3(E). (12)

YΔ CLOSED / NEUTRAL = PRIM YES-SEC NO

WHERE USED

To supply three-phase, 240-volt loads. With a disabled unit, bank can be reconnected in open-wye, open-delta for emergency service. If a ground is required, it may be placed on either an X1 or an X_2 bushing as shown. (5)

DIAGRAM



(5)

BANK RATING

When units of different kva's are used, maximum safe bank rating is three times the kva of the smallest unit. (5)

CAUTION

The transformers are susceptible to burnouts on primary faults. Transformer may act as a grounding transformer for unbalanced primary conditions, reducing its own capacity for connected load, with possible burnouts. If one phase of the primary supply is opened, the bank automatically becomes open-wye, open-delta and continues to supply the three-phase load although with reduced capacity. Possible transformer burnout and sympathetic tripping may occur. (5)

STATIC DISCHARGE

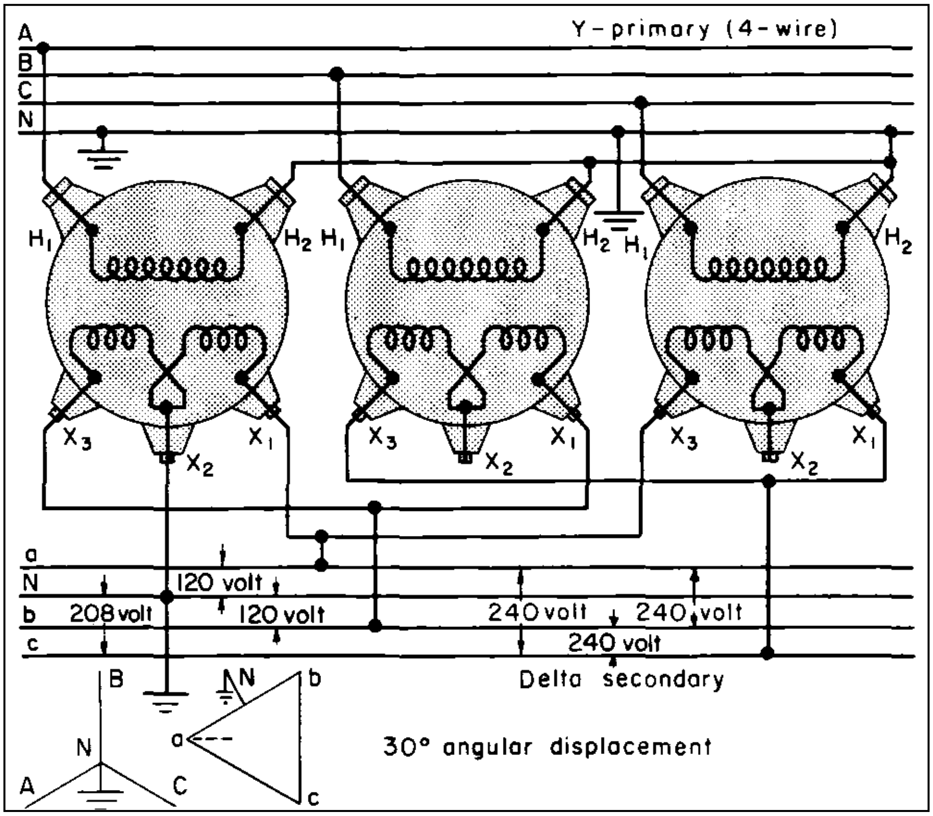
Potentially present on a non-grounded primary wye connection. A high, excessive voltage results on a 3-phase Y-Δ connection on the secondary line to ground when one leg of the primary is open. The voltage present is static with no power and bleeds off when taken to ground. This static can damage a volt-ohm meter. The static is greater when the secondary feeder is short and lesser when the secondary feeder is long. The static problem is resolved by grounding one phase or the center tap of one transformer on the secondary side, but this usually requires special KWH metering. This static condition is present only when a primary line is open, not the secondary. This static condition can occur on an open (2-transformers) or closed (3-transformers) bank. This static condition can occur with any primary voltage. (6)

YΔ CLOSED / NEUTRAL = PRIM YES-SEC YES

WHERE USED

For supplying three-phase, 240 VAC loads with small amounts of 120/240 VAC single-phase loads. With a disabled unit, bank can be reconnected in open-wye, open-delta for emergency service. (5)

DIAGRAM



(5)

BANK RATING

The other two units each carry 1/6 of the 120/240volt single-phase load and 1/3 of the 240-volt three-phase load. (5)

CAUTION

The transformers are susceptible to burnouts on primary faults. Transformer may act as a grounding transformer for unbalanced primary conditions, reducing its own capacity for connected load with possible burnouts. If one phase of the primary supply is opened, the bank automatically becomes open-wye, open-delta and continues to supply the three-phase load although with reduced capacity. Possible transformer burnout and sympathetic tripping may occur. (5)

HIGH-LEG MARKING

NEC 2002: 110.15 High-Leg Marking.

On a 4-wire, delta-connected system where the midpoint of one phase winding is grounded to supply lighting and similar loads, the conductor or busbar having the higher phase voltage to ground shall be durably and permanently marked by an outer finish that is orange in color or by other effective means. Such identification shall be placed at each point on the system where a connection is made if the grounded conductor is also present. (9)

NEC 2002 Handbook:
Added for the 2002 Code, this section now contains a requirement that appeared in 384-3(e) of the 1999 NEC. This requirement was moved to Article 110, where the application becomes a more general requirement.

The high leg is common on a 240/120-volt 3-phase, 4-wire delta system. It is typically designated as "B phase." The high-leg marking is required to be the color orange or other similar effective means and is intended to prevent problems due to the lack of complete standardization where metered and non-metered equipment are installed in the same installation. Electricians should always test each phase relative to ground with suitable equipment to determine exactly where the high leg is located in the system. (12)

ARRANGEMENT OF BUSBARS AND CONDUCTORS

NEC 2002: 408.3 / Support and Arrangement of Busbars and Conductors / (E) Phase Arrangement
The phase arrangement on 3-phase buses shall be A, B, C from front to back, top to bottom, or left to right, as viewed from the front of the switchboard or panelboard. The B phase shall be that phase having the higher voltage to ground on 3-phase, 4-wire, delta-connected systems. Other busbar arrangements shall be permitted for additions to existing installations and shall be marked.

Exception: Equipment within the same single section or multisection switchboard or panelboard as the meter on 3-phase, 4-wire, delta-connected systems shall be permitted to have the same phase configuration as the metering equipment.

FPN: See 110.15 for requirements on marking the busbar or phase conductor having the higher voltage to ground where supplied from a 4-wire, delta-connected system. (9)

NEC 2002 Handbook:
The high leg is common on a 240/120-volt, 3-phase, 4-wire delta system. It is typically designated as "B phase." Section 110.15 requires the high-leg marking to be the color orange or other similar effective means of identification. Electricians should always test each phase to ground with suitable equipment in order to know exactly where this high leg is located in the system.

The exception to 408.3(E) permits the phase leg having the higher voltage to ground to be located at the right-hand position (C phase), making it unnecessary to transpose the panelboard or switchboard busbar arrangement ahead of and beyond a metering compartment. The exception recognizes the fact that metering compartments have been standardized with the high leg at the right position (C phase) rather than in the center on B phase.

See also 110.15, 215.8, and 230.56 for further information on identifying conductors with the higher voltage to ground. Other busbar arrangements for making additions to existing installations are permitted by 408.3(E). (12)

WYE-WYE CLOSED

YY CLOSED / NEUTRAL = PRIM YES-SEC YES

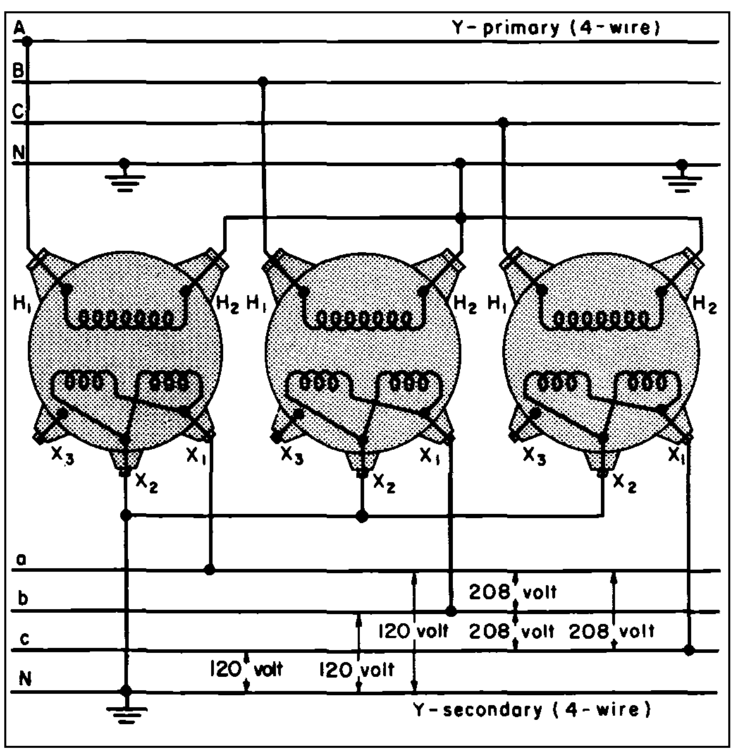
WHERE USED

To supply single- and three-phase loads on four-wire, multi-grounded systems. When a system has changed from delta to a four-wire wye in order to increase system capacity, existing transformers may be used. (Example: Old system was 2400 volts delta; new system is 2400/4160Y volts. Existing 2400/4160Y-volt transformers may be connected in wye and used.) (5)

YY FOR LIGHTING AND POWER

This diagram shows a system on which the primary voltage was increased from 2400 volts to 4160 volts to increase the potential capacity of the system. The previously delta-connected distribution transformers are now connected from line to neutral. The secondaries are connected in Y. In this system, the primary neutral is connected to the neutral of the supply voltage through a metallic conductor and carried with the phase conductor to minimize telephone interference. If the neutral of the transformer is isolated from the system neutral, an unstable condition results at the transformer neutral caused primarily by third harmonic voltages. If the transformer neutral is connected to ground, the possibility of telephone interference is greatly enhanced, and there is also a possibility of resonance between the line capacitance to ground and the magnetizing impedance of the transformer. Dotted lines indicate transformer tanks are grounded. (3)

DIAGRAM



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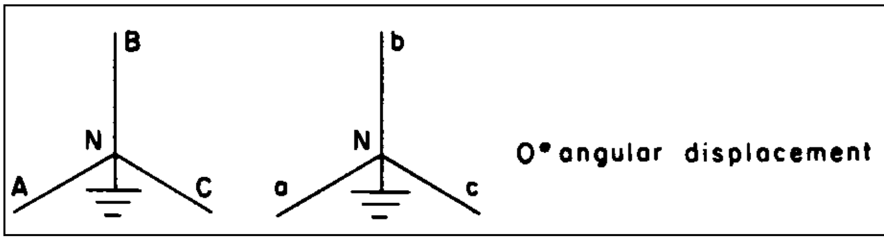


(5)

CAUTION

The primary neutral should be tied firmly to the system neutral; otherwise, excessive voltages may develop on the secondary side. (5)

It is necessary that the primary neutral be available when this connection is used, and the neutrals of the primary system and of the bank are tied together as shown. If the three-phase load is unbalanced, part of the load current flows in the primary neutral. The third-harmonic component of the transformer exciting current also flows in the primary neutral. For these reasons, it is necessary that the neutrals be tied together as shown. If this tie were omitted, the line to neutral voltages on the secondary would be very unstable. That is, if the load on one phase were heavier than on the other two, phases would rise. Also, large third-harmonic voltages would appear between lines and neutral, both in the transformers and in the secondary system, in addition to the 60-Hz component of voltage. This means that for a given value of RMS voltage, the peak voltage would be much higher than for a pure 60-Hz voltage. This overstresses the insulation both in the transformers and in all apparatus connected to the secondaries. (11)

IMPEDANCE & GROUNDING

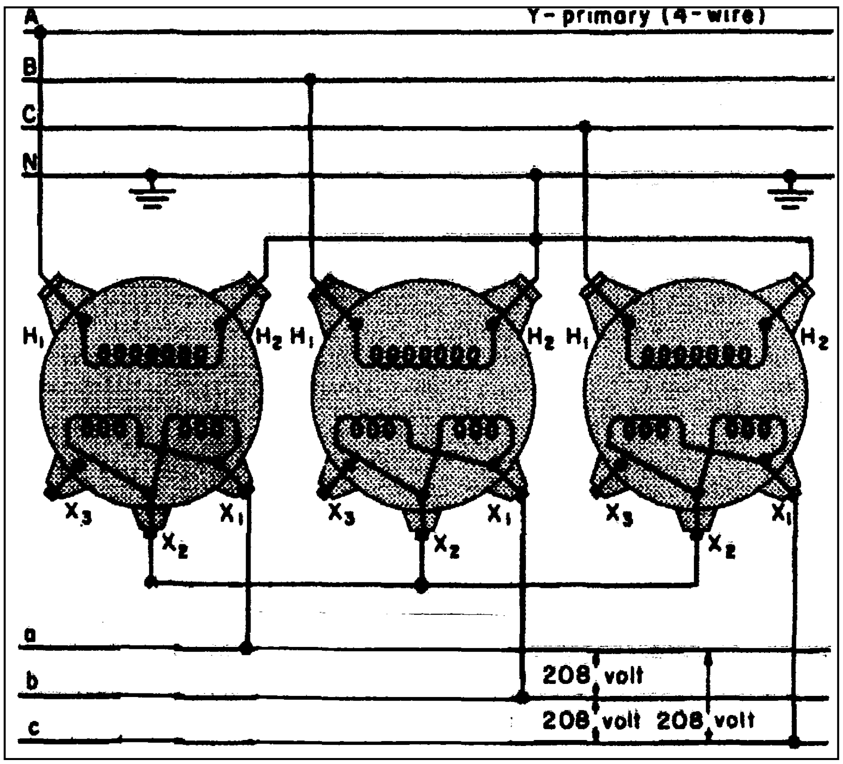
The wye-grounded/wye-grounded connection should be used only on a grounded system. It will pass ground-fault current from the primary system. Single and three-phase loads may be connected depending on the rating of the individual units, it is not necessary that the impedance of each unit in the bank be the same. (2)

YY CLOSED / NEUTRAL = PRIM YES-SEC NO

WHERE USED

Used only by instructions from responsible project engineers, supervisors or manufacture representatives. The primary wye must remain grounded at all times. The secondary wye can be isolated by request for the operation of an electronic or programmable sensor monitoring down-hole pump activities. (6)

DIAGRAM



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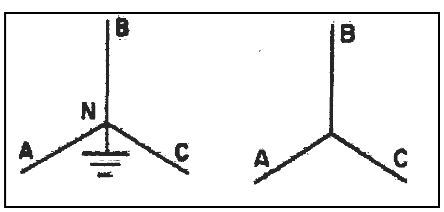


CAUTION DOWN-HOLE SENSORS

Some down-hole sensors will function properly with the secondary of a Y-Y grounded, and thus by habit the secondary should initially be grounded unless or until instructed otherwise.

By experience, there have been times that the primary ground in a Y-Y has created adverse effects on a down-hole sensor and field personnel have been asked to remove the primary ground connection. Field personnel should never take it upon themselves to remove the primary ground of a Y-Y. Field personnel must relay such a request to their immediate supervisor. The supervisor, in turn, must contact the owner of the down-hole equipment and clearly explain the request to remove a ground and the potentially excessive damage this action might have on transformers, drives or motors.

After clearly explaining the dangers of an isolated YY primary connection to a client and the client insists on having the ground removed, then one would comply only with the safety addition of a "chain ground" (a fourth or neutral cutout) to be temporally closed prior to closing the three power cutouts to avoid adverse ferroresonance effects. After the three power cutouts are closed, then the chain ground cutout would be opened.

In coordinating with a pump technician concerning an improperly functioning down-hole sensor, a transformer connection should not be readily assumed to be the cause over a faulty or incorrectly installed sensor.

An ungrounded primary on a Y-Y will pass ground-fault current from the primary system to the secondary. An ungrounded primary on a Y-Y may also develop excessive voltages on the secondary side. (6)

It is necessary that the primary neutral be available when this connection is used, and the neutrals of the primary system and of the bank are tied together as shown. If the three-phase load is unbalanced, part of the load current flows in the primary neutral. The third-harmonic component of the transformer exciting current also flows in the primary neutral. For these reasons, it is necessary that the neutrals be tied together as shown. If this tie were omitted, the line to neutral voltages on the secondary would be very unstable. That is, if the load on one phase were heavier than on the other two, phases would rise. Also, large third-harmonic voltages would appear between lines and neutral, both in the transformers and in the secondary system, in addition to the 60-Hz component of voltage. This means that for a given value of RMS voltage, the peak voltage would be much higher than for a pure 60-Hz voltage. This overstresses the insulation both in the transformers and in all apparatus connected to the secondaries. (11)

WYE-DELTA OPEN

YΔ OPEN / NEUTRAL = PRIM YES-SEC NO

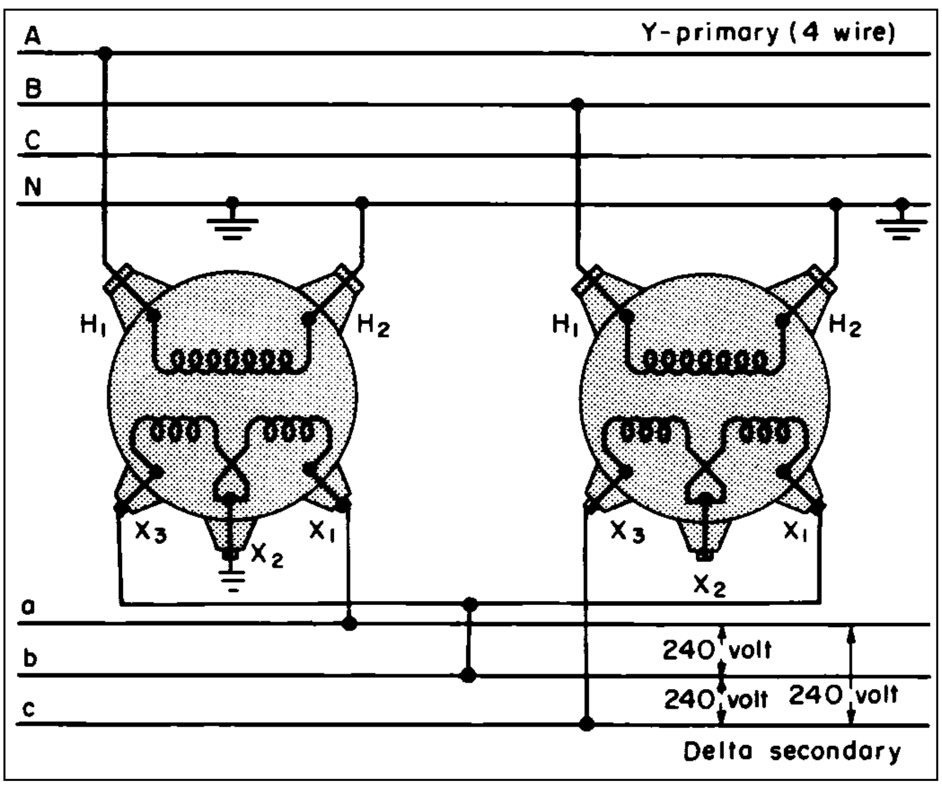
WHERE USED

To supply large single-phase, 240-volt loads with small amounts of three-phase loads. (Usually transformers of different kva sizes are used.) Also used for emergency operation when one unit of a four-wire primary, wye-delta bank is disabled. If a ground is required, it may be placed on an X1 or an X_2 bushing as shown. (5)

OPEN Y-DELTA

When operating Y-delta and one phase is disabled, service may be maintained at reduced load as shown. The neutral in this case must be connected to the neutral of the step-up bank though a copper conductor. The system is unbalanced, electro-statically and electro-magnetically, so that telephone interference may be expected if the neutral is connected to ground. The useful capacity of the open Y-delta bank is 87 percent of the capacity of the installed transformers when the two units are identical. The capacity is 57 percent of a three transformer bank. (3)

DIAGRAM



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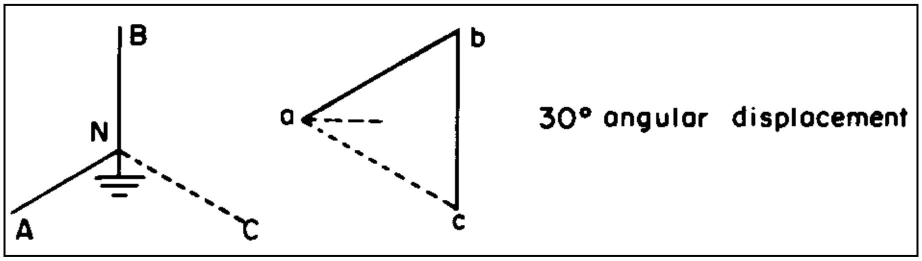

(5)

BANK RATING

This connection is relatively inefficient where three-phase loads predominate since it has only 86.6% of the rating of the two units making up the three-phase bank. It also has only 57.7 % of the three-phase rating of a closed delta-delta bank of three units. (5)

STATIC DISCHARGE

Potentially present on a non-grounded primary wye connection. A high, excessive voltage results on a 3-phase Y-Δ connection on the secondary line to ground when one leg of the primary is open. The voltage present is static with no power and bleeds off when taken to ground. This static can damage a volt-ohm meter. The static is greater when the secondary feeder is short and lesser when the secondary feeder is long. The static problem is resolved by grounding one phase or the center tap of one transformer on the secondary side, but this usually requires special KWH metering. This static condition is present only when a primary line is open, not the secondary. This static condition can occur on an open (2-transformers) or closed (3-transformers) bank. This static condition can occur with any primary voltage. (6)

YΔ OPEN / NEUTRAL = PRIM YES-SEC YES

WHERE USED

For supplying large single-phase 240-volt and 120/240-volt loads with small amounts of three-phase loads. (Usually transformers of different kva sizes are used.) Also used for emergency operation when one unit of a four-wire, wye-delta bank is disabled. (5)

OPEN Y-DELTA

When operating Y-delta and one phase is disabled, service may be maintained at reduced load as shown. The neutral in this case must be connected to the neutral of the step-up bank through a copper conductor. The system is unbalance, electro-statically and electro-magnetically, so that telephone interference may be expected if the neutral is connected to ground. The useful capacity of the open Y-delta bank is 87 percent of the capacity of the installed transformers when the two units are identical. The capacity is 57 percent of a three transformer bank. (3)

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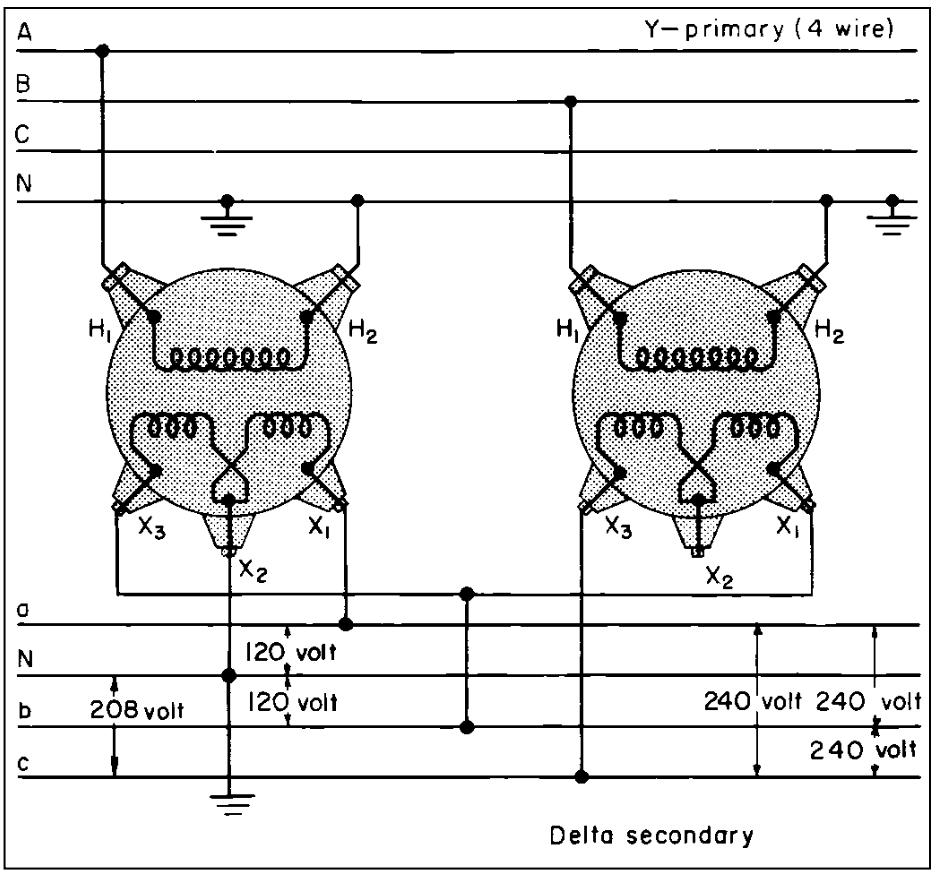
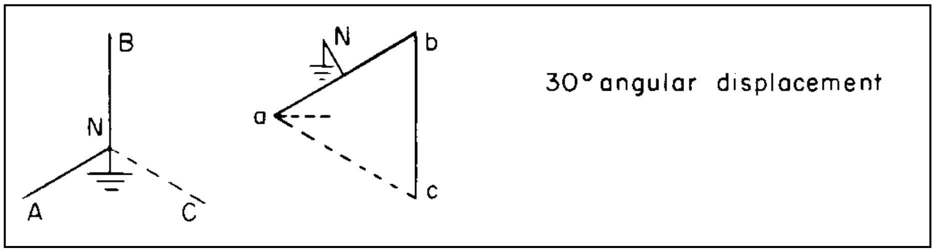


(5)



(5)

BANK RATING

This connection is relatively inefficient where three-phase loads predominate since it has only 86.6% of the rating of the two units making up the three-phase bank. It also has only 57.7% of the three-phase rating of a closed delta-delta bank of three units. (5)

HIGH-LEG MARKING

NEC 2002: 110.15 High-Leg Marking.
On a 4-wire, delta-connected system where the midpoint of one phase winding is grounded to supply lighting and similar loads, the conductor or busbar having the higher phase voltage to ground shall be durably and permanently marked by an outer finish that is orange in color or by other effective means. Such identification shall be placed at each point on the system where a connection is made if the grounded conductor is also present. (9)

NEC 2002 Handbook:
Added for the 2002 Code, this section now contains a requirement that appeared in 384-3(e) of the 1999 NEC. This requirement was moved to Article 110, where the application becomes a more general requirement.

The high leg is common on a 240/120-volt 3-phase, 4-wire delta system. It is typically designated as "B phase." The high-leg marking is required to be the color orange or other similar effective means and is intended to prevent problems due to the lack of complete standardization where metered and non-metered equipment are installed in the same installation. Electricians should always test each phase relative to ground with suitable equipment to determine exactly where the high leg is located in the system. (12)

ARRANGEMENT OF BUSBARS AND CONDUCTORS

NEC 2002: 408.3 / Support and Arrangement of Busbars and Conductors / (E) Phase Arrangement
The phase arrangement on 3-phase buses shall be A, B, C from front to back, top to bottom, or left to right, as viewed from the front of the switchboard or panelboard. The B phase shall be that phase having the higher voltage to ground on 3-phase, 4-wire, delta-connected systems. Other busbar arrangements shall be permitted for additions to existing installations and shall be marked.

Exception: Equipment within the same single section or multisection switchboard or panelboard as the meter on 3-phase, 4-wire, delta-connected systems shall be permitted to have the same phase configuration as the metering equipment.

FPN: See 110.15 for requirements on marking the busbar or phase conductor having the higher voltage to ground where supplied from a 4-wire, delta-connected system. (9)

NEC 2002 Handbook:
The high leg is common on a 240/120-volt, 3-phase, 4-wire delta system. It is typically designated as "B phase." Section 110.15 requires the high-leg marking to be the color orange or other similar effective means of identification. Electricians should always test each phase to ground with suitable equipment in order to know exactly where this high leg is located in the system.

The exception to 408.3(E) permits the phase leg having the higher voltage to ground to be located at the right-hand position (C phase), making it unnecessary to transpose the panelboard or switchboard busbar arrangement ahead of and beyond a metering compartment. The exception recognizes the fact that metering compartments have been standardized with the high leg at the right position (C phase) rather than in the center on B phase.

See also 110.15, 215.8, and 230.56 for further information on identifying conductors with the higher voltage to ground. Other busbar arrangements for making additions to existing installations are permitted by 408.3(E). (12)

WYE-WYE OPEN

YY OPEN / NEUTRAL =

WHERE USED

An open wye-wye is not an operative connection. A disabled transformer on a closed wye-wye bank renders the bank inoperative. (6)

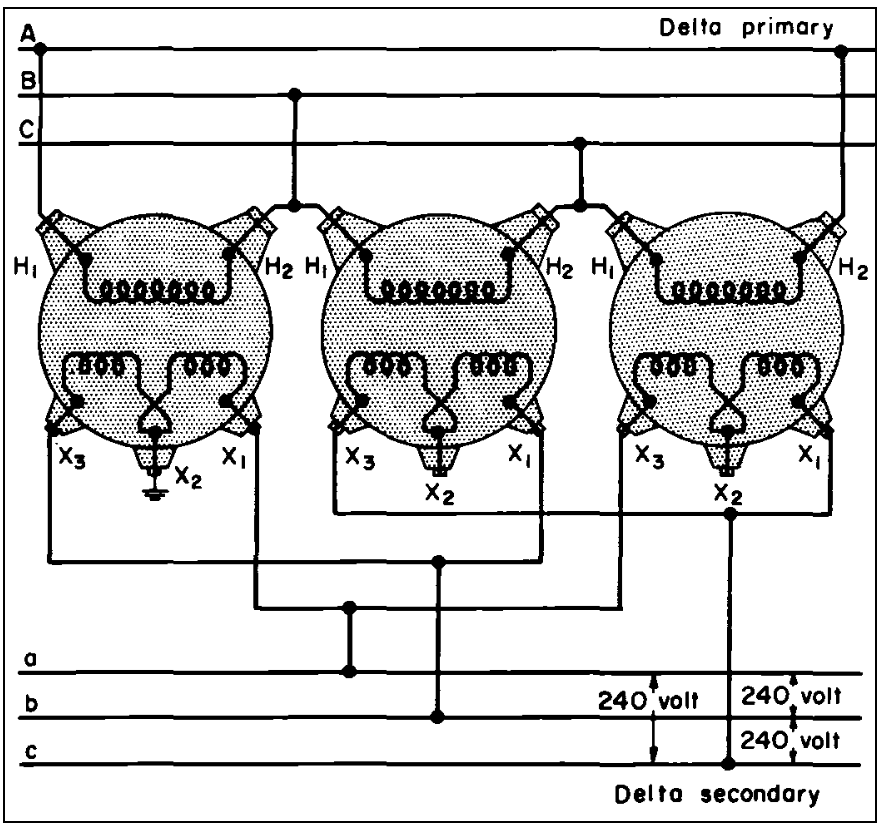
DELTA-DELTA CLOSED

ΔΔ CLOSED / NEUTRAL = PRIM NO-SEC NO

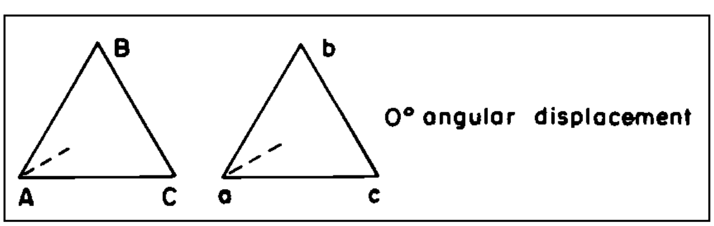
WHERE USED

To supply three-phase loads with good utilization of transformers (full nameplate kva is available). No problem from third harmonic overvoltage or telephone interference. With a disabled unit, bank can be reconnected in open-delta for emergency service, in which case the rating of the bank will be 57.7% of the original bank rating. If a ground is required, it may be placed on either an X1 or an X_2 bushing as shown. (5)

DIAGRAM



(5)



CAUTION

High circulating currents will result unless all units are connected on same regulating taps and have same voltage ratios. Bank output is reduced unless matching impedance transformers are used. (5)

IMPEDANCE

When three transformers are operated in a closed-delta bank, care should be taken to make certain the impedances of the three units are practically the same. Transformers having more than 10% difference in impedance rating should not be operated together in a closed-delta bank unless a reactor is used to increase the impedance of the unit having the lower impedance rating to a value equal to the other units. If the voltage ratio of all three of the transformers is not the same, there will be a voltage tending to circulate current inside the delta. The current will be limited by the impedance of the three transformers considered as a series circuit.

It is a good practice, before applying voltage to three transformers in closed delta, to insert a fuse wire between the leads coming from the high-voltage bushings of two transformers closing the delta bank. The fuse wire should be of sufficient size to carry the exciting current of the transformers. The use of this fuse wire offers a very simple means of making certain the transformers have the proper polarity.

This connection should not be used with CSP transformers if used to supply a combined three-phase and three-wire single-phase load due to unequal voltage division of single-phase load when the tapped transformer breaker is opened. (2)

ΔΔ CLOSED / NEUTRAL = PRIM NO-SEC YES

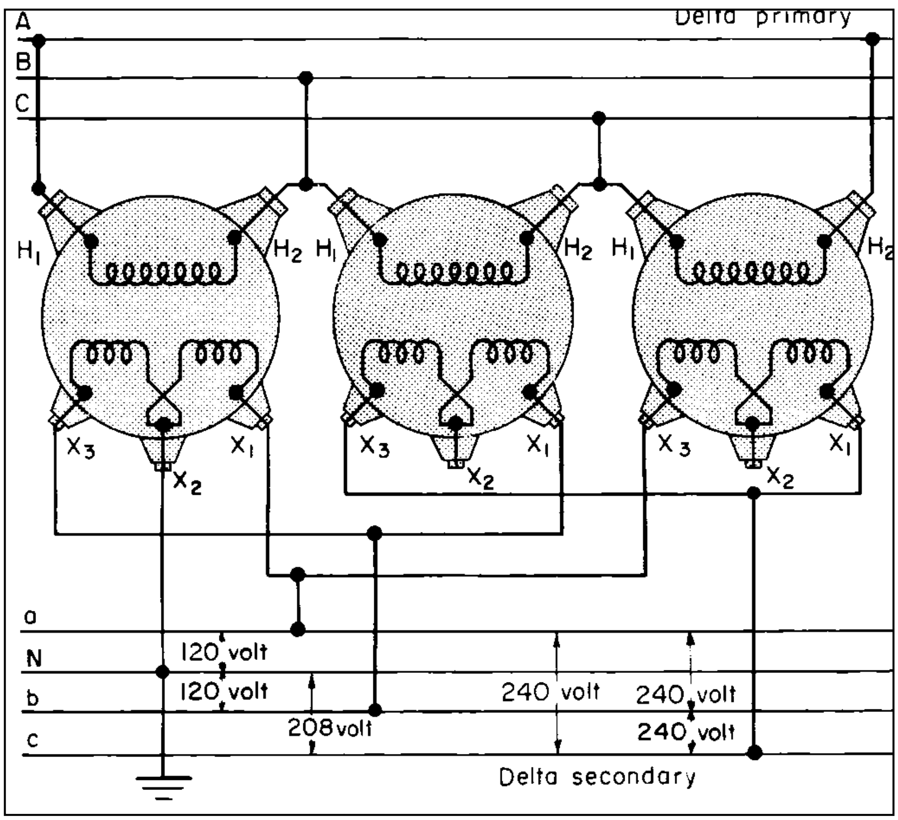
WHERE USED

For supplying three-phase, 240-volt loads with small amounts of 120/240-volt, single-phase load. No problem from third harmonic overvoltage or telephone interference. With a disabled unit, bank can be reconnected in open-delta for emergency service. (5)

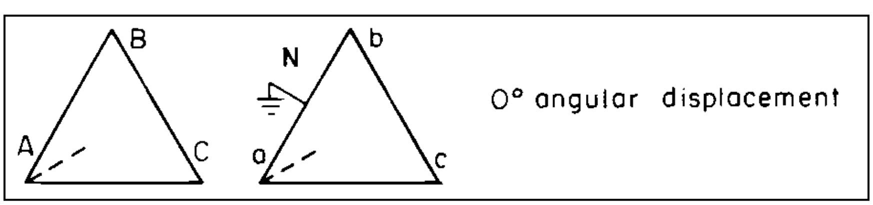
DELTA-DELTA FOR LIGHTING AND POWER

This connection is often used to supply a small single-phase lighting load and three-phase power load simultaneously. As shown is diagram, the mid-tap of the secondary of one transformer is grounded. Thus, the small lighting load is connected across the transformer with the mid-tap and the ground wire common to both 120 volt circuits. The single-phase lighting load reduces the available three-phase capacity. This connection requires special watt-hour metering and is not available from all utilities. (3)

DIAGRAM



(5)



(5)

BANK RATING

The transformer with the mid-tap carries 2/3 of the 120/240-volt, single-phase load and 1/3 of the 240-volt, three-phase load. The other two units each carry 1/3 of both the 120/240- and 240-volt loads. (5)

CAUTION

High circulating currents will result unless all units are connected on same regulating taps and have same voltage ratios. Bank rating is reduced unless matching impedance transformers are used. The secondary neutral bushing can be grounded on *only one* of the three transformers. (5)

IMPEDANCE

When three transformers are operated in a closed-delta bank, care should be taken to make certain the impedances of the three units are practically the same. Transformers having more than 10% difference in impedance rating should not be operated together in a closed-delta bank unless a reactor is used to increase the impedance of the unit having the lower impedance rating to a value equal to the other units. If the voltage ratio of all three of the transformers is not the same, there will be a voltage tending to circulate current inside the delta. The current will be limited by the impedance of the three transformers considered as a series circuit.

It is a good practice, before applying voltage to three transformers in closed delta, to insert a fuse wire between the leads coming from the high-voltage bushings of two transformers closing the delta bank. The fuse wire should be of sufficient size to carry the exciting current of the transformers. The use of this fuse wire offers a very simple means of making certain the transformers have the proper polarity.

This connection should not be used with CSP transformers if used to supply a combined three-phase and three-wire single-phase load due to unequal voltage division of single-phase load when the tapped transformer breaker is opened. (2)

HIGH-LEG MARKING

NEC 2002: 110.15 High-Leg Marking.
On a 4-wire, delta-connected system where the midpoint of one phase winding is grounded to supply lighting and similar loads, the conductor or busbar having the higher phase voltage to ground shall be durably and permanently marked by an outer finish that is orange in color or by other effective means. Such identification shall be placed at each point on the system where a connection is made if the grounded conductor is also present. (9)

NEC 2002 Handbook:
Added for the 2002 Code, this section now contains a requirement that appeared in 384-3(e) of the 1999 NEC. This requirement was moved to Article 110, where the application becomes a more general requirement.

The high leg is common on a 240/120-volt 3-phase, 4-wire delta system. It is typically designated as “B phase.” The high-leg marking is required to be the color orange or other similar effective means and is intended to prevent problems due to the lack of complete standardization where metered and non-metered equipment are installed in the same installation. Electricians should always test each phase relative to ground with suitable equipment to determine exactly where the high leg is located in the system. (12)

ARRANGEMENT OF BUSBARS AND CONDUCTORS

NEC 2002: 408.3 / Support and Arrangement of Busbars and Conductors / (E) Phase Arrangement
The phase arrangement on 3-phase buses shall be A, B, C from front to back, top to bottom, or left to right, as viewed from the front of the switchboard or panelboard. The B phase shall be that phase having the higher voltage to ground on 3-phase, 4-wire, delta-connected systems. Other busbar arrangements shall be permitted for additions to existing installations and shall be marked.

Exception: Equipment within the same single section or multisection switchboard or panelboard as the meter on 3-phase, 4-wire, delta-connected systems shall be permitted to have the same phase configuration as the metering equipment.

FPN: See 110.15 for requirements on marking the busbar or phase conductor having the higher voltage to ground where supplied from a 4-wire, delta-connected system. (9)

NEC 2002 Handbook:
The high leg is common on a 240/120-volt, 3-phase, 4-wire delta system. It is typically designated as "B phase." Section 110.15 requires the high-leg marking to be the color orange or other similar effective means of identification. Electricians should always test each phase to ground with suitable equipment in order to know exactly where this high leg is located in the system.

The exception to 408.3(E) permits the phase leg having the higher voltage to ground to be located at the right-hand position (C phase), making it unnecessary to transpose the panelboard or switchboard busbar arrangement ahead of and beyond a metering compartment. The exception recognizes the fact that metering compartments have been standardized with the high leg at the right position (C phase) rather than in the center on B phase.

See also 110.15, 215.8, and 230.56 for further information on identifying conductors with the higher voltage to ground. Other busbar arrangements for making additions to existing installations are permitted by 408.3(E). (12)

DELTA-WYE CLOSED

ΔY CLOSED / NEUTRAL = PRIM NO-SEC YES

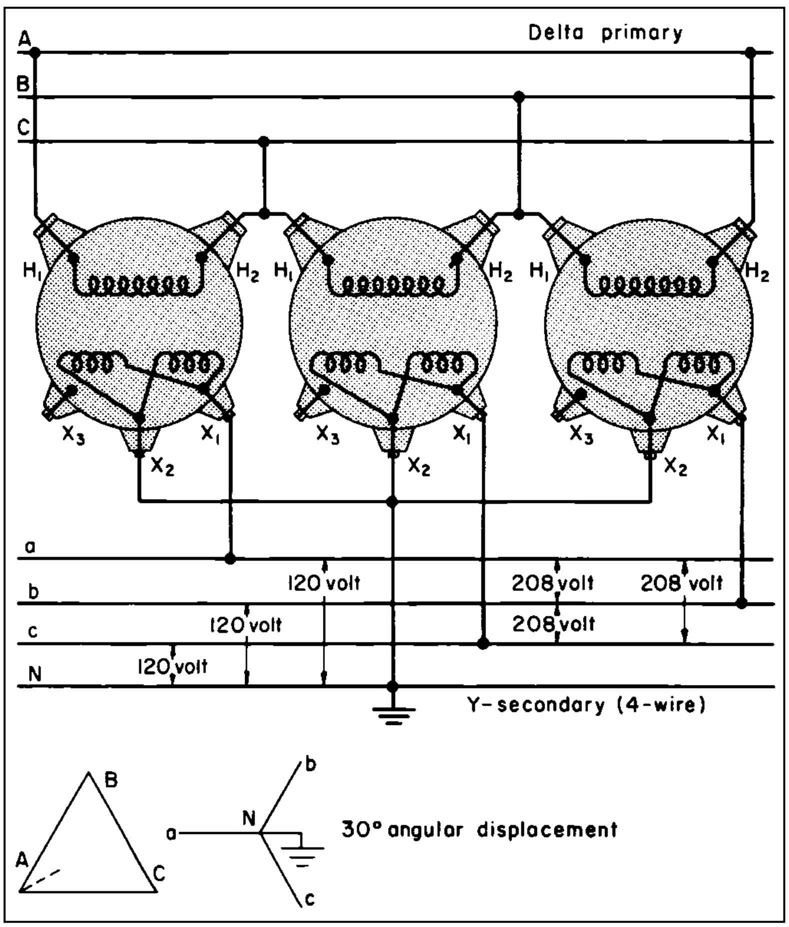
WHERE USED

To supply 208 volts and 120 volts on systems where both can be taken from all three phases. The connection permits balancing single-phase loads among the three phases. (5)

DELTA-WYE FOR LIGHTING AND POWER

In the previous banks the single-phase lighting load is all on one phase, resulting in unbalanced primary currents in any one bank. To eliminate this difficulty, the delta-Y system finds many uses. Here the neutral of the secondary three-phase system is grounded, and the single-phase loads are connected between the different phase wires and the neutral, while the three-phase loads are connected to the phase wires. Thus, the single-phase load can be balanced on three phases in each bank, and banks may be paralleled if desired. (3)

DIAGRAM



(5)

BANK RATING

When units of different kva's are used, maximum safe bank rating is three times the kva of the smallest unit. A disabled transformer renders the bank inoperative. (5)

IMPEDANCE

With a delta-wye grounded connection, a combination of single and three-phase loads may be connected. This is the most common connection used to obtain a grounded secondary system. A grounded system is readily relayed for phase-to-ground faults and the problem of high transients due to arcing grounds is minimized.

It is not necessary that the impedance of each unit in the bank be the same. A combination of single and three-phase loads may be connected without causing any circulating currents. (2)

ΔY CLOSED / NEUTRAL = PRIM NO-SEC NO

WHERE USED

A delta-wye configuration with the wye secondary isolated is an operative configuration but impractical. With the secondary floating the load applied must be perfectly balanced. If the secondary load is imbalanced the transformers would become unstable. This configuration should be avoided in favor of a delta-wye with the secondary wye solidly grounded. (6)

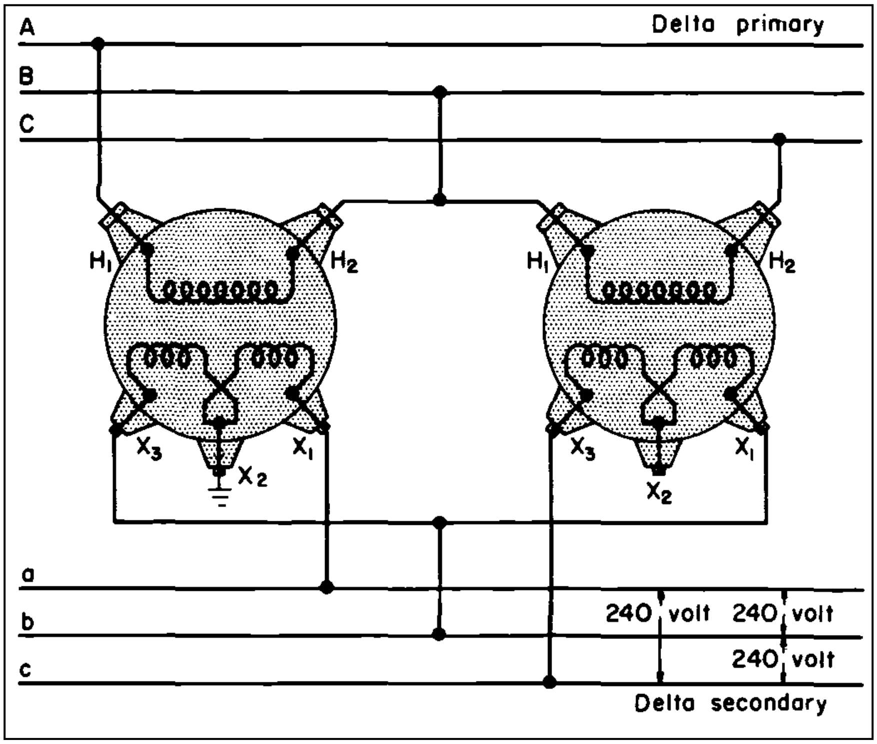
DELTA-DELTA OPEN

ΔΔ OPEN / NEUTRAL = PRIM NO-SEC NO

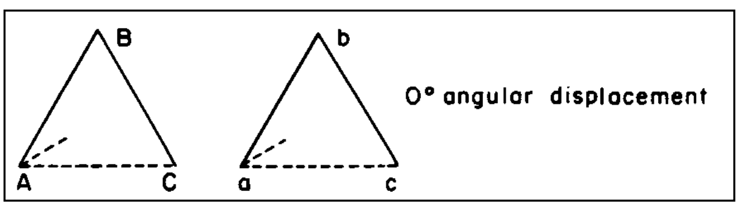
WHERE USED

To supply large single-phase power loads with small amounts of three-phase loads. (Usually transformers of different kva sizes are used.) Also used for emergency operation when one unit of a delta-delta bank is disabled. If a ground is required, it may be placed on either an X1 or an X_2 bushing as shown. (5)

DIAGRAM



(5)



BANK RATING

The connection is relatively inefficient where three-phase loads predominate since it has only 86.6 % of the rating of the two units making up the three-phase bank. It also has only 57.7% of the three-phase rating of a closed delta-delta bank of three units. (5)

IMPEDANCE & DE-RATING

In this connection, the units will transform 86.6% of their rating, that is, two 100-kva units connected open delta will each transform 86.6 kva or a total of 173.2 kva. This is the case because the line currents must equal the winding currents; therefore, the bank rating is reduced by the ratio of normal transformer current to normal line current (1/1.73) or 57.7%. The individual transformation in terms of kva is 57.7% X 3/2 = 86.6%, since three-phase voltage is delivered with only two units.

With the open-delta connection, it is not necessary for the transformers to have the same impedance.

The voltage regulation of an open-delta bank is poor and different for each phase resulting in unbalanced voltage conditions that may be detrimental to three-phase induction-motor operations. (2)

ΔΔ OPEN / NEUTRAL = PRIM NO-SEC YES

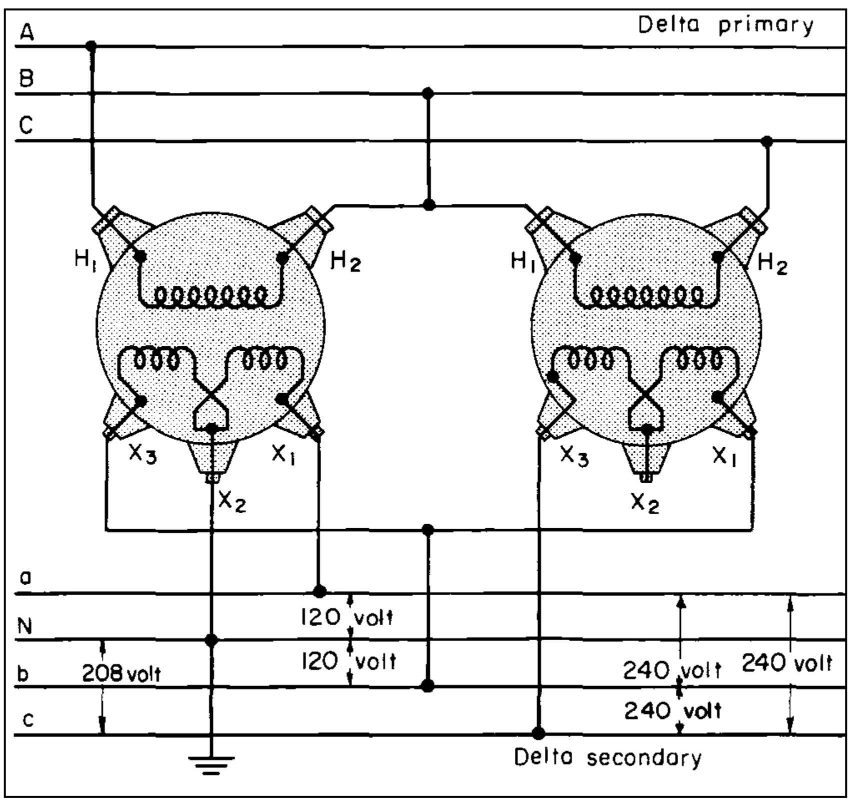
WHERE USED

To supply large 240-volt and 120-volt, single-phase loads with small amounts of three-phase load. (Usually transformers of different kva sizes are used.) Also used for emergency operation when one unit of a bank is disabled. (5)

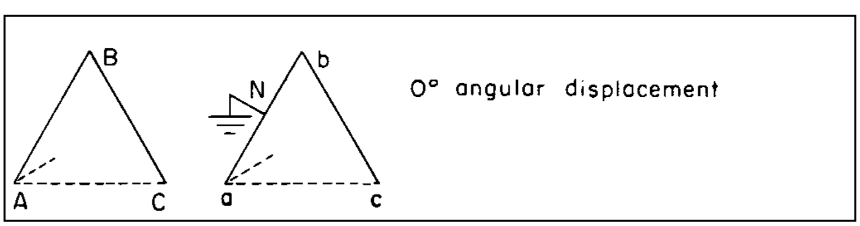
OPEN DELTA FOR LIGHTING AND POWER

Where the secondary load is a combination of single-phase lighting and three-phase power, the open-delta connected bank is frequently used. This connection is used when the single-phase lighting load is large as compared with the three-phase power load. Here two different size transformers may be used with the lighting load connected across the larger rated unit. The useful capacity of the open-delta bank is 87 percent of the capacity of the installed units when the transformers are identical. The capacity is 57 percent of a three transformer bank. (3)

DIAGRAM



(5)



(5)

BANK RATING

The connection is relatively inefficient where three-phase loads predominate since it has only 86.6 % of the rating of the two units making up the three-phase bank. It also has only 57.7% of the three-phase rating of a closed delta-delta bank of three units. (5)

IMPEDANCE & DE-RATING

In this connection, the units will transform 86.6% of their rating, that is, two 100-kva units connected open delta will each transform 86.6 kva or a total of 173.2 kva. This is the case because the line currents must equal the winding currents; therefore, the bank rating is reduced by the ratio of normal transformer current to normal line current (1/1.73) or 57.7%. The individual transformation in terms of kva is 57.7% X 3/2 = 86.6%, since three-phase voltage is delivered with only two units.

With the open-delta connection, it is not necessary for the transformers to have the same impedance.

The voltage regulation of an open-delta bank is poor and different for each phase resulting in unbalanced voltage conditions that may be detrimental to three-phase induction-motor operations. (2)

HIGH-LEG MARKING

NEC 2002: 110.15 High-Leg Marking.
On a 4-wire, delta-connected system where the midpoint of one phase winding is grounded to supply lighting and similar loads, the conductor or busbar having the higher phase voltage to ground shall be durably and permanently marked by an outer finish that is orange in color or by other effective means. Such identification shall be placed at each point on the system where a connection is made if the grounded conductor is also present. (9)

NEC 2002 Handbook:
Added for the 2002 Code, this section now contains a requirement that appeared in 384-3(e) of the 1999 NEC. This requirement was moved to Article 110, where the application becomes a more general requirement.

The high leg is common on a 240/120-volt 3-phase, 4-wire delta system. It is typically designated as “B phase.” The high-leg marking is required to be the color orange or other similar effective means and is intended to prevent problems due to the lack of complete standardization where metered and non-metered equipment are installed in the same installation. Electricians should always test each phase relative to ground with suitable equipment to determine exactly where the high leg is located in the system. (12)

ARRANGEMENT OF BUSBARS AND CONDUCTORS

NEC 2002: 408.3 / Support and Arrangement of Busbars and Conductors / (E) Phase Arrangement
The phase arrangement on 3-phase buses shall be A, B, C from front to back, top to bottom, or left to right, as viewed from the front of the switchboard or panelboard. The B phase shall be that phase having the higher voltage to ground on 3-phase, 4-wire, delta-

connected systems. Other busbar arrangements shall be permitted for additions to existing installations and shall be marked.

Exception: Equipment within the same single section or multisection switchboard or panelboard as the meter on 3-phase, 4-wire, delta-connected systems shall be permitted to have the same phase configuration as the metering equipment.

FPN: See 110.15 for requirements on marking the busbar or phase conductor having the higher voltage to ground where supplied from a 4-wire, delta-connected system. (9)

NEC 2002 Handbook:
The high leg is common on a 240/120-volt, 3-phase, 4-wire delta system. It is typically designated as “B phase.” Section 110.15 requires the high-leg marking to be the color orange or other similar effective means of identification. Electricians should always test each phase to ground with suitable equipment in order to know exactly where this high leg is located in the system.

The exception to 408.3(E) permits the phase leg having the higher voltage to ground to be located at the right-hand position (C phase), making it unnecessary to transpose the panelboard or switchboard busbar arrangement ahead of and beyond a metering compartment. The exception recognizes the fact that metering compartments have been standardized with the high leg at the right position (C phase) rather than in the center on B phase.

See also 110.15, 215.8, and 230.56 for further information on identifying conductors with the higher voltage to ground. Other busbar arrangements for making additions to existing installations are permitted by 408.3(E). (12)

DELTA-WYE OPEN

ΔY OPEN / NEUTRAL =

WHERE USED

An open delta-wye is not an operative connection. A disabled transformer on a closed delta-wye bank renders the bank inoperative. (6)

CHAPTER II THREE-PHASE TRANSFORMERS

WYE-DELTA CLOSED

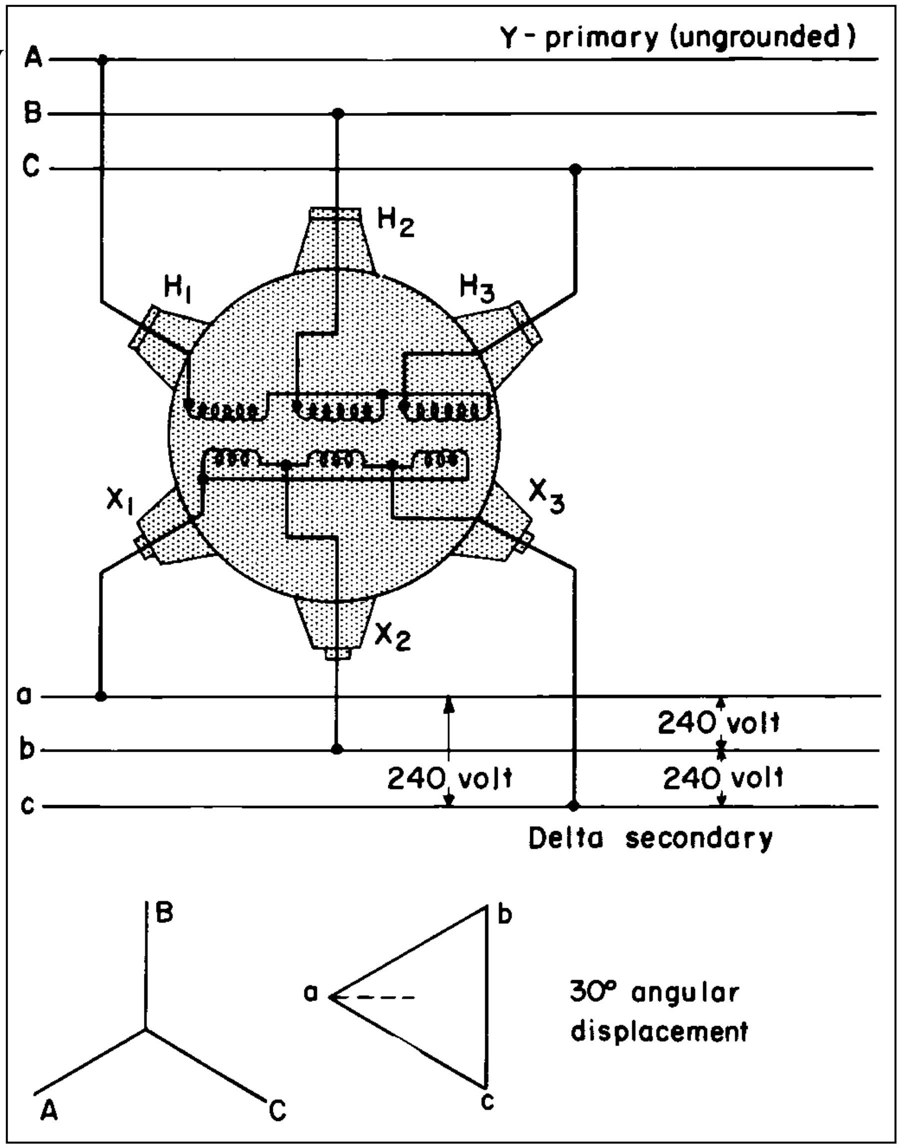
YΔ CLOSED / NEUTRAL = PRIM NO-SEC NO

WHERE USED

To supply three-phase loads. No problem from third harmonic over-voltage or telephone interference. (5)

DIAGRAM

3-wire "V
Primary



(5)

STATIC DISCHARGE

Potentially present on a non-grounded primary wye connection. A high, excessive voltage results on a 3-phase Y-Δ connection on the secondary line to ground when one leg of the primary is open. The voltage present is static with no power and bleeds off when taken to ground. This static can damage a volt-ohm meter. The static is greater when the secondary feeder is short and lesser when the secondary feeder is long. The static problem is resolved by grounding one phase or the center tap of one transformer on the secondary side, but this usually requires special KWH metering. This static condition is present only when a primary line is open, not the secondary. This static condition can occur on an open (2-transformers) or closed (3-transformers) bank. This static condition can occur with any primary voltage. (6)

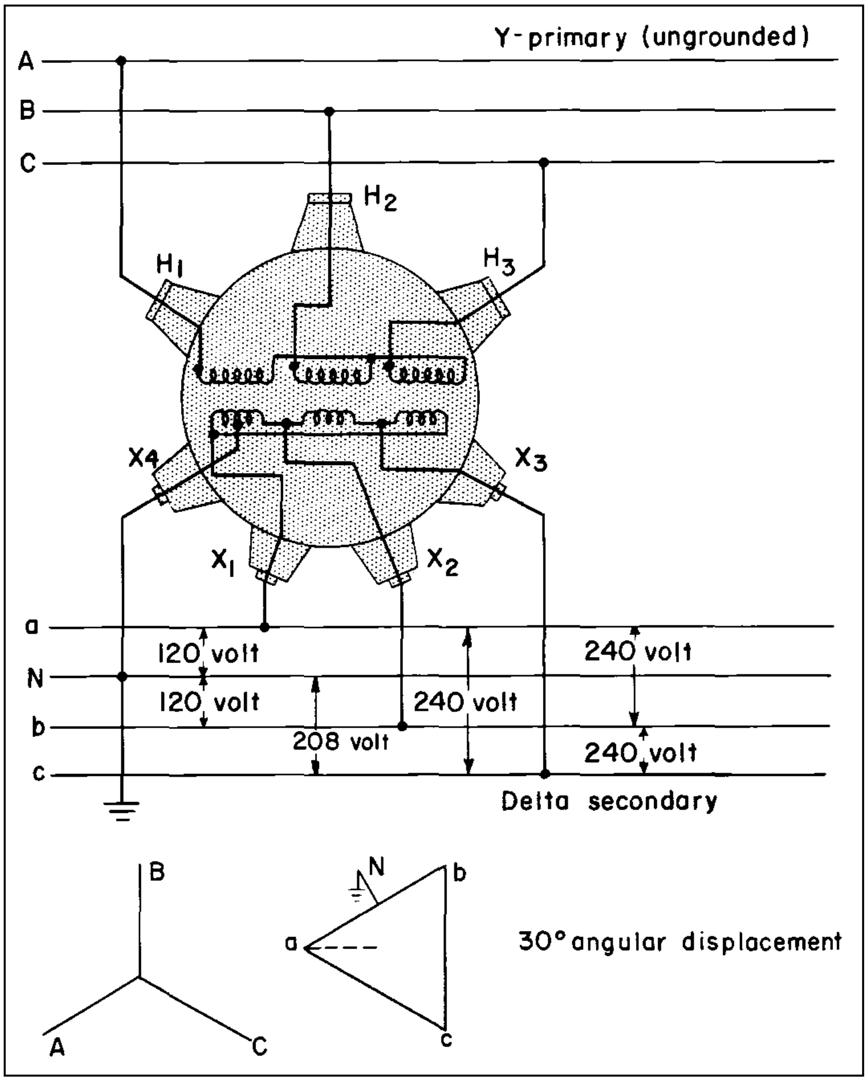
YΔ CLOSED / NEUTRAL = PRIM NO-SEC YES

WHERE USED

For supplying three-phase, 240-volt loads with small amounts of 120-volt, single-phase loads. Transformers 150 kva and smaller, 95 KV BIL and below, have a 120-volt reduced kva lighting tap with 5% of transformer rated kva available. When 5% of the rated kva of the transformer is taken from the 120-volt tap on the 240-volt connection, the three-phase capacity is reduced by 25%. If the three-phase transformer secondary is 480 volts and 5% of the rated kva of the transformer is taken from the 120-volt tap on the 480-volt connection, the three-phase capacity is reduced by 55%. No problem from third harmonic over-voltage or telephone interference. (5)

DIAGRAM

3-wire "V" Primary



(5)

NOTE

Provided with a 120-volt reduced kva tap (5)

HIGH-LEG MARKING

NEC 2002: 110.15 High-Leg Marking.
On a 4-wire, delta-connected system where the midpoint of one phase winding is grounded to supply lighting and similar loads, the conductor or busbar having the higher phase voltage to ground shall be durably and permanently marked by an outer finish that is orange in color or by other effective means. Such identification shall be placed at each point on the system where a connection is made if the grounded conductor is also present. (9)

NEC 2002 Handbook:
Added for the 2002 Code, this section now contains a requirement that appeared in 384-3(e) of the 1999 NEC. This requirement was moved to Article 110, where the application becomes a more general requirement.

The high leg is common on a 240/120-volt 3-phase, 4-wire delta system. It is typically designated as “B phase.” The high-leg marking is required to be the color orange or other similar effective means and is intended to prevent problems due to the lack of complete standardization where metered and non-metered equipment are installed in the same installation. Electricians should always test each phase relative to ground with suitable equipment to determine exactly where the high leg is located in the system. (12)

ARRANGEMENT OF BUSBARS AND CONDUCTORS

NEC 2002: 408.3 / Support and Arrangement of Busbars and Conductors / (E) Phase Arrangement
The phase arrangement on 3-phase buses shall be A, B, C from front to back, top to bottom, or left to right, as viewed from the front of the switchboard or panelboard. The B phase shall be that phase having the higher voltage to ground on 3-phase, 4-wire, delta-connected systems. Other busbar arrangements shall be permitted for additions to existing installations and shall be marked.

Exception: Equipment within the same single section or multisection switchboard or panelboard as the meter on 3-phase, 4-wire, delta-connected systems shall be permitted to have the same phase configuration as the metering equipment.

FPN: See 110.15 for requirements on marking the busbar or phase conductor having the higher voltage to ground where supplied from a 4-wire, delta-connected system. (9)

NEC 2002 Handbook:
The high leg is common on a 240/120-volt, 3-phase, 4-wire delta system. It is typically designated as “B phase.” Section 110.15 requires the high-leg marking to be the color orange or other similar effective means of identification. Electricians should always test each phase to ground with suitable equipment in order to know exactly where this high leg is located in the system.

The exception to 408.3(E) permits the phase leg having the higher voltage to ground to be located at the right-hand position (C phase), making it unnecessary to transpose the panelboard or switchboard busbar arrangement ahead of and beyond a metering compartment. The exception recognizes the fact that metering compartments have been

standardized with the high leg at the right position (C phase) rather than in the center on B phase.

See also 110.15, 215.8, and 230.56 for further information on identifying conductors with the higher voltage to ground. Other busbar arrangements for making additions to existing installations are permitted by 408.3(E). (12)

WYE-WYE CLOSED

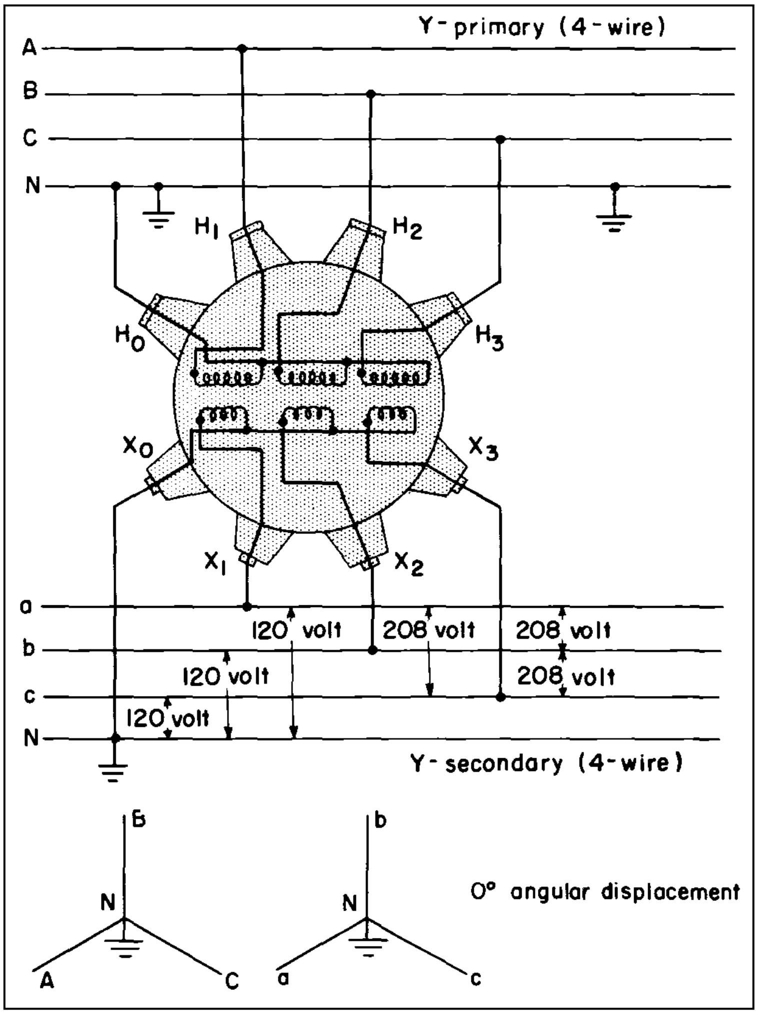
YY CLOSED / NEUTRAL = PRIM YES-SEC YES

WHERE USED

To supply 208 volts and 120 volts on systems where both can be taken from all three phases. The connection permits balancing single-phase loads among the three phases. (5)

DIAGRAM

4-wire Grounded-y Primary



(5)

CAUTION

The primary neutral should be tied firmly to the system neutral; otherwise, excessive voltages may develop on the secondary side.

This transformer, if of the three-legged, three-phase core type, should not be used in applications subject to sustained phase-to-ground faults, unbalanced loadings, loss of one primary phase or other unbalanced conditions. This is because the magnetic characteristics of the transformer will permit current to circulate in the tank under certain operating or fault conditions which causes tank heating. (5)

WYE-DELTA OPEN

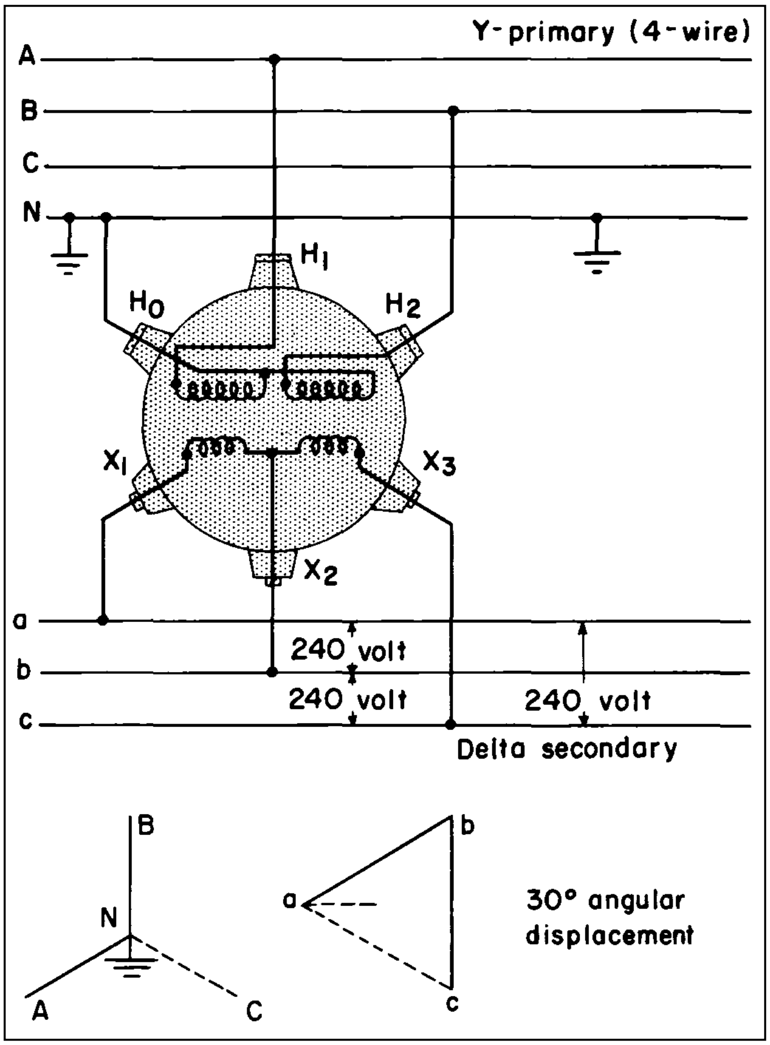
YΔ OPEN / NEUTRAL = PRIM YES-SEC NO

WHERE USED

To supply large single-phase, 240-volt loads simultaneously with small amounts of three-phase loads. Usually, the two sets of windings in the transformer are of different kva size. (5)

DIAGRAM

Four-wire Grounded Y Primary



(5)

TRANSFORMER RATING

Where three-phase loads predominate, the transformer is relatively inefficient. For three-phase loads, the transformer *is* rated only 86.6% of the rating of the two sets of windings when they are equal in size and less than this when unequal. (5)

STATIC DISCHARGE

Potentially present on a non-grounded primary wye connection. A high, excessive voltage results on a 3-phase Y-Δ connection on the secondary line to ground when one leg of the primary is open. The voltage present is static with no power and bleeds off when taken to ground. This static can damage a volt-ohm meter. The static is greater when the secondary feeder is short and lesser when the secondary feeder is long. The static problem is resolved by grounding one phase or the center tap of one transformer on the secondary side, but this usually requires special KWH metering. This static condition is present only when a primary line is open, not the secondary. This static condition can occur on an open (2-transformers) or closed (3-transformers) bank. This static condition can occur with any primary voltage. (6)

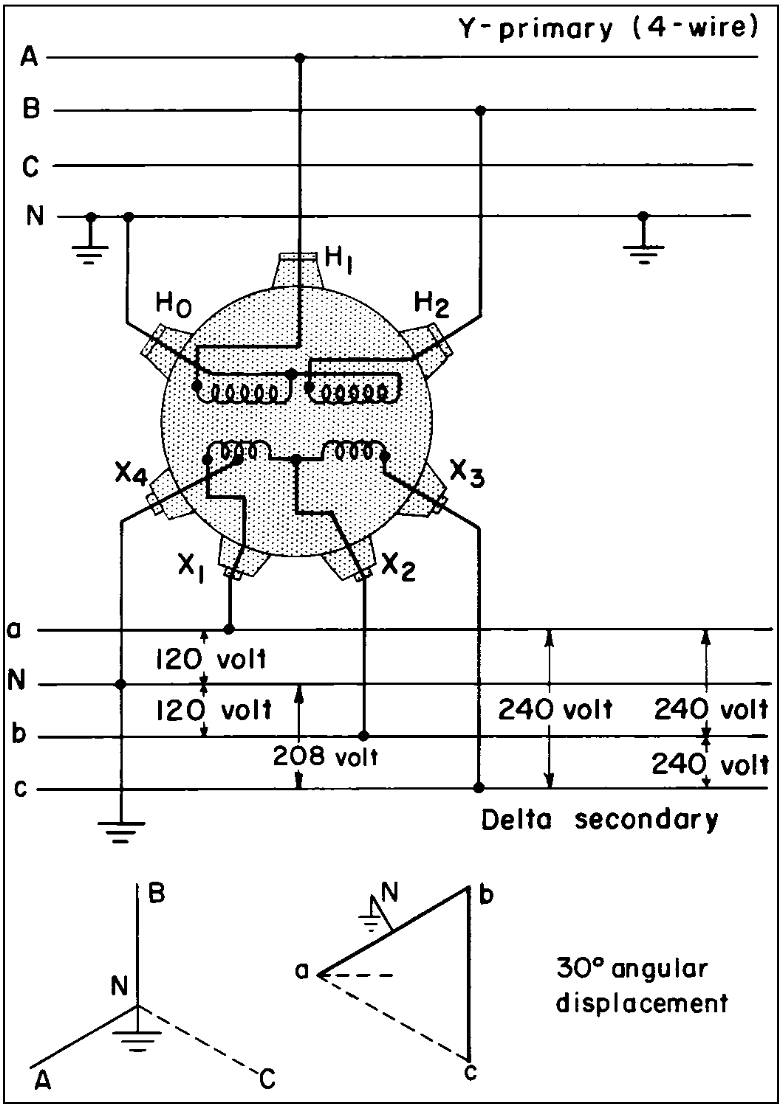
YΔ OPEN / NEUTRAL = PRIM YES-SEC YES

WHERE USED

To supply large 240-volt and 120-volt, single-phase loads simultaneously with small amounts of three-phase load. Usually, the two sets of windings in the transformer are of different kva size. (5)

DIAGRAM

4-wire Grounded-Y Primary



(5)

TRANSFORMER RATING

Where three-phase loads predominate, the transformer is relatively inefficient. For three-phase loads, the transformer is rated only 86.6% of the rating of the two sets of windings when they are equal in size and less than this when unequal. (5)

HIGH-LEG MARKING

NEC 2002: 110.15 High-Leg Marking.
On a 4-wire, delta-connected system where the midpoint of one phase winding is grounded to supply lighting and similar loads, the conductor or busbar having the higher phase voltage to ground shall be durably and permanently marked by an outer finish that is orange in color or by other effective means. Such identification shall be placed at each point on the system where a connection is made if the grounded conductor is also present. (9)

NEC 2002 Handbook:
Added for the 2002 Code, this section now contains a requirement that appeared in 384-3(e) of the 1999 NEC. This requirement was moved to Article 110, where the application becomes a more general requirement.

The high leg is common on a 240/120-volt 3-phase, 4-wire delta system. It is typically designated as "B phase." The high-leg marking is required to be the color orange or other similar effective means and is intended to prevent problems due to the lack of complete standardization where metered and non-metered equipment are installed in the same installation. Electricians should always test each phase relative to ground with suitable equipment to determine exactly where the high leg is located in the system. (12)

ARRANGEMENT OF BUSBARS AND CONDUCTORS

NEC 2002: 408.3 / Support and Arrangement of Busbars and Conductors / (E) Phase Arrangement
The phase arrangement on 3-phase buses shall be A, B, C from front to back, top to bottom, or left to right, as viewed from the front of the switchboard or panelboard. The B phase shall be that phase having the higher voltage to ground on 3-phase, 4-wire, delta-connected systems. Other busbar arrangements shall be permitted for additions to existing installations and shall be marked.

Exception: Equipment within the same single section or multisection switchboard or panelboard as the meter on 3-phase, 4-wire, delta-connected systems shall be permitted to have the same phase configuration as the metering equipment.

FPN: See 110.15 for requirements on marking the busbar or phase conductor having the higher voltage to ground where supplied from a 4-wire, delta-connected system. (9)

NEC 2002 Handbook:
The high leg is common on a 240/120-volt, 3-phase, 4-wire delta system. It is typically designated as "B phase." Section 110.15 requires the high-leg marking to be the color orange or other similar effective means of identification. Electricians should always test each phase to ground with suitable equipment in order to know exactly where this high leg is located in the system.

The exception to 408.3(E) permits the phase leg having the higher voltage to ground to be located at the right-hand position (C phase), making it unnecessary to transpose the panelboard or switchboard busbar arrangement ahead of and beyond a metering compartment. The exception recognizes the fact that metering compartments have been

standardized with the high leg at the right position (C phase) rather than in the center on B phase.

See also 110.15, 215.8, and 230.56 for further information on identifying conductors with the higher voltage to ground. Other busbar arrangements for making additions to existing installations are permitted by 408.3(E). (12)

DELTA-DELTA CLOSED

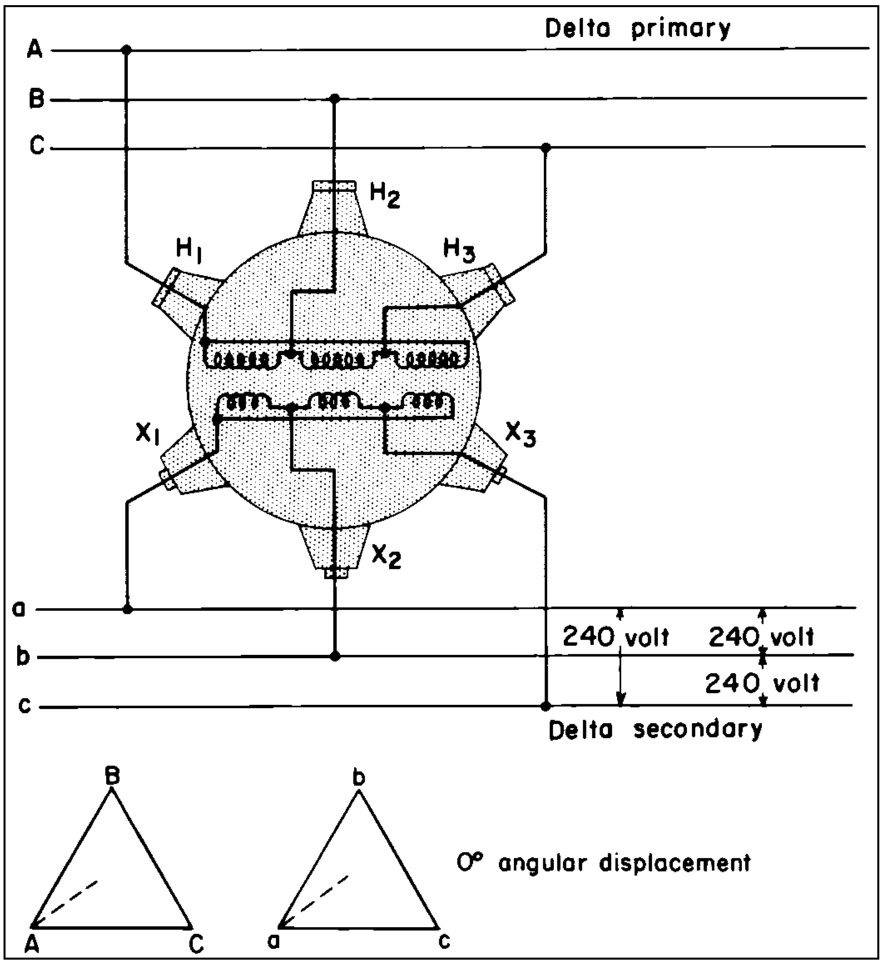
ΔΔ CLOSED / NEUTRAL = PRIM NO-SEC NO

WHERE USED

To supply three-phase loads with good utilization of transformers (full nameplate kva is available). No problem from third harmonic over-voltage or telephone interference. (5)

DIAGRAM

3-wire
Delta
Primary



(5)

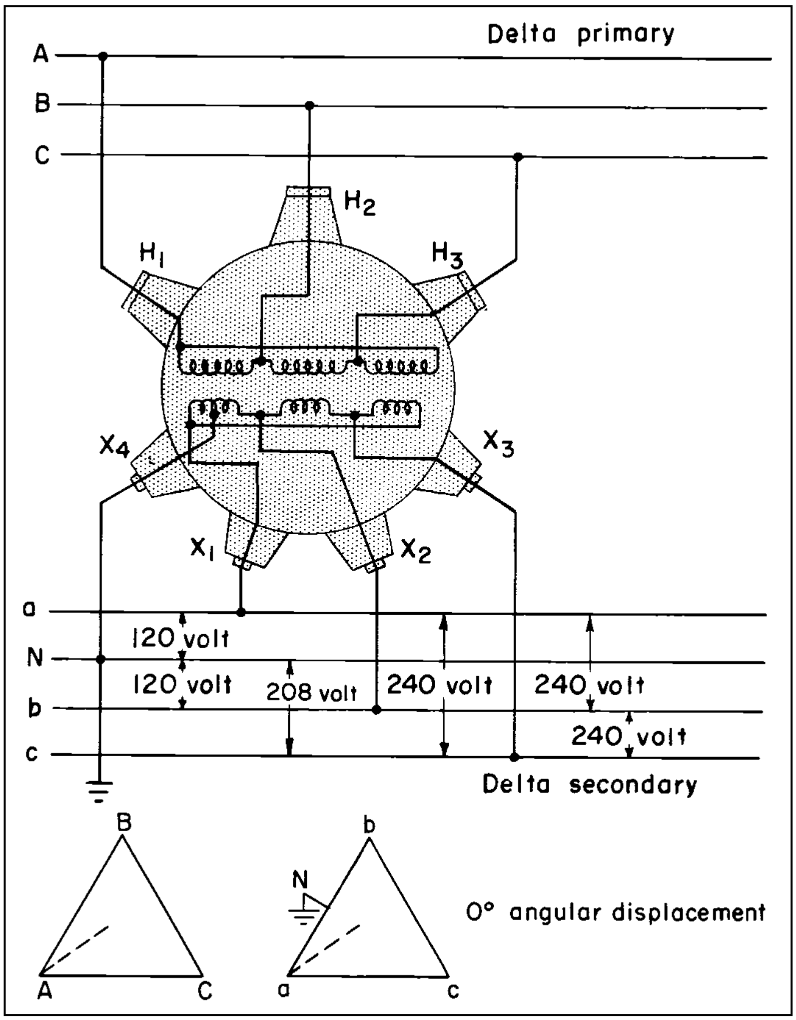
ΔΔ CLOSED / NEUTRAL = PRIM NO-SEC YES

WHERE USED

For supplying three-phase, 240-volt loads with small amounts of 120-volt, single-phase load. Transformers 150 kva and smaller, 95 KV BIL and below, have a 120-volt reduced kva lighting tap with 5% of transformer rated kva available. When 5% of the rated kva of the transformer is taken from the 120-volt tap on the 240-volt connection, the three-phase capacity is reduced by 25%. If the three-phase transformer secondary is 480 volts and 5% of the rated kva of the transformer is taken from the 120-volt tap on the 480-volt connection, the three-phase capacity is reduced by 55%. No problem from third harmonic over-voltage or telephone interference. (5)

DIAGRAM

3-wire delta Primary



(5)

PROVIDED

With a 120-volt reduced kva tap (5)

HIGH-LEG MARKING

NEC 2002: 110.15 High-Leg Marking.
On a 4-wire, delta-connected system where the midpoint of one phase winding is grounded to supply lighting and similar loads, the conductor or busbar having the higher phase voltage to ground shall be durably and permanently marked by an outer finish that is orange in color or by other effective means. Such identification shall be placed at each point on the system where a connection is made if the grounded conductor is also present. (9)

NEC 2002 Handbook:
Added for the 2002 Code, this section now contains a requirement that appeared in 384-3(e) of the 1999 NEC. This requirement was moved to Article 110, where the application becomes a more general requirement.

The high leg is common on a 240/120-volt 3-phase, 4-wire delta system. It is typically designated as "B phase." The high-leg marking is required to be the color orange or other similar effective means and is intended to prevent problems due to the lack of complete standardization where metered and non-metered equipment are installed in the same installation. Electricians should always test each phase relative to ground with suitable equipment to determine exactly where the high leg is located in the system. (12)

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Exception: Equipment within the same single section or multisection switchboard or panelboard as the meter on 3-phase, 4-wire, delta-connected systems shall be permitted to have the same phase configuration as the metering equipment.

FPN: See 110.15 for requirements on marking the busbar or phase conductor having the higher voltage to ground where supplied from a 4-wire, delta-connected system. (9)

NEC 2002 Handbook:
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DELTA-WYE CLOSED

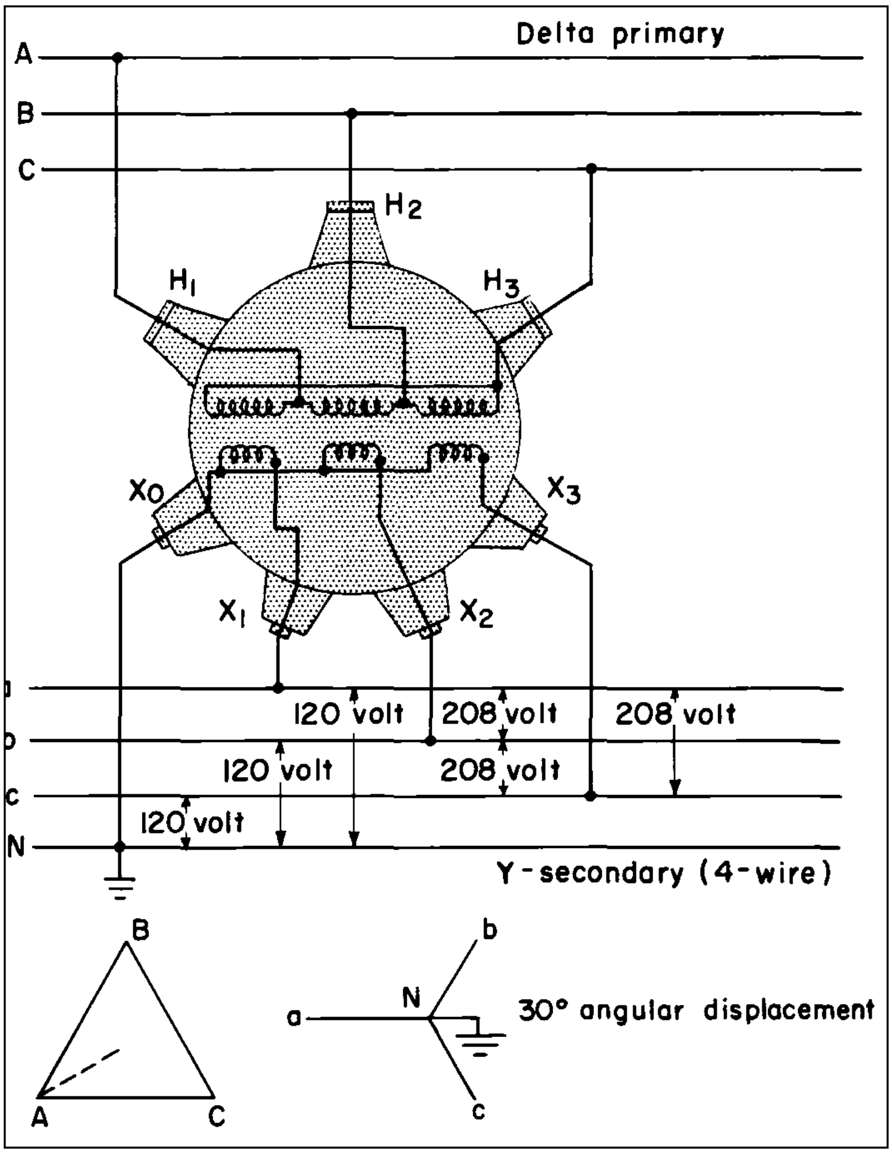
ΔY CLOSED / NEUTRAL = PRIM NO-SEC YES

WHERE USED

To supply 208 volts and 120 volts on systems where both can be taken from all three phases. The connection permits balancing single-phase loads among the three phases. (5)

DIAGRAM

3-wire
Delta
Primary



(5)

DELTA-DELTA OPEN

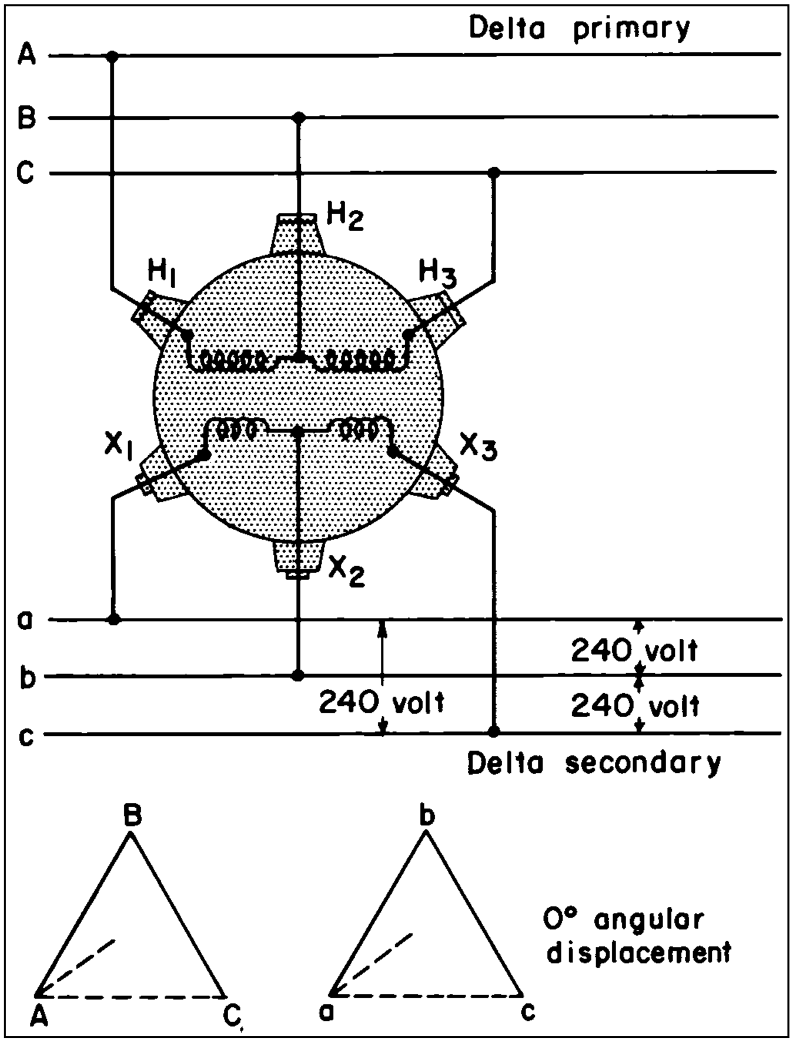
ΔΔ OPEN / NEUTRAL = PRIM NO-SEC NO

WHERE USED

To supply large single-phase power loads simultaneously with small amounts of three-phase loads. Usually, the two sets of windings in the transformer are of different kva size. (5)

DIAGRAM

3-wire
Delta primary



(5)

TRANSFORMER RATING

Where three-phase loads predominate, the transformer is relatively inefficient. For three-phase loads, the transformer is rated only 86.6% of the rating of the two sets of windings when they are equal in size and less than this when unequal. (5)

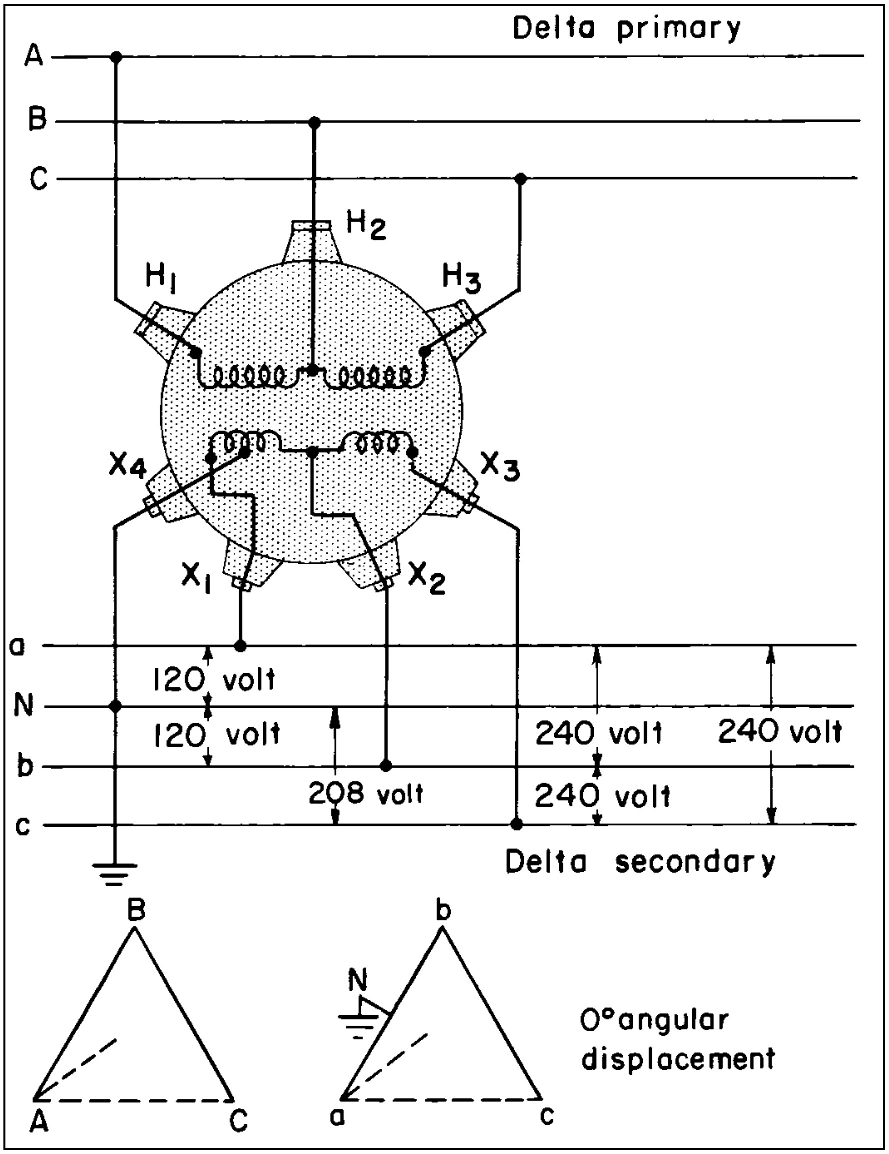
ΔΔ OPEN / NEUTRAL = PRIM NO-SEC YES

WHERE USED

To supply large 240-volt and 120-volt, single-phase loads simultaneously with small amounts of three-phase load. Usually, the two sets of windings in the transformer are of different kva size. (5)

DIAGRAM

3-wire Delta Primary



(5)

TRANSFORMER RATING

Where three-phase loads predominate, the transformer is relatively inefficient. For three-phase loads, the transformer is rated only 86.6% of the rating of the two sets of windings when they are equal in size and less than this when unequal. (5)

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FPN: See 110.15 for requirements on marking the busbar or phase conductor having the higher voltage to ground where supplied from a 4-wire, delta-connected system. (9)

NEC 2002 Handbook:
The high leg is common on a 240/120-volt, 3-phase, 4-wire delta system. It is typically designated as “B phase.” Section 110.15 requires the high-leg marking to be the color orange or other similar effective means of identification. Electricians should always test each phase to ground with suitable equipment in order to know exactly where this high leg is located in the system.

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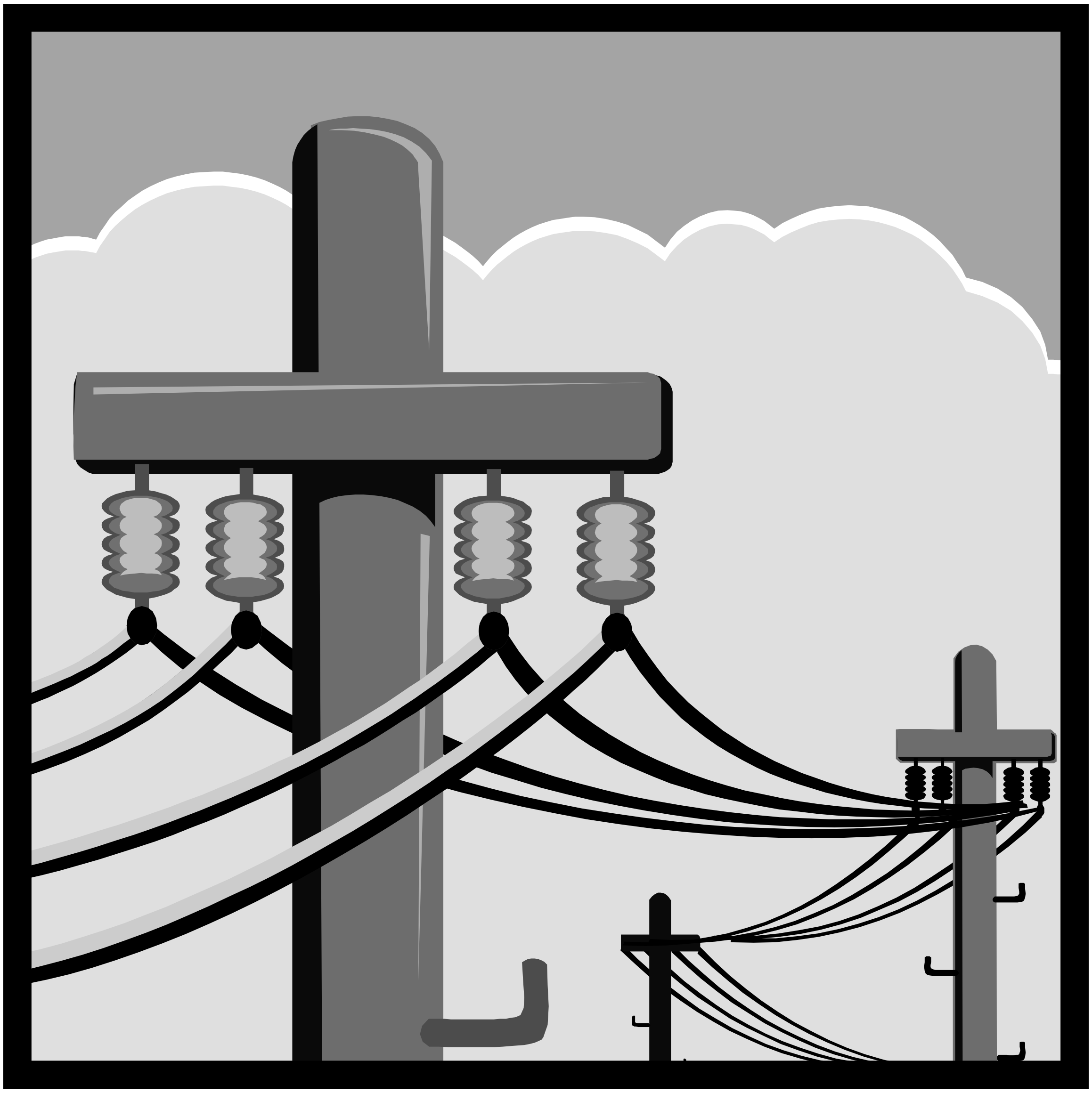
See also 110.15, 215.8, and 230.56 for further information on identifying conductors with the higher voltage to ground. Other busbar arrangements for making additions to existing installations are permitted by 408.3(E). (12)

CHAPTER III SINGLE-PHASE TRANSFORMERS



SINGLE-PHASE OPTIONS

1Ø - 120 VOLT SERVICE

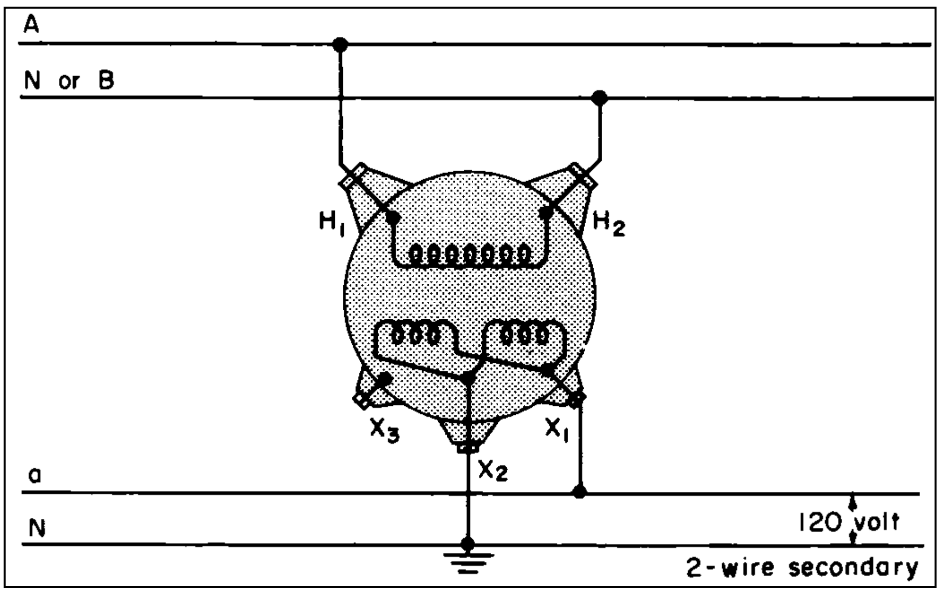
WHERE USED

For supplying customers who require 120 VAC single-phase power only. For modern homes, this connection usually is not considered adequate. (5)

1Ø - 120 VOLT LIGHTING LOAD

The transformer is connected between high voltage line and load with the 120/240-volt winding connected in parallel. This connection is used where the load is comparatively small and the length of the secondary circuit is short. It is often used for a single customer. Dotted line indicates tank is grounded. (3)

DIAGRAM



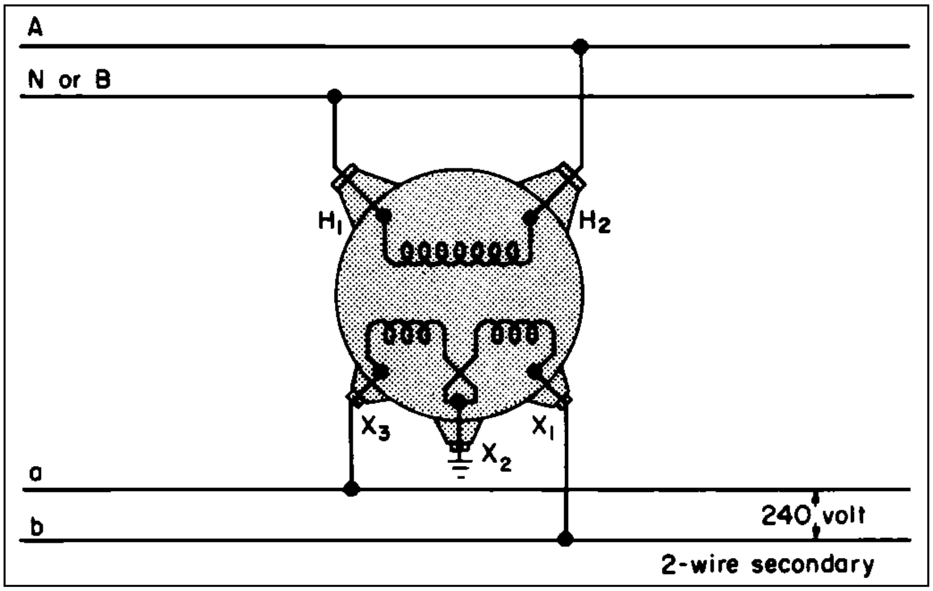
(5)

1Ø - 240 VOLT SERVICE

WHERE USED

For supplying customers who require 240 VAC single-phase power only. If a ground is required, it may be placed on the X_2 bushing as shown. (5)

DIAGRAM



(5)

1Ø - 120/240 VOLT SERVICE

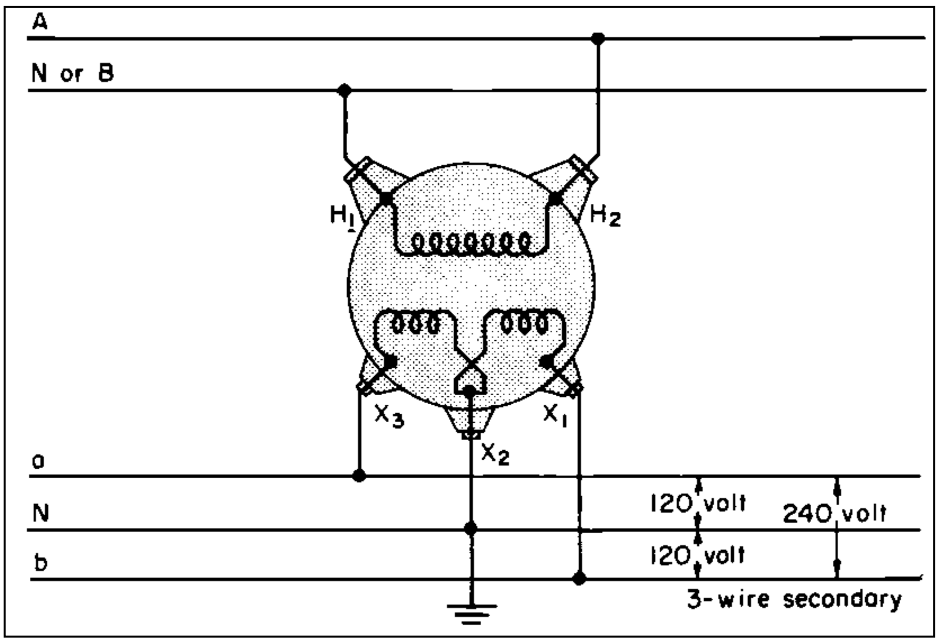
WHERE USED

For supplying customers who require both 120 VAC and 240 VAC, single-phase power. This is the recommended connection for serving modern homes. (5)

1Ø - 120/240-3W LIGHT AND POWER LOAD

Here the 120/240-volt winding is connected in series and the mid-point brought out, making it possible to serve both 120 and 240-volt loads simultaneously. This connection is used in most urban distribution circuits. Dotted line indicates tank is grounded. (3)

DIAGRAM



(5)

1Ø - 120/240 VOLT SERVICE CALCULATION

A typical single phase transformer that might feed power to a residential house can be somewhat confusing in that, although it has two distinct branches, it is nevertheless one winding divided into two. The two branches that are 120 VAC in reference to the transformers neutral are not two phases, but one phase split in two.

One may calculate the total load on a residential single-phase transformer by checking all of the components connected to the transformer, but this is not practical. A more reasonable approach might be to measure amperage at any 240 VAC device that is operating, such as an electric heater or air conditioner, then measure amperage at the breaker panel on branches 1 and 2 and subtract ½ of the 240 VAC load. The same result could be accomplished in reverse by turning off all 240 VAC devices, then measuring amperage on branches 1 and 2, then turning on the 240 VAC devices and add the increase of only one of branch 1 or 2 and then add the increase to the original subtotal of branches 1 and 2. Simply adding branch 1 and 2 together will result in an inaccurate high reading because the 240 VAC load is flowing equally through both branches. (See: Single-Phase Load Example)

The neutral will carry the imbalance of amperage between branch 1 and branch 2. If branch 1 has a load of 25 amps and branch 2 has a load of 30 amps, the neutral will carry a load of 5 amps. This is why a relatively balanced load is important on a single phase application. (6)

1Ø - 120/240 CALCULATION EXAMPLE

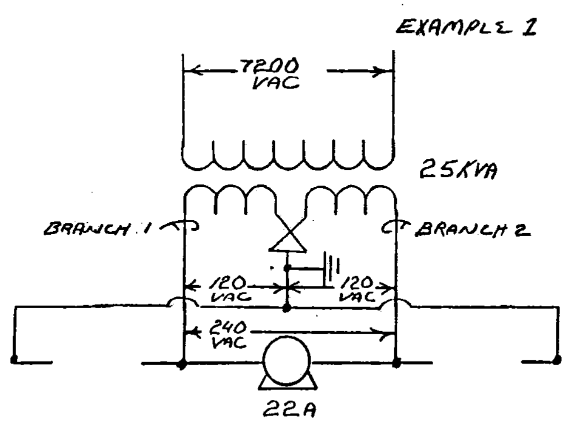


IMAGE 1	
FLA@ 7200 VAC	3.47
FLA@ 240	104.20
BRANCH 1 AMPS	22.00
BRANCH 2 AMPS	22.00
ACTUAL AMPS @ 7200 VAC	.73
ACTUAL AMPS @ 240 VAC	22.00

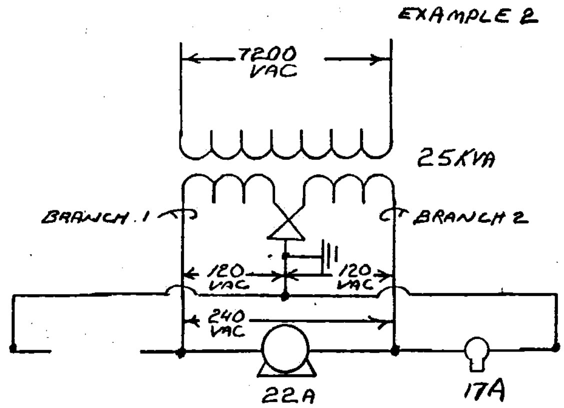


IMAGE 2	
FLA@ 7200 VAC	3.47
FLA@ 240	104.20
BRANCH 1 AMPS	22.00
BRANCH 2 AMPS	39.00
ACTUAL AMPS @ 7200 VAC	1.29
ACTUAL AMPS @ 240 VAC	39.00

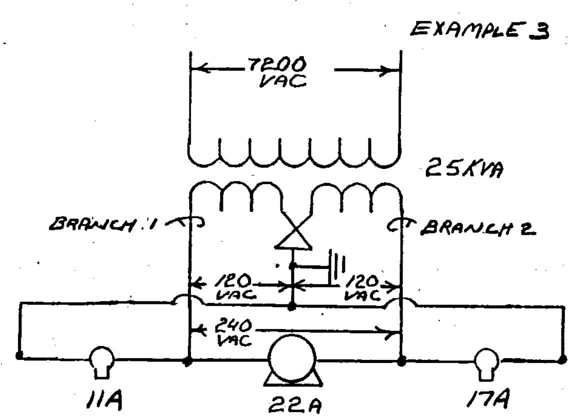


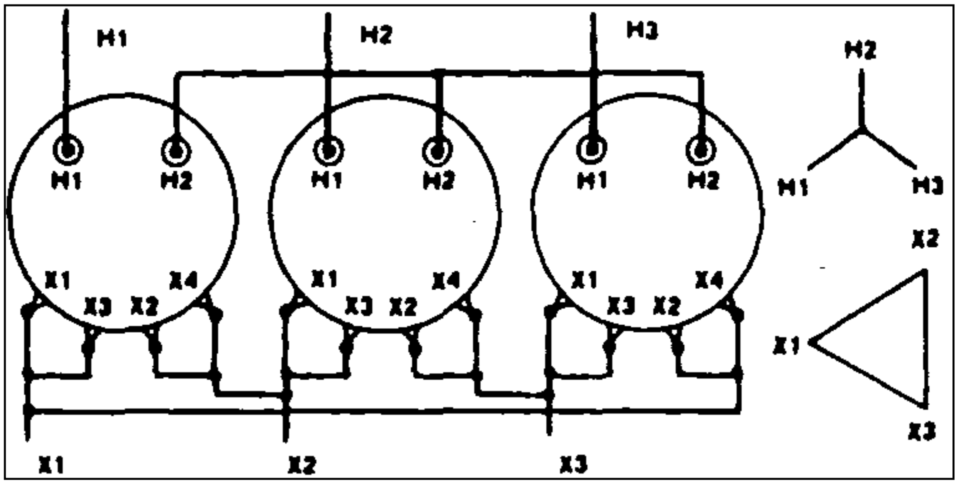
IMAGE 1	
FLA@ 7200 VAC	3.47
FLA@ 240	104.20
BRANCH 1 AMPS	33.00
BRANCH 2 AMPS	39.00
ACTUAL AMPS @ 7200 VAC	1.66
ACTUAL AMPS @ 240 VAC	50.00

(6)

CHAPTER IV   MULTI-TAP TRANSFORMERS

FACT = 4 BUSHING SECONDARY

YΔ 480 THRU 960



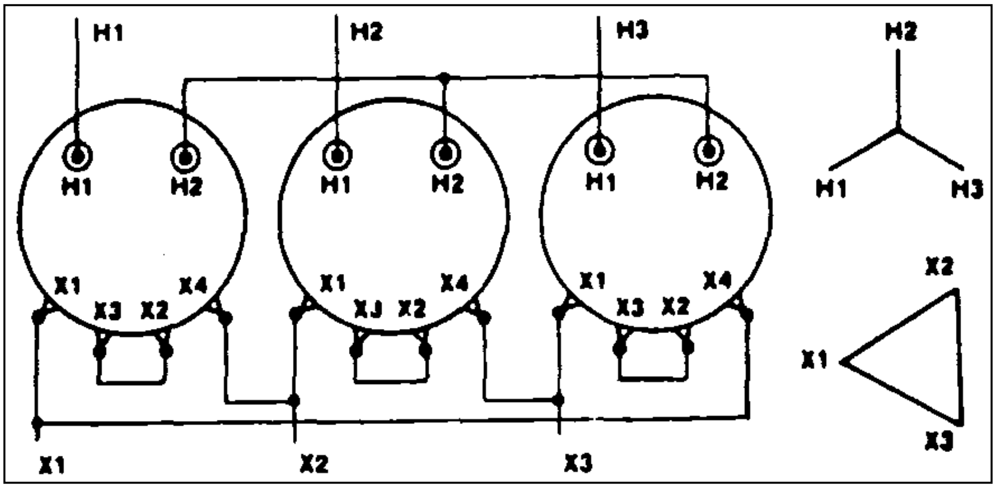
SEC. SWITCH NO.1	SEC. SWITCH NO.2	SEC. VOLTAGE	3 PHASE LINE CURRENT			
			3-37 1/2 kVA	3-50 kVA	3-75 kVA	3-100 kVA
1	1	480	135.3	180.4	270.6	360.8
2	1					
2	2	540	120.2	160.3	240.4	320.6
3	2					
3	3	600	108.2	144.3	216.4	288.6
4	3					
4	4	660	98.4	131.2	196.8	262.4
5	4					
5	5	720	90.2	120.2	180.4	240.4
6	5					
6	6	780	83.2	111.0	166.4	222.0
7	6					
7	7	840	77.3	103.0	154.6	206.0
8	7					
8	8	900	72.1	96.2	144.2	192.4
9	8					
9	9	960	67.6	90.2	135.2	180.4

Caution 1:
Primary neutrals should not be grounded or tied into system neutral since a single-phase ground fault may result in extensive blowing of fuses throughout the system.

Caution 2:
On 19920/34500 grd Y applications, see application brief 4 in catalog.

FACT = 4 BUSHING SECONDARY

YΔ 960 THRU 1920



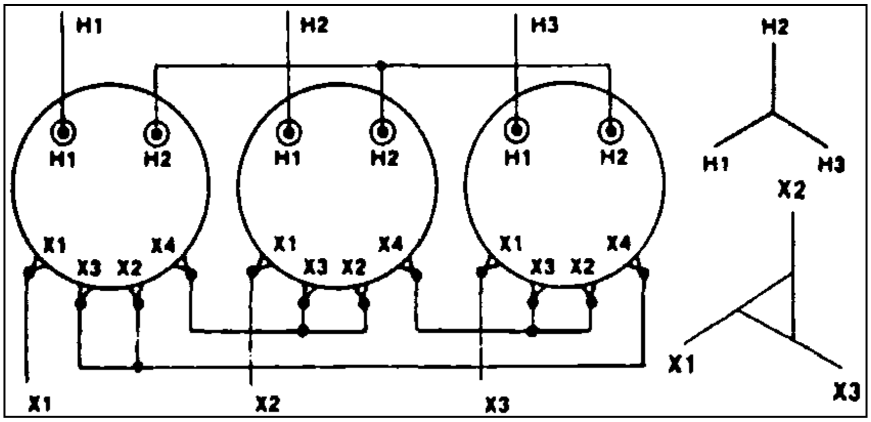
SEC. SWITCH NO.1	SEC. SWITCH NO.2	SEC. VOLTAGE	3 PHASE LINE CURRENT			
			3-37 1/2 kVA	3-50 kVA	3-75 kVA	3-100 kVA
1	1	960	67.6	90.2	135.2	180.4
2	1	1020	63.6	84.9	127.2	169.8
2	2	1080	60.1	80.1	120.2	160.2
3	2	1140	56.9	75.9	113.8	151.8
3	3	1200	54.1	72.1	108.2	144.2
4	3	1260	51.5	68.7	103.0	137.4
4	4	1320	49.2	65.6	98.4	131.2
5	4	1380	47.0	62.7	94.0	125.4
5	5	1440	45.1	60.1	90.2	120.2
6	5	1500	43.3	57.7	86.6	115.4
6	6	1560	41.6	55.5	83.2	111.0
7	6	1620	40.0	53.4	80.0	106.8
7	7	1680	38.6	51.5	77.2	103.0
8	7	1740	37.3	49.7	74.6	99.4
8	8	1800	36.0	48.1	72.0	96.2
9	8	1860	34.9	46.5	69.8	93.0
9	9	1920	33.8	45.1	67.6	90.2

Caution 1:
Primary neutrals should not be grounded or tied into system neutral since a single-phase ground fault may result in extensive blowing of fuses throughout the system.

Caution 2:
On 19920/34500 grd Y applications see application brief 4 in catalog.

FACT = 4 BUSHING SECONDARY

Y-XΔ 1731 THRU 2540



SEC. SWITCH NO.1	SEC. SWITCH NO.2	SEC. VOLTAGE	3 PHASE LINE CURRENT			
			3-37 1/2 kVA	3-50 kVA	3-75 kVA	3-100 kVA
1	9	1731	37.5	50.0	75.0	100.1
2	9	1831	35.5	47.3	70.9	94.6
3	9	1931	33.6	44.8	67.3	89.7
4	9	2032	32.0	42.6	63.9	85.2
5	9	2133	30.5	40.6	60.9	81.2
6	9	2235	29.1	38.7	58.1	77.1
7	9	2336	27.8	37.1	55.6	74.1
8	9	2438	26.6	35.5	53.3	71.0
9	9	2540	25.6	34.1	51.1	68.2

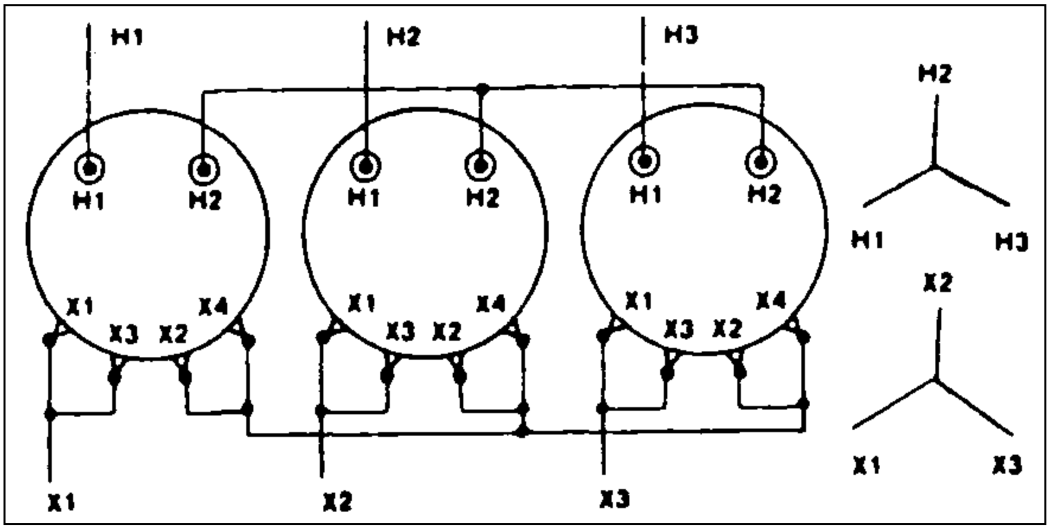
Caution:
1. The secondary switch (#2) must remain on position 9.
2. The secondary switch (#1) can be adjusted to any position 1 thru 9

Application Brief 6: FACT transformers can be connected in a wye-extended delta connection by using the X2 and X3 bushings as a mid tap in each transformer. This connection will allow 32.3% higher secondary thru phase voltage over the maximum standard delta connected voltage. A wye-extended delta connection has all the operating advantages of a wye-delta with none of the problems associated with wye-wye. Three of these operating advantages are:

1) A wye-extended delta is suitable for use on a three wire system. Just as in the case of a wye-delta the transformer neutral must *not* be connected to the system neutral or to ground.
2) The third harmonic component of exciting current flows around the delta portion of the extended delta secondary exactly as it does in a wye-delta.
3) The output voltage will be balanced, even if the load is unbalanced, because of the interlocking nature of a wye-delta. The neutral point remains fixed relative to the three phases.

FACT = 4 BUSHING SECONDARY

YY 831 THRU 1663

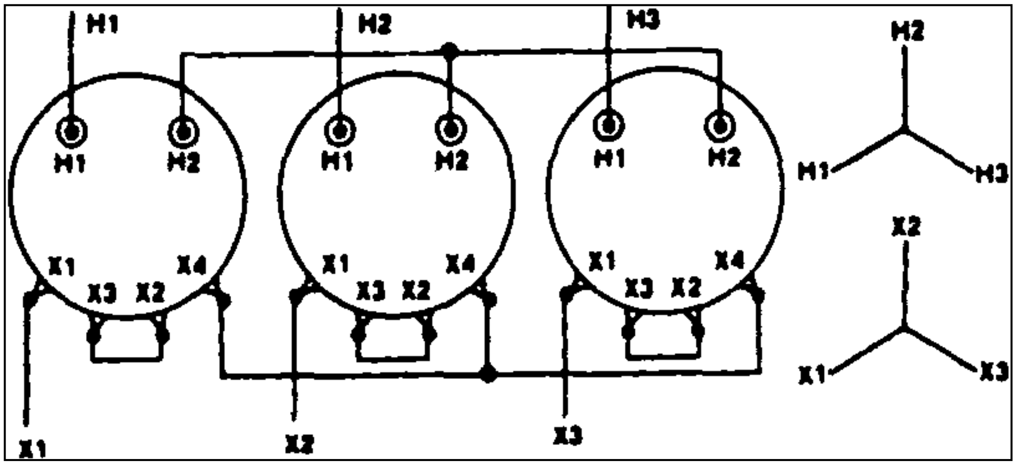


SEC. SWITCH NO.1	SEC. SWITCH NO.2	SEC. VOLTAGE	3 PHASE LINE CURRENT			
			3-37 1/2 kVA	3-50 kVA	3-75 kVA	3·100 kVA
1	1	831	78.1	104.1	156.2	208.2
2	1					
2	2	935	69.4	92.5	138.8	185.0
3	2					
3	3	1039	62.5	83.3	125.0	166.6
4	3					
4	4	1143	56.8	75.7	113.6	151.4
5	4					
5	5	1247	52.0	69.4	104.0	138.8
6	5					
6	6	1351	48.0	64.1	96.0	128.2
7	6					
7	7	1455	44.6	59.5	89.2	119.0
8	7					
8	8	1559	41.6	55.5	83.2	111.0
9	8					
9	9	1663	39.0	52.0	78.0	104.0

Caution:
1. The primary and secondary neutrals should be connected to the system neutral when connected Y-Y.

FACT = 4 BUSHING SECONDARY

YY 1663 THRU 3325

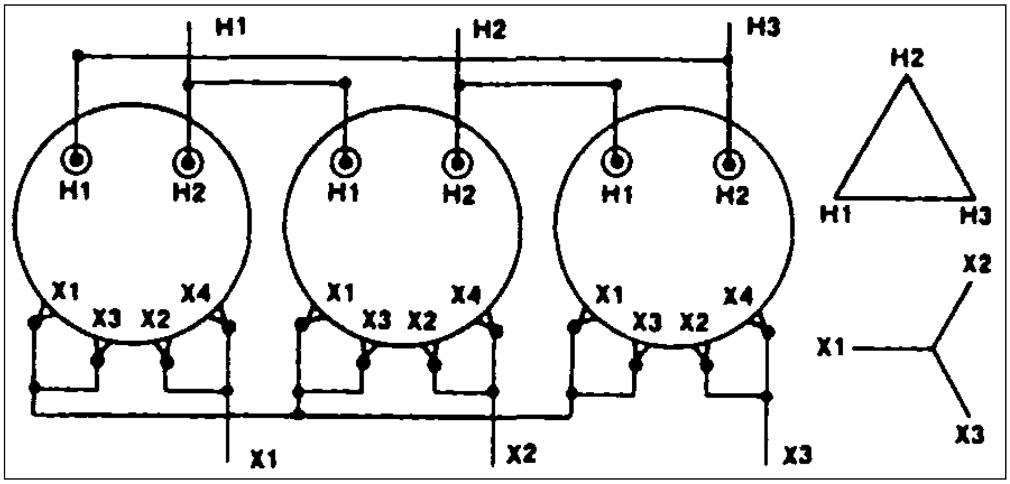


SEC. SWITCH NO.1	SEC. SWITCH NO.2	SEC. VOLTAGE	3 PHASE LINE CURRENT			
			3-37 1/2 kVA	3-50 kVA	3-75 kVA	3-100 kVA
1	1	1663	39.0	52.0	78.0	104.0
2	1	1767	36.7	49.0	73.4	98.0
2	2	1871	34.7	43.2	69.4	92.4
3	2	1974	32.9	43.8	65.8	87.6
3	3	2078	31.2	41.6	62.4	83.2
4	3	2182	29.7	39.6	59.4	79.2
4	4	2286	28.4	37.8	56.8	75.6
5	4	2390	27.1	36.2	54.2	72.4
5	5	2494	26.0	34.7	52.0	69.4
6	5	2598	25.0	33.3	50.0	66.6
6	6	2702	24.0	32.0	48.0	64.0
7	6	2806	23.1	30.8	46.2	61.6
7	7	2910	22.3	29.7	44.6	59.4
8	7	3014	21.5	28.7	43.0	57.4
8	8	3118	20.8	27.7	41.6	55.4
9	8	3222	20.1	26.8	40.2	53.6
9	9	3325	19.5	26.0	39.0	52.0

CAUTION:
1) The primary and secondary neutrals should be connected to the system neutral when connected Y-Y.

FACT = 4 BUSHING SECONDARY

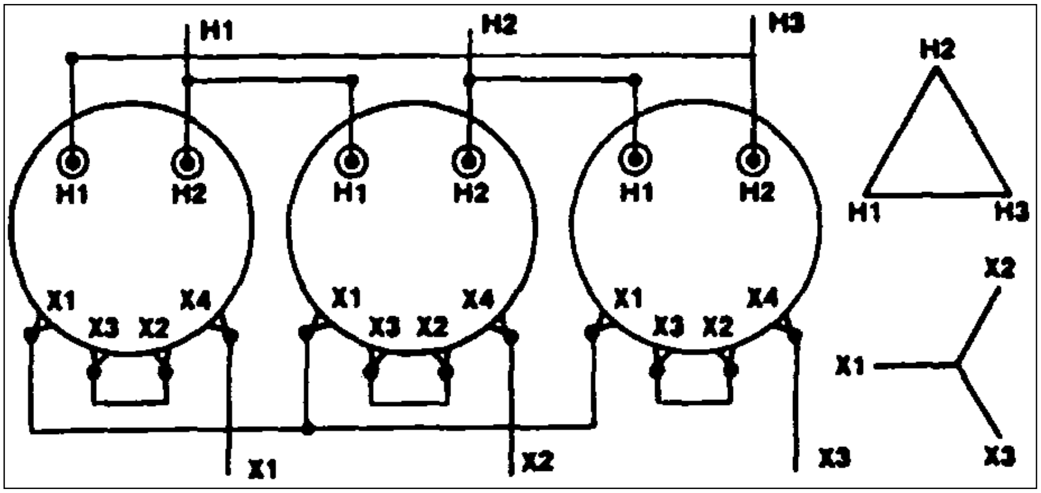
ΔY 831 THRU 1663



SEC. SWITCH NO.1	SEC. SWITCH NO.2	SEC. VOLTAGE	3 PHASE LINE CURRENT			
			3-37 1/2 kVA	3-50 kVA	3-75 kVA	3-100 kVA
1	1	831	78.1	104.1	156.2	208.2
2	1					
2	2	935	69.4	92.5	138.8	185.0
3	2					
3	3	1039	62.5	83.3	125.0	166.6
4	3					
4	4	1143	56.8	75.7	113.6	151.4
5	4					
5	5	1247	52.0	69.4	104.0	138.8
6	5					
6	6	1351	48.0	64.1	96.0	128.2
7	6					
7	7	1455	44.6	59.5	89.2	119.0
8	7					
8	8	1559	41.6	55.5	83.2	111.0
9	8					
9	9	1663	39.0	52.0	78.0	104.0

FACT = 4 BUSHING SECONDARY

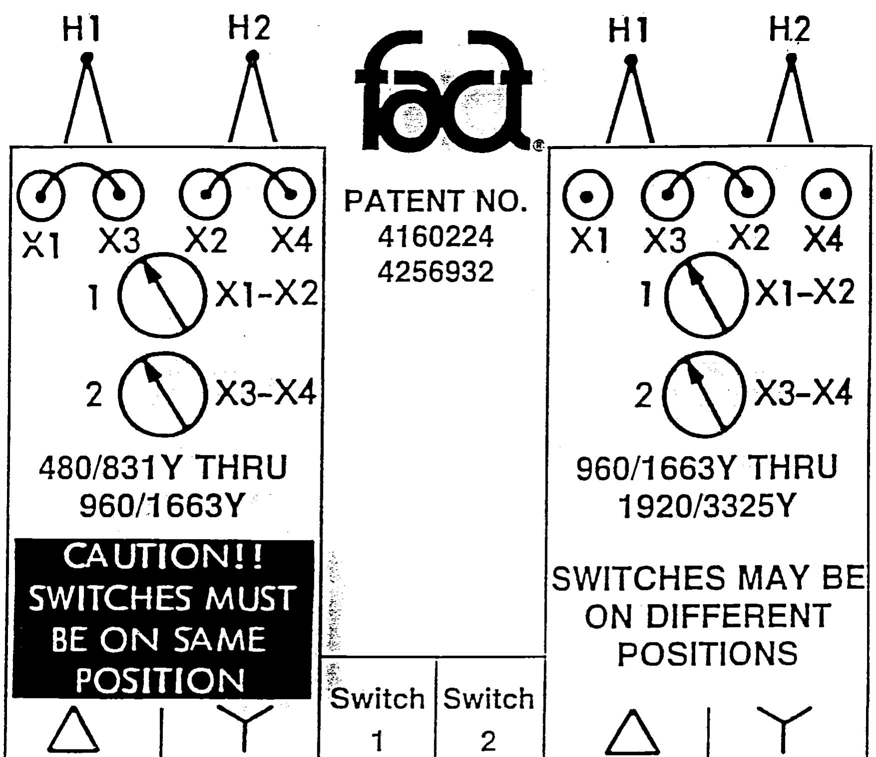
ΔY 1663 THRU 3325



SEC. SWITCH NO.1	SEC. SWITCH NO.2	SEC. VOLTAGE	3 PHASE LINE CURRENT			
			3-37 1/2 kVA	3-50 kVA	3-75 kVA	3-100 kVA
1	1	1663	39.0	52.0	78.0	104.0
2	1	1767	36.7	49.0	73.4	98.0
2	2	1871	34.7	46.2	69.4	92.4
3	2	1974	32.9	43.8	65.8	87.6
3	3	2078	31.2	41.6	62.4	83.2
4	3	2182	29.7	39.6	59.4	79.2
4	4	2286	28.4	37.8	56.8	75.6
5	4	2390	27.1	36.2	54.2	72.4·
5	5	2494	26.0	34.7	52.0	69.4
6	5	2598	25.0	33.3	50.0	66.6
6	6	2702	24.0	32.0	48.0	64.0
7	6	2806	23.1	30.8	46.2	61.6
7	7	2910	22.3	29.7	44.6	59.4
8	7	3014	21.5	28.7	43.0	57.4
8	8	3118	20.8	27.7	41.6	55.4
9	8	3222	20.1	26.8	40.2	53.6
9	9	3325	19.5	26.0	39.0	52.0

FACT = 4 BUSHING SECONDARY NOTES

SWITCH PLATE (37 ½ KVA, 50 KVA, 75 KVA, 100 KVA)



Δ	Y	Switch 1	Switch 2	Δ	Y
480	831	1	1	960	1663
		2	1	1020	1767
540	935	2	2	1080	1871
		3	2	1140	1974
600	1039	3	3	1200	2078
		4	3	1260	2182
660	1143	4	4	1320	2286
		5	4	1380	2390
720	1247	5	5	1440	2494
		6	5	1500	2598
780	1351	6	6	1560	2702
		7	6	1620	2806
840	1455	7	7	1680	2910
		8	7	1740	3014
900	1559	8	8	1800	3118
		9	8	1860	3222
960	1663	9	9	1920	3325

Secondary voltage range: 480-1920 connected delta • 1731-2540 connected extended delta • 831-3325 connected wye

GENERAL

MISCELLANEOUS

Unless noted; all charts, articles and drawings in the section are credited to = (1)

Southwest Electric FACT transformers include models 125, 225, 325, 425

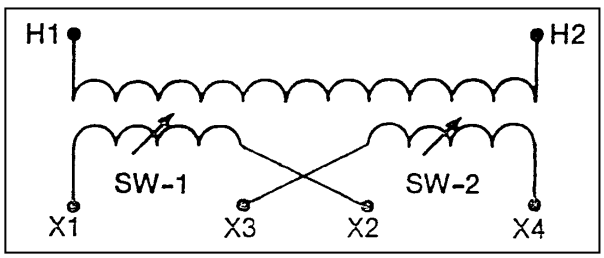
Transformers covered in this publication covers sizes 37 ½ kva, 50 kva, 75 kva, and 100 kva.

Refer to the Southwest Electric FACT manual for sizes 167 kva and 200 kva.

All of the following "Application Brief" articles are from Southwest Electric Company.

480 VOLT CONTROL CIRCUIT

Application Brief 3: Any bank of FACT~ transformers 100 kVA and below can be connected such that 480 volts is available for control circuits. Schematically a FACT is as follows:



With proper caution as to transformer loading a bank of FACT® transformers can be adjusted to deliver from 960 to 1440 volts delta in 60 volt steps or from 1663 to 2494 volts wye in 104 volt steps while, at the same time, delivering power to a 480 volt circuit, either three phase or single phase. This is possible without de-rating the transformers. This discussion will be confined to single phase 480 volt control where the control power requirement is less than one percent of one transformer's rating. For purposes of this discussion the following will also be required:

1) Grounding the control power and therefore grounding the motor circuit is acceptable.
2) The transformers are operated at rated voltage.
3) Terminals X1 & X2 will be the 480 volt source therefore switch number one must remain in position one.
4) The primary is connected wye.
4) Only FACT 125 & 225 transformers 100 kVA and below are used.

Consult Southwest Electric Co., Oklahoma City for further information and technical assistance for your application.

OPERATION ABOVE RATED VOLTAGE

Application Brief 5: FACT transformers rated 7200/12470Y volts may be used on a 7620/13200Y volt system without exceeding rated temperature rise (65°c) and without sacrificing transformer life.

Note: when 7200 volt FACT transformers are applied to a 7620/ 13200Y system *all* secondary voltages are 5.83 percent higher than shown on the nameplate.

FACT TRANSFORMERS MEET OR EXCEED THE FOLLOWING STANDARD: ANSI Standard, C57.12.00-1980, *General Requirements for Distribution, Power, and Regulating Transformers, and Shunt Reactors,* paragraph 2.4. "Transformers shall be capable of: (1) Delivering rated output in kV A at 5 percent above rated secondary voltage without exceeding the limiting temperature rise. This requirement applies when the power factor of the load is 80 percent or higher. (2) Operating at 10 percent above rated secondary voltage at no load without exceeding the limiting temperature rise. (3) The foregoing requirements apply to the rated voltage, rated frequency, and rated kVA for any tap."

YY FOR USE ON A DOWN-HOLE PUMP

In respect to the secondary of an YY connection being purposely isolated from ground for the function of a down-hole pump sensor. The typical connection for YY is grounding both the primary and secondary. The primary must be grounded without exception in the YY configuration. The secondary can float, that is to be isolated from ground. (1)

Some down-hole sensors will function properly with the secondary of a Y-Y grounded, and thus by habit the secondary should initially be grounded unless or until instructed otherwise.

By experience, there have been times that the primary ground in a Y-Y has created adverse effects on a down-hole sensor and field personnel have been asked to remove the primary ground connection. Field personnel should never take it upon themselves to remove the primary ground of a Y-Y. Field personnel must relay such a request to their immediate supervisor. The supervisor, in turn, must contact the owner of the down-hole equipment and clearly explain the request to remove a ground and the potentially excessive damage this action might have on transformers, drives or motors.

After clearly explaining the dangers of an isolated YY primary connection to a client and the client insists on having the ground removed, then one would comply only with the safety addition of a “chain ground” (a fourth or neutral cutout) to be temporally closed prior to closing the three power cutouts to avoid adverse ferroresonance effects. After the three power cutouts are closed, then the chain ground cutout would be opened.

In coordinating with a pump technician, concerning an improperly functioning down-hole sensor, a transformer connection should not be readily assumed to be the cause of the problem over a faulty or incorrectly installed sensor.

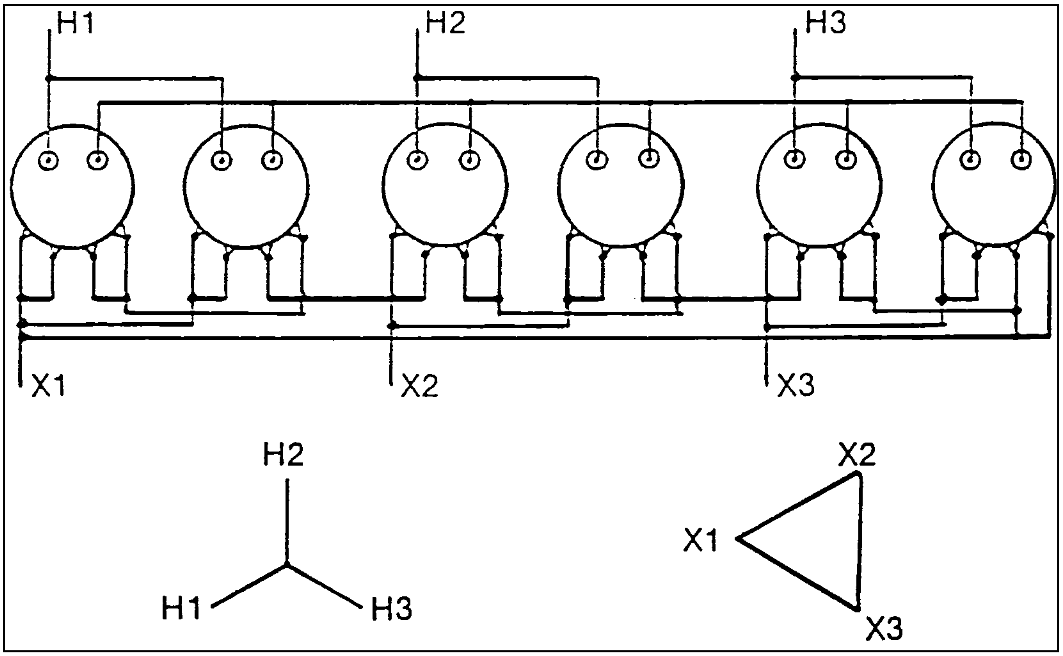
There is some evidence, based on field experience, that some multi-tap transformer brands connected Y-Y and used on down-hole pumps, do not adversely affect sensors while other multi-tap transformer brands installed in conjunction with the same equipment and parameters, will adversely affect sensors.

An ungrounded primary on a Y-Y will pass ground-fault current from the primary system to the secondary. An ungrounded primary on a Y-Y may also develop excessive voltages on the secondary side. (6)

It is necessary that the primary neutral be available when this connection is used, and the neutrals of the primary system and of the bank are tied together as shown. If the three-phase load is unbalanced, part of the load current flows in the primary neutral. Also the third-harmonic component of the transformer exciting current; flows in the primary neutral. For these reasons, it is necessary that the neutrals be tied together as shown. If this tie were omitted, the line to neutral voltages on the secondary would be very unstable. That is, if the load on one phase were heavier than on the other two, phases would rise. Also, large third-harmonic voltages would appear between lines and neutral, both in the transformers and in the secondary system, in addition to the 60-Hz component of voltage. This means that for a given value of RMS voltage, the peak voltage would be much higher than for a pure 60-Hz voltage. This overstresses the insulation both in the transformers and in all apparatus connected to the secondaries. (11)

FACT = 4 BUSHING SECONDARY PARALLELED

YΔ 480 THRU 960

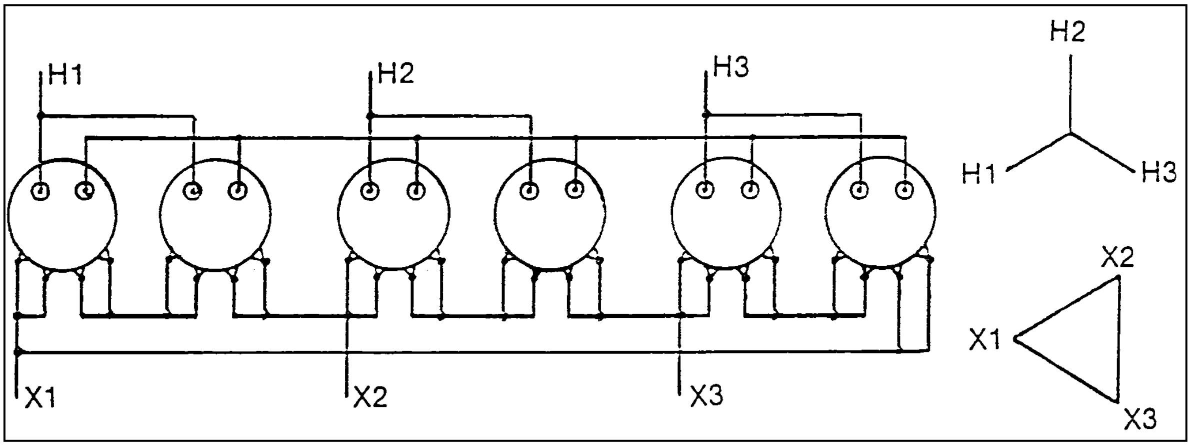


SWITCH POSITION		THREE PHASE VOLTS	THREE PHASE LINE CURRENT	
#1 X1-X2	#2 X3-X4		450 kVA 6-75	600 kVA 6-100
1	1	480	541.2	721.7
2	2	540	481.1	641.5
3	3	600	433.0	577.4
4	4	660	393.6	524.9
5	5	720	360.8	481.1
6	6	780	333.1	444.1
7	7	840	309.3	412.4
8	8	900	188.6	384.9
9	9	960	270.6	360.8

Caution:
1) Do not connect the primary neutral to ground or to the system neutral.
2) All secondary switches must be on the same position.
3) Currents beyond secondary bushings are large. Proper cable sizing and extreme caution must be exercised while making up complete bank.

FACT = 4 BUSHING SECONDARY PARALLELED

YΔ 960 THRU 1920

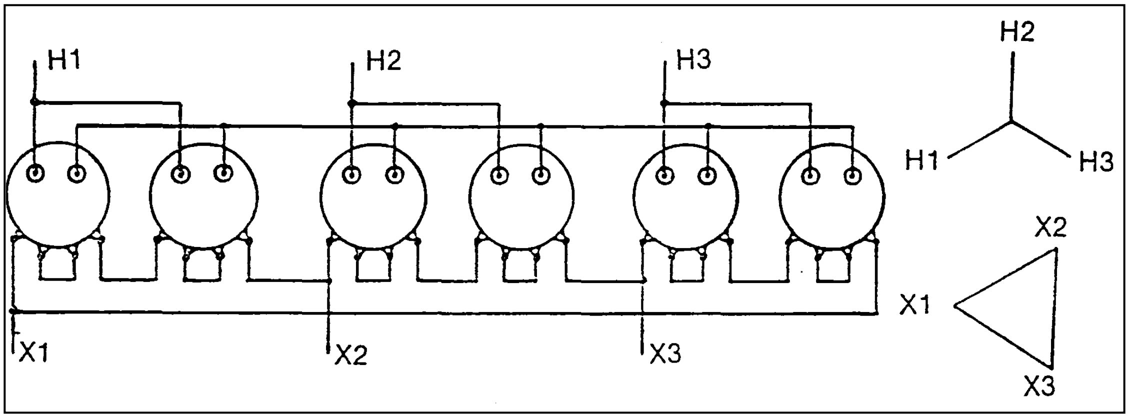


SWITCH POSITION		THREE PHASE VOLTS	THREE PHASE LINE CURRENT	
#1	#2		450 kVA	600 kVA
1	1	960	270.6	360.8
2	2	1080	240.4	320.6
3	3	1200	216.4	288.6
4	4	1320	196.8	262.4
5	5	1440	180.4	240.4
6	6	1560	166.4	222.0
7	7	1680	153.5	205.0
8	8	1800	144.2	192.4
9	9	1920	135.2	180.4

Caution:
1) Do not connect the primary neutral to ground or to the system neutral.
2) All secondary switches must be on the same position.

FACT = 4 BUSHING SECONDARY PARALLELED

YΔ 1920 THRU 3840



SWITCH POSITION			THREE PHASE VOLTS	THREE PHASE LINE CURRENT	
#1		*#2*		450 kVA	600 kVA
1		1	1920	135.2	180.4
2		1	2040	127.2	169.8
3		2	2280	113.8	151.8
3		3	2400	108.2	144.2
4		3	2520	103.0	137.4
4		4	2640	98.4	131.2
5		4	2760	94.0	125.4
5		5	2880	90.2	120.2
6		5	3000	86.6	115.4
6		6	3120	83.2	111.0
7		6	3240	80.0	106.8
7		7	3360	77.2	103.0
8		7	3480	74.6	99.4
8		8	3600	72.0	96.2
9		8	3720	69.8	93.0
9		9	3840	67.6	90.2

1) Do not connect the primary neutral to ground or to the system neutral.

FACT = 4 BUSHING SECONDARY PARALLELED NOTES

GENERAL

MISCELLANEOUS

Unless noted; all articles, charts and drawings in the section are credited to = (1)

LOADS ABOVE 300 KVA

Application Brief 7: FACT transformers are suitable to power loads between 300 kVA and 600 kVA where the voltage requirement is between 480 and 3840.This is accomplished by using two FACT transformers per phase with the primaries paralleled and the secondaries seriesed. This application has operating advantages not available in other submersible pump type transformers. Five of these advantages are:

1) Severe short circuits will not damage FACT transformers; thru-fault currents in this application are no higher than in three transformer bank connections.
2) Custom built transformers are not required.
3) The secondary voltage is adjustable from 480 through 3840 volts in 60 volt or 120 volt steps.
4) A wye-delta connection may be used on a three wire primary with all the advantages associated with wye-delta.

These transformers will never become surplus as a custom built unit does. At the end of the life of the present load the six-transformer bank becomes two banks of standard FACT transformers useful on smaller submersible pump loads or standard 460 volt motors at full kV A rating.

Also see information on FACT 167 & 200 kVA

YY FOR USE ON A DOWN-HOLE PUMP

In respect to the secondary of an YY connection being purposely isolated from ground for the function of a down-hole pump sensor. The typical connection for YY is grounding both the primary and secondary. The primary must be grounded without exception in the YY configuration. The secondary can float, that is to be isolated from ground. (1)

Some down-hole sensors will function properly with the secondary of a Y-Y grounded, and thus by habit the secondary should initially be grounded unless or until instructed otherwise.

By experience, there have been times that the primary ground in a Y-Y has created adverse effects on a down-hole sensor and field personnel have been asked to remove the primary ground connection. Field personnel should never take it upon themselves to remove the primary ground of a Y-Y. Field personnel must relay such a request to their immediate supervisor. The supervisor, in turn, must contact the owner of the down-hole equipment and clearly explain the request to remove a ground and the potentially excessive damage this action might have on transformers, drives or motors.

After clearly explaining the dangers of an isolated YY primary connection to a client and the client insists on having the ground removed, then one would comply only with the safety addition of a "chain ground" (a fourth or neutral cutout) to be temporally closed prior to closing the three power cutouts to avoid adverse ferroresonance effects. After the three power cutouts are closed, then the chain ground cutout would be opened.

In coordinating with a pump technician, concerning an improperly functioning down-hole sensor, a transformer connection should not be readily assumed to be the cause of the problem over a faulty or incorrectly installed sensor.

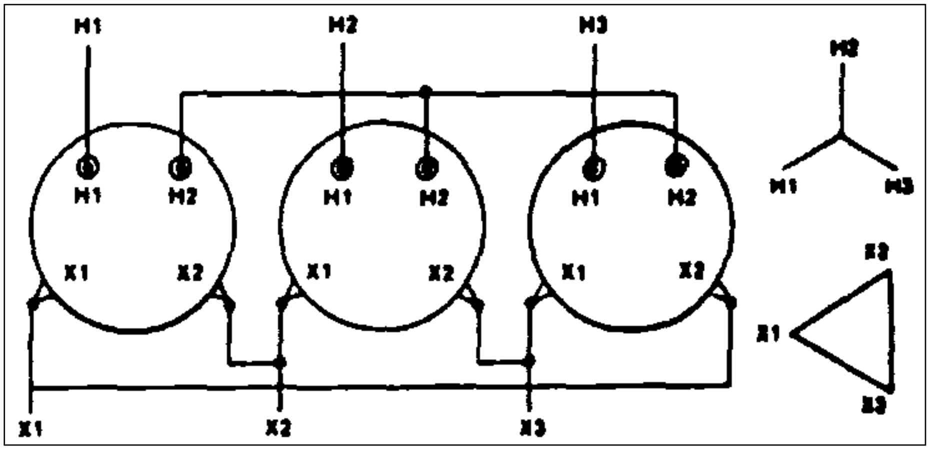
There is some evidence, based on field experience, that some multi-tap transformer brands connected Y-Y and used on down-hole pumps, do not adversely affect sensors while other multi-tap transformer brands installed in conjunction with the same equipment and parameters, will adversely affect sensors.

An ungrounded primary on a Y-Y will pass ground-fault current from the primary system to the secondary. An ungrounded primary on a Y-Y may also develop excessive voltages on the secondary side. (6)

It is necessary that the primary neutral be available when this connection is used, and the neutrals of the primary system and of the bank are tied together as shown. If the three-phase load is unbalanced, part of the load current flows in the primary neutral. Also the third-harmonic component of the transformer exciting current; flows in the primary neutral. For these reasons, it is necessary that the neutrals be tied together as shown. If this tie were omitted, the line to neutral voltages on the secondary would be very unstable. That is, if the load on one phase were heavier than on the other two, phases would rise. Also, large third-harmonic voltages would appear between lines and neutral, both in the transformers and in the secondary system, in addition to the 60-Hz component of voltage. This means that for a given value of RMS voltage, the peak voltage would be much higher than for a pure 60-Hz voltage. This overstresses the insulation both in the transformers and in all apparatus connected to the secondaries. (11)

FACT II = 2 BUSHING SECONDARY

YΔ 480 THRU 1440

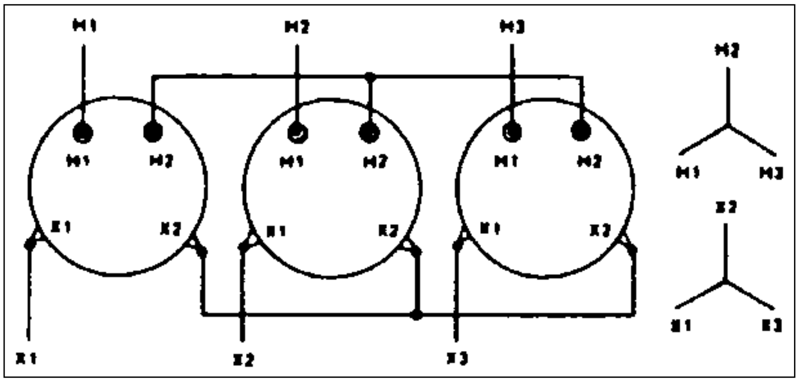


SEC. SWITCH NO.1	SEC. SWITCH NO.2	SEC. VOLTAGE	3 PHASE LINE CURRENT	
			3-25 kVA	3-37 1/2 kVA
1	1	480	90.2	135.3
2	1	540	80.2	120.3
2	2	600	72.2	108.3
3	2	660	65.6	98.4
3	3	720	60.1	90.2
4	3	780	55.5	83.3
4	4	840	51.5	77.3
5	4	900	48.1	72.2
5	5	960	45.1	67.7
6	5	1020	42.5	83.7
6	6	1080	40.1	60.1
7	6	1140	38.0	57.0
7	7	1200	36.1	54.1
8	7	1260	34.4	51.5
8	8	1320	32.8	49.2
9	8	1380	31.4	47.1
9	9	1440	30.1	45.1

Caution:
1. Primary neutrals should not be grounded or tied into system neutral since a single-phase ground fault may result in extensive blowing of fuses throughout the system.

FACT II = 2 BUSHING SECONDARY

YY 831 THRU 2494



SEC. SWITCH NO.1	SEC. SWITCH NO.2	SEC. VOLTAGE	3 PHASE LINE CURRENT	
			3-25 kVA	3·37 112 kVA
1	1	831	52.1	78.1
2	1	935	46.3	69.4
2	2	1039	41.6	62.5
3	2	1143	37.8	56.8
3	3	1247	34.7	52.0
4	3	1351	32.0	48.0
4	4	1455	29.7	44.6
5	4	1559	27.7	41.6
5	5	1663	26.0	39.0
6	5	1767	24.5	36.7
6	6	1871	23.1	34.7
7	6	1974	21.9	32.9
7	7	2078	20.8	31.2
8	7	2182	19.8	29.7
8	8	2286	18.9	28.4
9	8	2390	18.1	27.1
9	9	2494	17.3	26.0

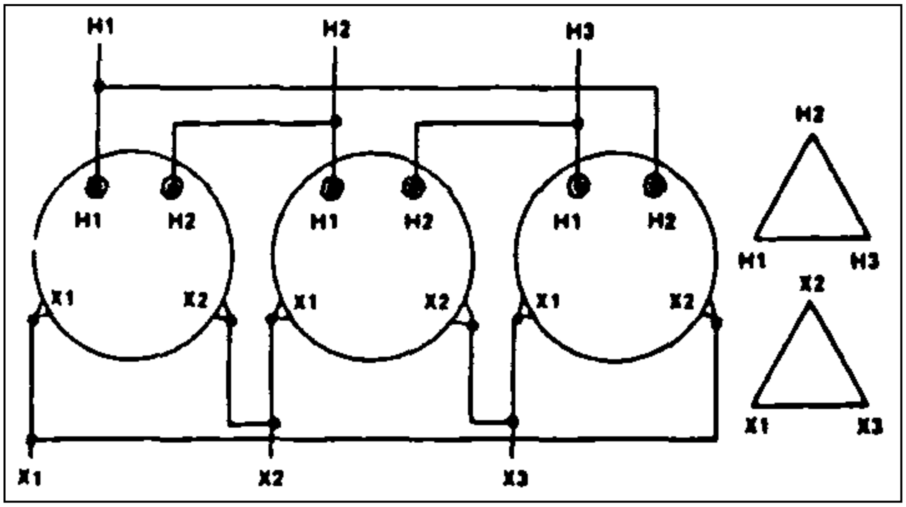
* Secondary neutral must be solidly grounded from 1455Y thru 2494Y

Caution:
1. On 4·wire primary systems, connect both primary and secondary neutrals to system neutral.

2. The primary and secondary neutrals should be connected to the system neutral when connected Y-Y.

FACT II = 2 BUSHING SECONDARY

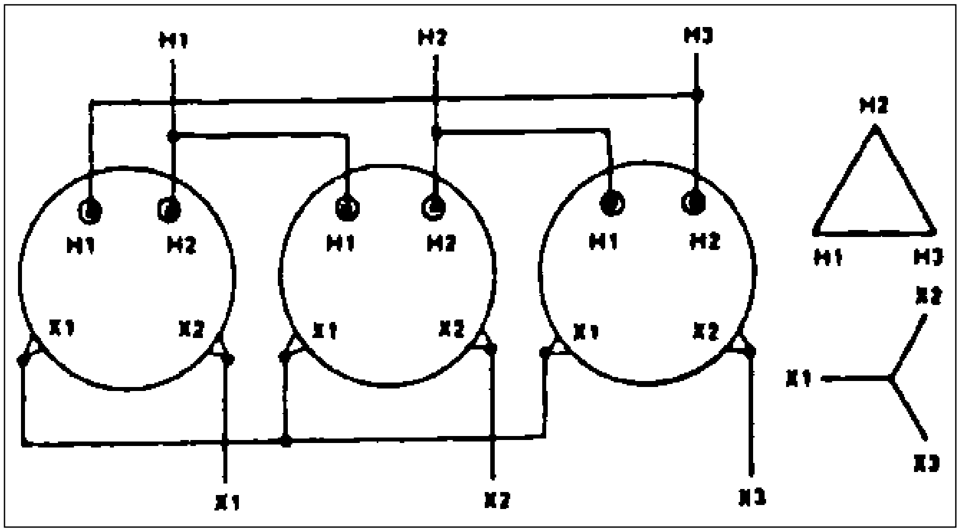
ΔΔ 480 THRU 1440



SEC. SWITCH NO.1	SEC. SWITCH NO.2	SEC. VOLTAGE	3 PHASE LINE CURRENT	
			3·25 kVA	3-37 1/2 kVA
1	1	480	90.2	135.3
2	1	540	80.2	120.3
2	2	600	72.2	108.3
3	2	660	65.6	98.4
3	3	720	60.1	90.2
4	3	780	55.5	83.3
4	4	840	51.5	77.3
5	4	900	48.1	72.2
5	5	960	45.1	67.7
6	5	1020	42.5	63.7
6	6	1080	40.1	60.1
7	6	1140	38.0	57.0
7	7	1200	36.1	54.1
8	7	1260	34.4	51.5
8	8	1320	32.8	49.2
9	8	1380	31.4	47.1
9	9	1440	30.1	45.1

FACT II = 2 BUSHING SECONDARY

ΔY 831 THRU 2494



SEC. SWITCH NO.1	SEC. SWITCH NO.2	SEC. VOLTAGE	3 PHASE LINE CURRENT	
			3-25 kVA	3·37 112 kVA
1	1	831	52.1	78.1
2	1	935	46.3	69.4
2	2	1039	41.6	62.5
3	2	1143	37.8	56.8
3	3	1247	34.7	52.0
4	3	1351	32.0	48.0
4	4	1455	29.7	44.6
5	4	1559	27.7	41.6
5	5	1663	26.0	39.0
6	5	1767	24.5	36.7
6	6	1871	23.1	34.7
7	6	1974	21.9	32.9
7	7	2078	20.8	31.2
8	7	2182	19.8	29.7
8	8	2286	18.9	28.4
9	8	2390	18.1	27.1
9	9	2494	17.3	26.0

* Secondary neutral must be solidly grounded from 1455Y thru 2494Y

FACT II = 2 BUSHING SECONDARY NOTES

SWITCH PLATE (25 KVA, 37 ½ KVA)

FACT II

Patent No. 4255734 & 4256932

SWITCH POSITION TOP	SWITCH POSITION BOT	Δ	Y		SWITCH POSITION TOP	SWITCH POSITION BOT	Δ	Y
1	1	480	831		6	6	1080	1871
2	1	540	935		7	6	1140	1974
2	2	600	1039		7	7	1200	2078
3	2	660	1143		8	7	1260	2182
3	3	720	1247		8	8	1320	2286
4	3	780	1351		9	8	1380	2390
4	4	840	1455		9	9	1440	2494
5	4	900	1559		SECONDARY NEUTRAL MUST BE SOLIDLY GROUNDED FROM 1455Y THRU 2494Y			
5	5	960	1663					
6	5	1020	1767					

Secondary voltage range: 480-1440 connected delta 8831-2494 connected wye

GENERAL

MISCELLANEOUS

Unless noted; all articles, charts and drawings in the section are credited to =   (1)

The FACT II transformer line carries the two sizes of 25 kVA and 37 ½ kVA.

The FACT II line was developed for the unique transformer requirements of the oil industry. Within the FACT voltage range and kVA range, FACT II and FACT are interchangeable. The two designs are interchangeable within one bank except in a delta-delta connection where impedance matching is necessary.

In a delta connection the secondary voltage range is 480 to 1440 in 60 volt steps (16 equal steps). In a wye connection the range is 831 to 2494 in 104 volt steps.

The unique tap arrangement is rated *full* kVA capacity at all tap positions.

The user is never required to open a FACT II transformer because all voltage adjustments are accomplished by the use of externally operated switches.

The unique tap arrangement of the FACT II allows adjustment through the full voltage range using only two secondary terminals per transformer.

The same bank of FACT II transformers will deliver power to a 460 volt surface motor or a submersible pump motor with a surface voltage requirement anywhere between 480 and 2494grdy*. In many applications, because of the full kVA capacity at all tap positions feature, a smaller bank of transformers is required.

The magnetic flux density in the core of a FACT II remains constant keeping the no-load loss and exciting current constant throughout the voltage range.

The total loss and impedance remain essentially unchanged throughout the voltage range.

Some of the features of FACT are not incorporated in FACT II. Because of higher impedance, FACT II is less suitable than FACT for open-delta application. A bank of FACT II transformers cannot supply two voltages at the same time. FACT II cannot be used in an extended delta connection.

The FACT line was developed specifically for the unique transformer requirements of the oil industry.

* Wye-Wye connection is only suitable when used on a four wire system with the transformer primary neutral connected to the system neutral.

YY FOR USE ON A DOWN-HOLE PUMP

In respect to the secondary of an YY connection being purposely isolated from ground for the function of a down-hole pump sensor. The typical connection for YY is grounding both the primary and secondary. The primary must be grounded without exception in the YY configuration. The secondary can float, that is to be isolated from ground. (1)

Some down-hole sensors will function properly with the secondary of a Y-Y grounded, and thus by habit the secondary should initially be grounded unless or until instructed otherwise.

By experience, there have been times that the primary ground in a Y-Y has created adverse effects on a down-hole sensor and field personnel have been asked to remove the primary ground connection. Field personnel should never take it upon themselves to remove the primary ground of a Y-Y. Field personnel must relay such a request to their immediate supervisor. The supervisor, in turn, must contact the owner of the down-hole equipment and clearly explain the request to remove a ground and the potentially excessive damage this action might have on transformers, drives or motors.

After clearly explaining the dangers of an isolated YY primary connection to a client and the client insists on having the ground removed, then one would comply only with the safety addition of a “chain ground” (a fourth or neutral cutout) to be temporally closed prior to closing the three power cutouts to avoid adverse ferroresonance effects. After the three power cutouts are closed, then the chain ground cutout would be opened.

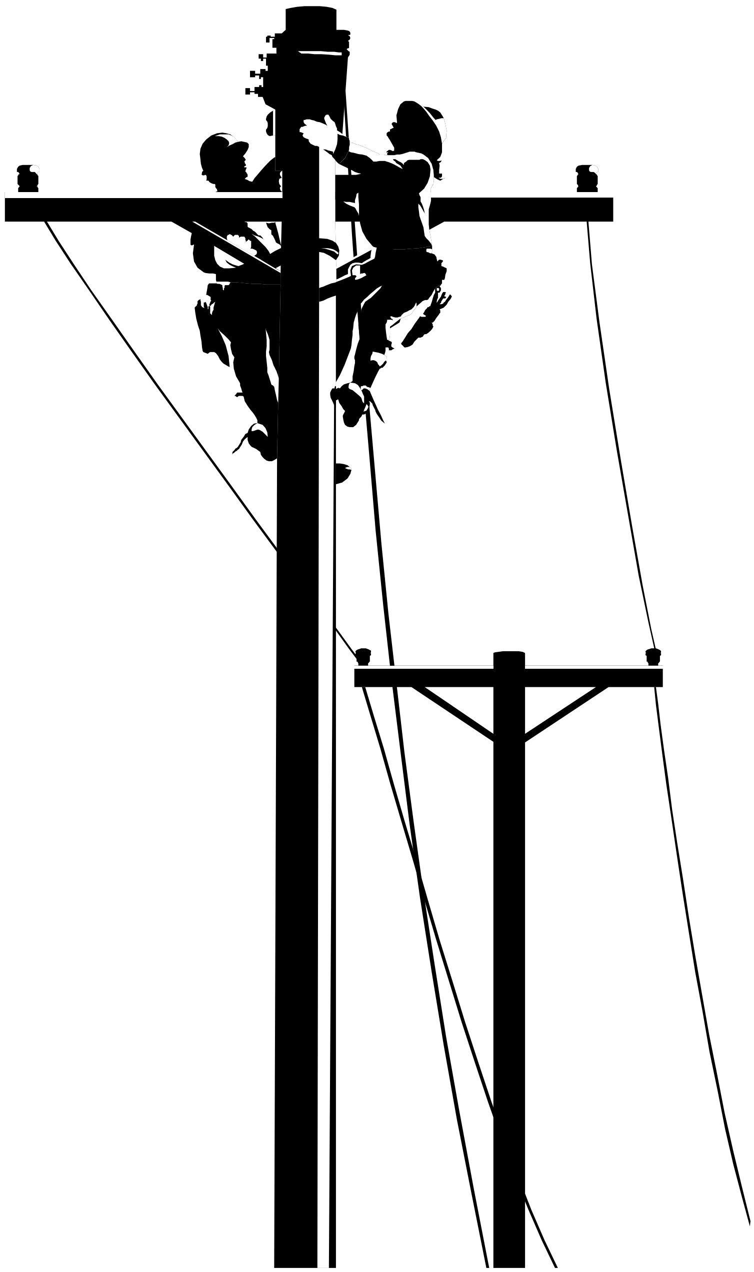
In coordinating with a pump technician, concerning an improperly functioning down-hole sensor, a transformer connection should not be readily assumed to be the cause of the problem over a faulty or incorrectly installed sensor.

There is some evidence, based on field experience, that some multi-tap transformer brands connected Y-Y and used on down-hole pumps, do not adversely affect sensors while other multi-tap transformer brands installed in conjunction with the same equipment and parameters, will adversely affect sensors.

An ungrounded primary on a Y-Y will pass ground-fault current from the primary system to the secondary. An ungrounded primary on a Y-Y may also develop excessive voltages on the secondary side. (6)

It is necessary that the primary neutral be available when this connection is used, and the neutrals of the primary system and of the bank are tied together as shown. If the three-phase load is unbalanced, part of the load current flows in the primary neutral. Also the third-harmonic component of the transformer exciting current; flows in the primary neutral. For these reasons, it is necessary that the neutrals be tied together as shown. If this tie were omitted, the line to neutral voltages on the secondary would be very unstable. That is, if the load on one phase were heavier than on the other two, phases would rise. Also, large third-harmonic voltages would appear between lines and neutral, both in the transformers and in the secondary system, in addition to the 60-Hz component of voltage. This means that for a given value of RMS voltage, the peak voltage would be much higher than for a pure 60-Hz voltage. This overstresses the insulation both in the transformers and in all apparatus connected to the secondaries. (11)

CHAPTER V BOOSTER TRANSFORMERS



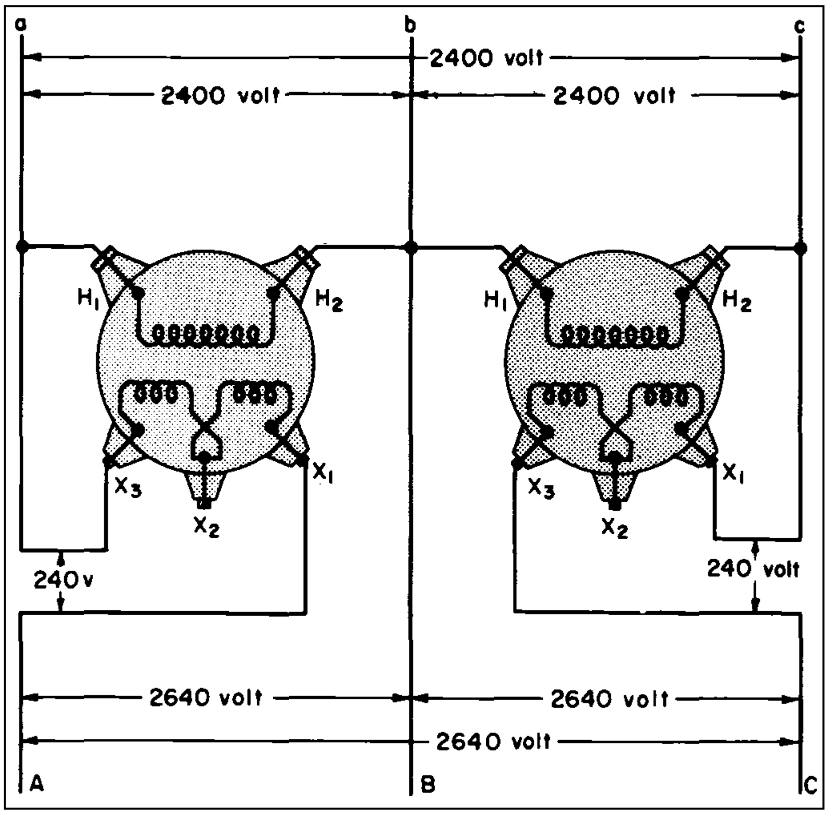
THREE-PHASE

BOOSTER 3Ø -3 WIRE / HIGH VOLTAGE

WHERE USED

To improve voltage at the outer limits of a three-phase, three-wire system. This connection will give a 10% boost in voltage, as shown for a 2400-volt system. By connecting the windings in parallel, a 5% boost is obtained, and the bank will buck the voltage if the lines to X3 and X1 are interchanged. (5)

DIAGRAM



(5)

CAUTION

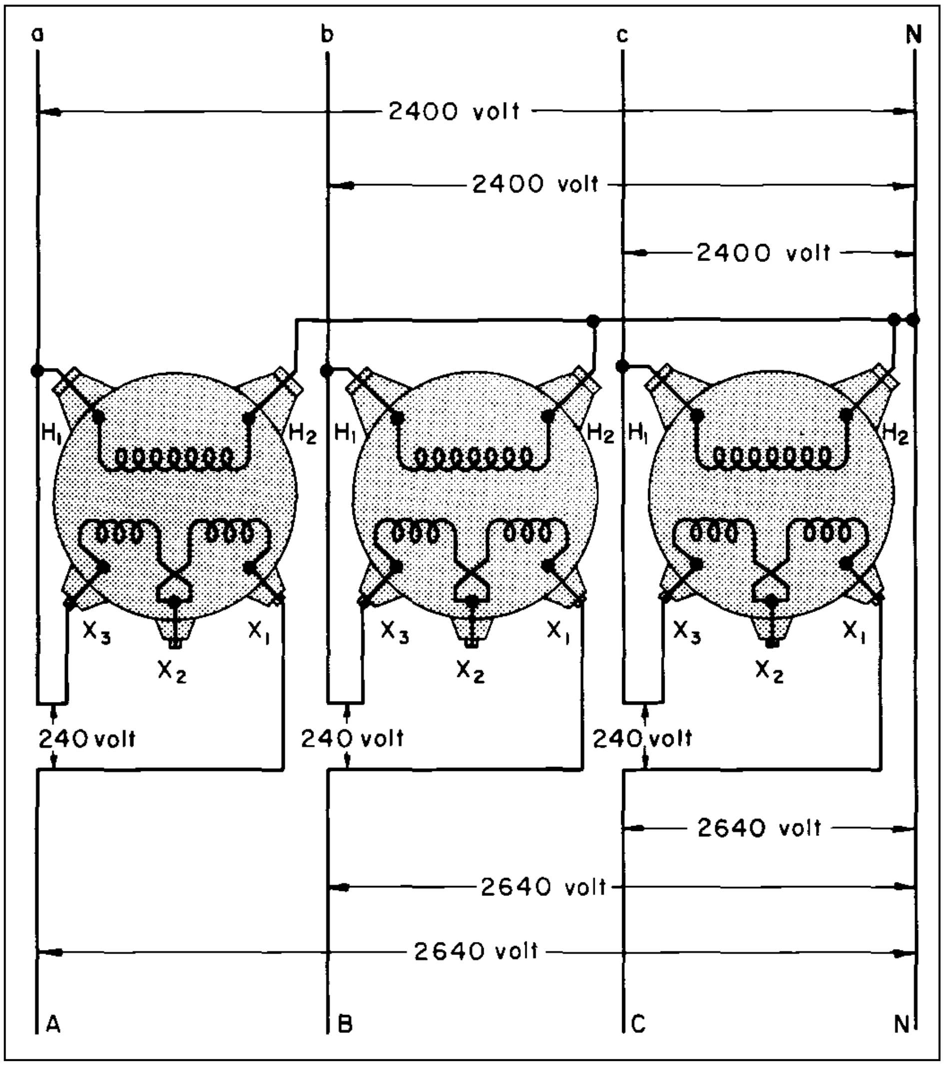
THIS IS AN EMERGENCY CONNECTION TRANSFORMERS ARE USUALLY PAINTED RED AS A WARNING. The transformer should not be fused or have any device by which it can be readily disconnected. The low-voltage windings and bushings must be insulated to the same value as the high-voltage. Transformer primary must never be opened while the secondary carries current, as dangerous voltages will be induced by the series winding. (5)

BOOSTER 3Ø - 4 WIRE / HIGH VOLTAGE

WHERE USED

For improving voltage at the outer limits of a system. This connection will give 5% or 10% boost in voltage as shown for a 2400-volt system. It may be connected to buck the voltage by interchanging the two low-voltage lines. (5)

DIAGRAM



(5)

CAUTION

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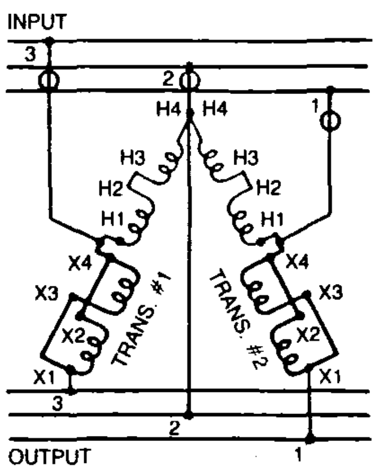
BUCK & BOOST 3Ø / LOW VOLTAGE

BUCK & BOOST 3Ø

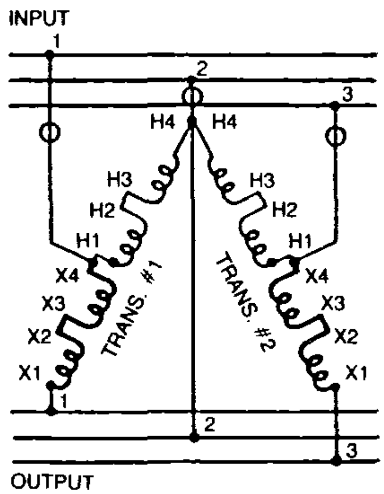
DIAGRAM

TRANSFORMER CONNECTIONS

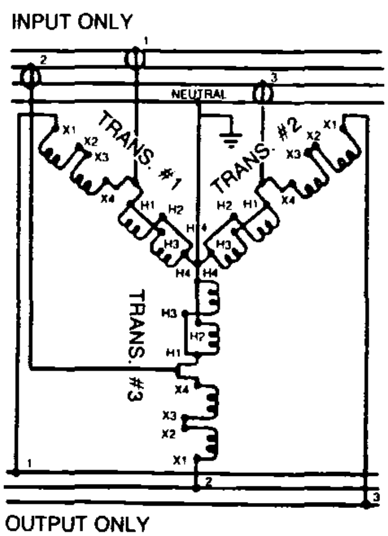
TYPICAL THREE-PHASE
BUCK AND BOOST CONNECTIONS



OPEN DELTA*



OPEN DELTA*



WYE*

Diagrams are for boost. For buck, reverse input and output, except for wye diagram, which cannot be reversed.

The symbol "O" used in these connection diagrams indicates where to field-install the overcurrent protective device, typically a fuse or circuit breaker. (3)

***It is recommended that all transformers be connected as shown on the manufacturer's nameplate.**

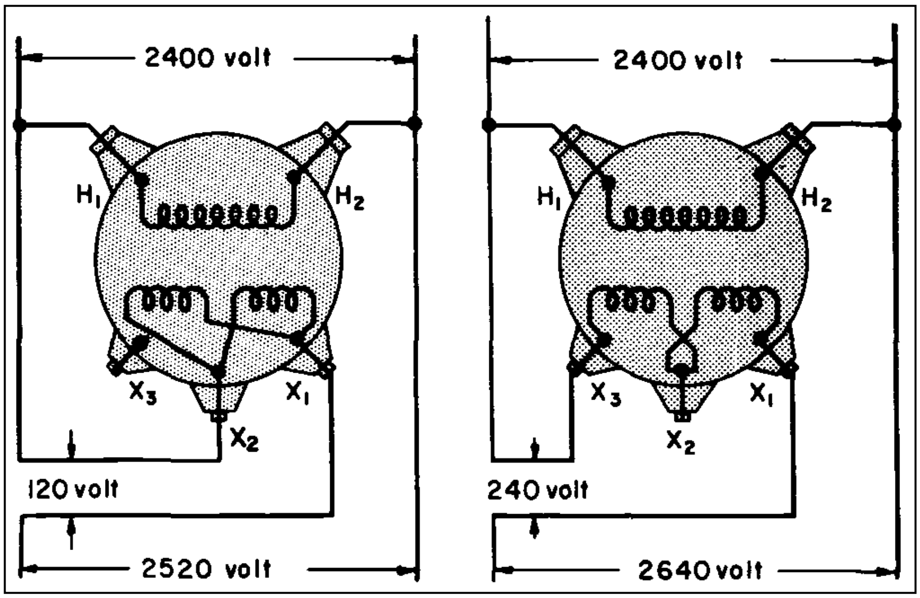
SINGLE-PHASE

BOOSTER 1Ø / HIGH VOLTAGE

WHERE USED

For improving voltage at the outer limits of a system. This connection will give 5% or 10% boost in voltage as shown for a 2400-volt system. It may be connected to buck the voltage by interchanging the two low-voltage lines. (5)

DIAGRAM



(5)

CAUTION

THIS IS AN EMERGENCY CONNECTION TRANSFORMERS ARE USUALLY PAINTED RED AS A WARNING. The transformer should not be fused or have any device by which it can be readily disconnected. The low-voltage windings and bushings must be insulated to the same value as the high-voltage. Transformer primary must never be opened while the secondary carries current, as dangerous voltages will be induced by the series winding. (5)

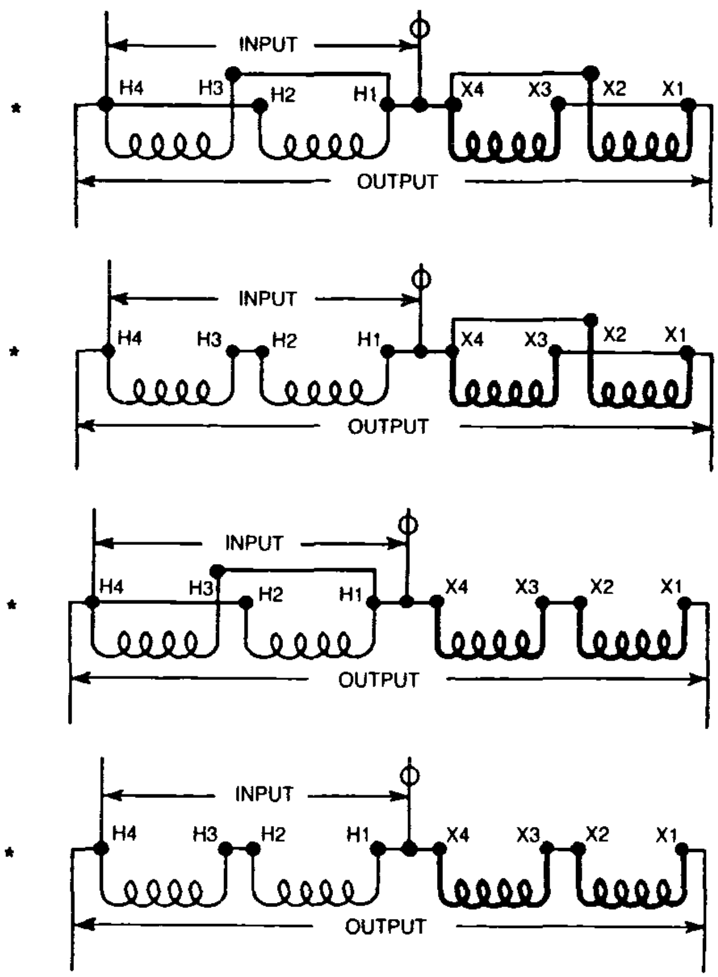
BUCK & BOOST 1Ø / LOW VOLTAGE

BUCK & BOOST 1Ø

DIAGRAM

TRANSFORMER CONNECTIONS

TYPICAL SINGLE-PHASE
BUCK AND BOOST CONNECTIONS

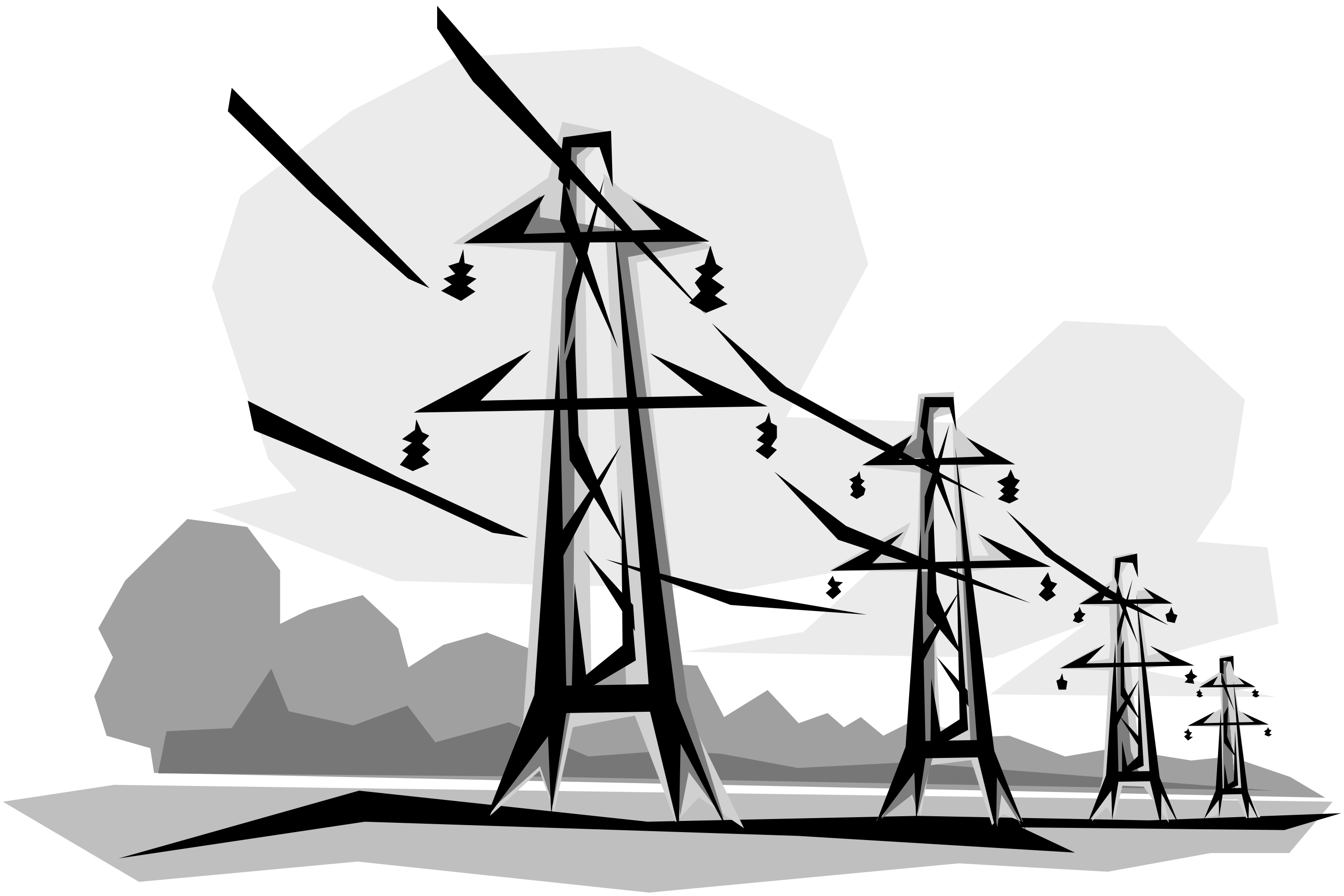


Diagrams are for boost. For buck, reverse input and output.

The symbol "O" used in these connection diagrams indicates where to field-install the overcurrent protective device, typically a fuse or circuit breaker. (3)

***It is recommended that all transformers be connected as shown on the manufacturer's nameplate.**

CHAPTER VI AUTO TRANSFORMERS



THREE-PHASE

YY AUTO 3Ø / NEUTRAL = PRIM YES-SEC NO

WHERE USED

For increasing voltage at the end of lines or to step up voltage where line extensions are being added to existing lines, such as from 6900 VAC to 7200 VAC. Cost per kva output is less than a two-winding transformer; losses are low, regulation is good, and exciting current is low. Voltage transformation greater than 3 to 1 is not recommended. (5)

FOR POWER FROM A 3Ø, 4W SYSTEM

When the ratio of transformation from the primary to secondary voltage is small, the most economical way of stepping down the voltage is by using autotransformers as shown. For the application, it is necessary that the neutral of the auto transformer bank be connected to the system neutral. Brand circuits shall not be supplied by autotransformers. (3)

CAUTION

Susceptive to burnouts if the system impedance is not great enough to limit the short-circuit current to 20 to 25 times the transformer-rated current. The primary neutral should be tied firmly to the system neutral; otherwise, excessive voltages may develop on the secondary side. (5)

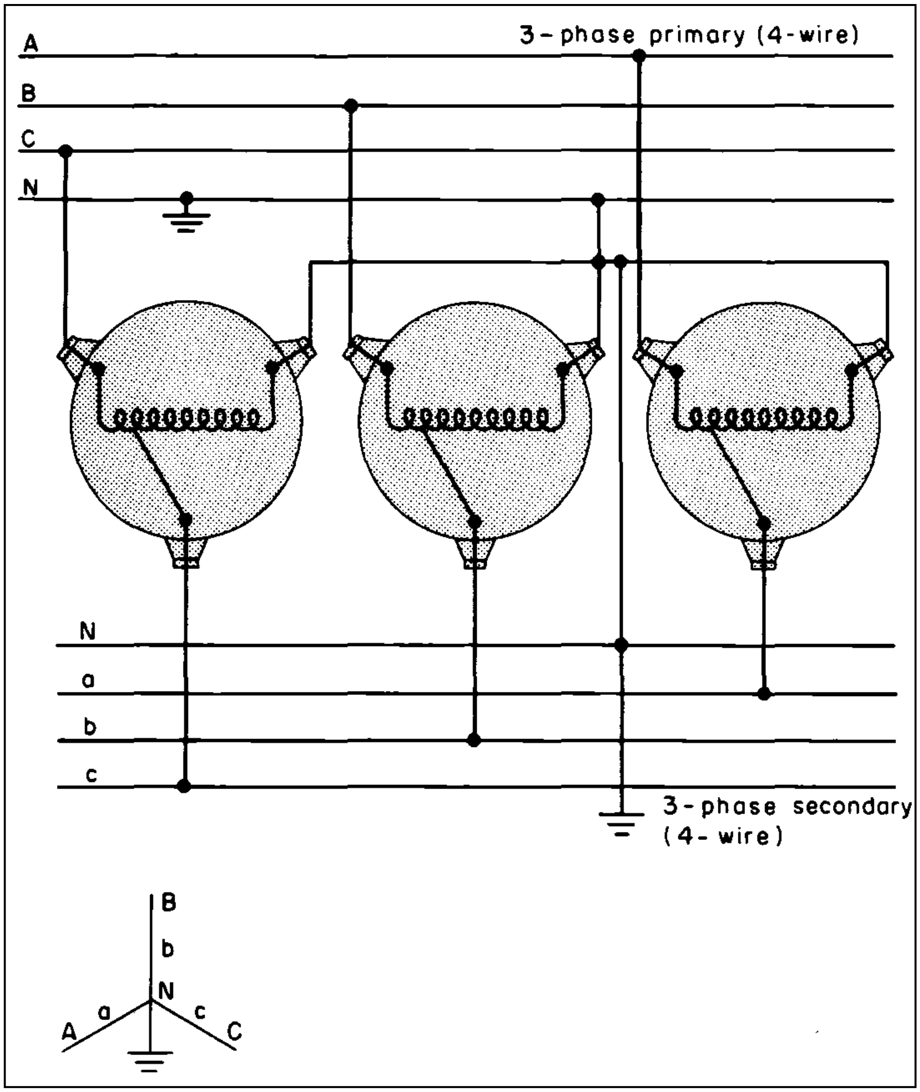
RATING & FUNCTION

A considerable saving in cost may often be experienced by using autotransformers instead of two-winding transformers. When it is desired to affect a small change in voltage, or where both high and low voltages are low, there is usually no reason why an autotransformer cannot be used as successfully as a two-winding transformer.

Autotransformers should not, except under special conditions, be used where the difference between the high-voltage and low-voltage ratings is great. This is because the occurrence of grounds at certain points will subject the insulation on the low-voltage circuit to the same stress as the high-voltage circuit.

Autotransformers are rated on the basis of output KVA rather than the transformer KVA. Efficiencies, regulation and other electrical characteristics are also based on output rating. (5)

DIAGRAM


3-phase primary (4-wire)
A
B
C
N
N
a
b
c
3-phase secondary
(4-wire)
B
b
N
A
a
c
C

(5)

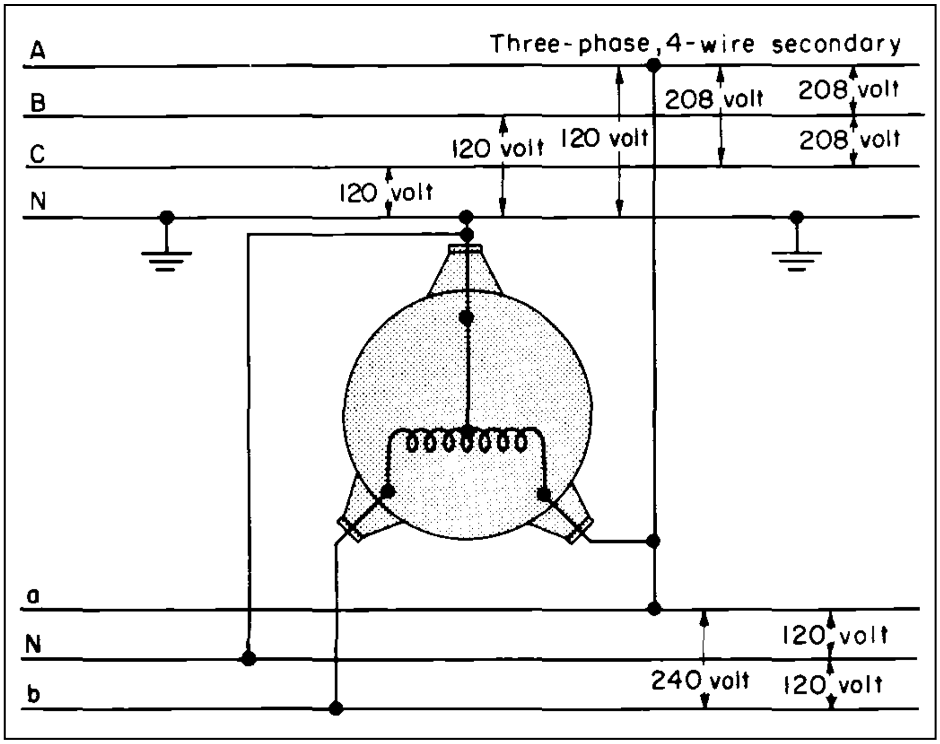
SINGLE-PHASE

1Ø - AUTOTRANSFORMER

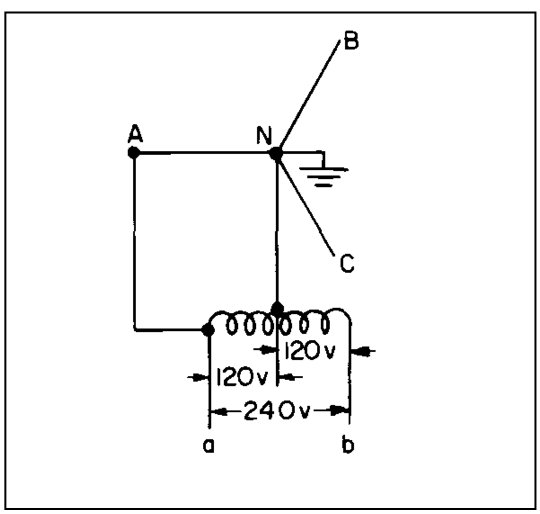
WHERE USED

For converting from a 208Y/120 VAC system to an l20/240 VAC system. This is probably the most economical method of doing this job. (5)

DIAGRAM

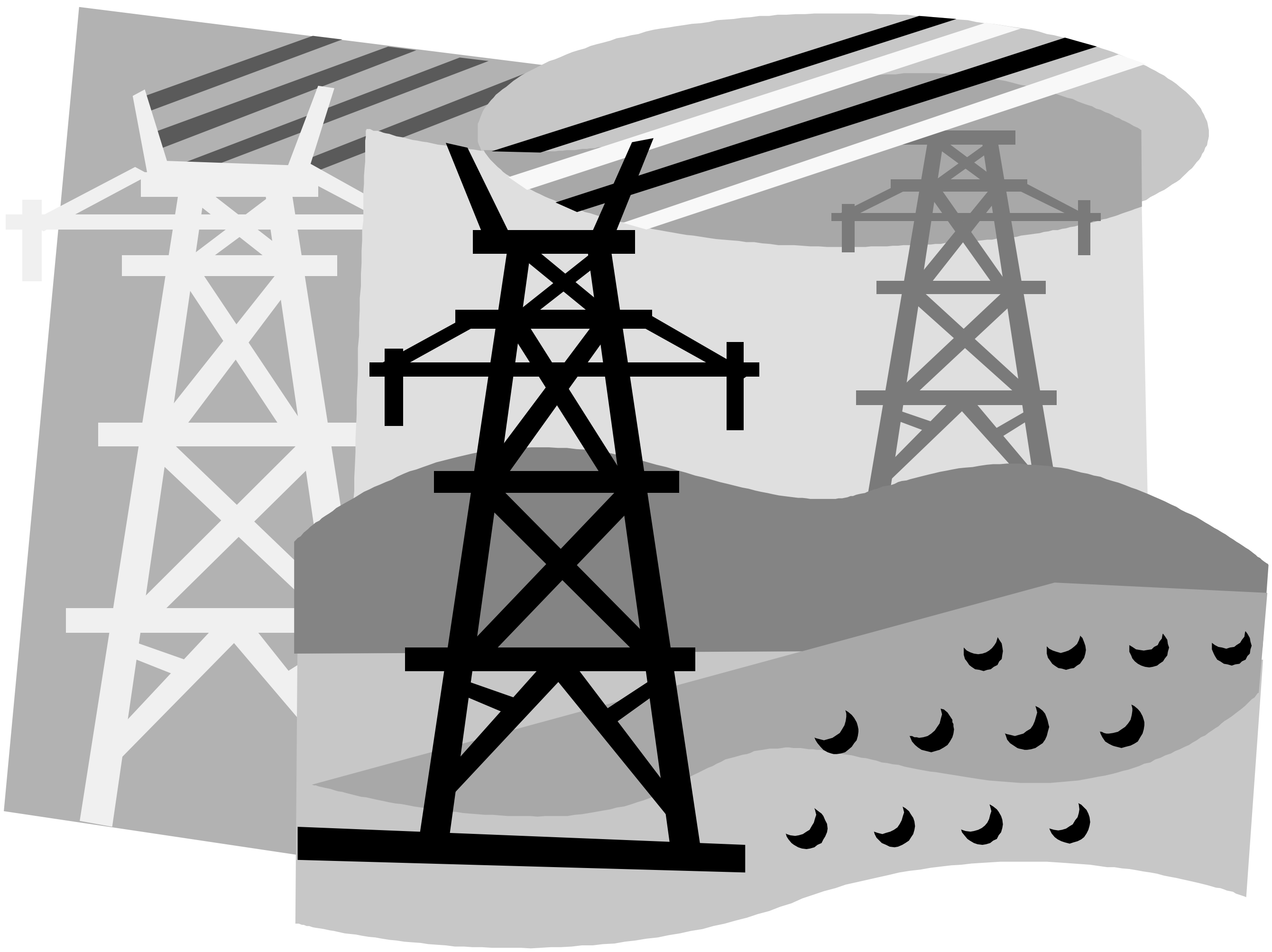


(5)



(5)

CHAPTER VII DRY TYPE TRANSFORMERS

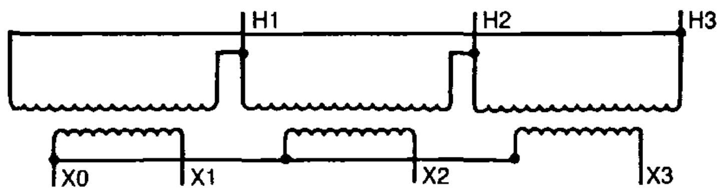


THREE-PHASE

DRY-TYPE 3Ø

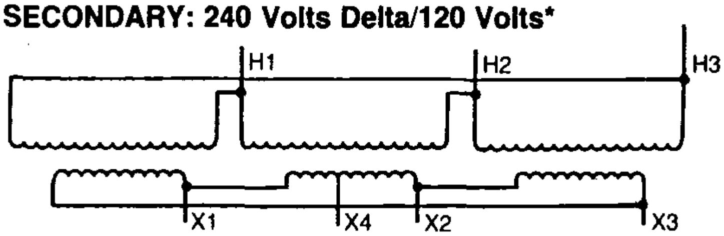
DIAGRAM

PRIMARY: 480 Volts Delta
SECONDARY: 208Y/120 Volts*



PRIMARY VOLTS	CONNECT PRIMARY LINES TO	CONNECT SECONDARY LINES TO
480	H1, H2, H3	—
SECONDARY VOLTS		
208	—	X1, X2, X3
120, 1 PHASE	—	X1 to X0 X2 to X0 X3 to X0

PRIMARY: 480 Volts Delta
SECONDARY: 240 Volts Delta/120 Volts*



PRIMARY VOLTS	CONNECT PRIMARY LINES TO	CONNECT SECONDARY LINES TO
480	H1, H2, H3	—
SECONDARY VOLTS		
240	—	X1, X2, X3
120	—	X1, X4 or X2, X4

(3)

HIGH-LEG MARKING

NEC 2002: 110.15 High-Leg Marking.
On a 4-wire, delta-connected system where the midpoint of one phase winding is grounded to supply lighting and similar loads, the conductor or busbar having the higher phase voltage to ground shall be durably and permanently marked by an outer finish that is orange in color or by other effective means. Such identification shall be placed at each point on the system where a connection is made if the grounded conductor is also present.

(9)

NEC 2002 Handbook:
Added for the 2002 Code, this section now contains a requirement that appeared in 384-3(e) of the 1999 NEC. This requirement was moved to Article 110, where the application becomes a more general requirement.

The high leg is common on a 240/120-volt 3-phase, 4-wire delta system. It is typically designated as "B phase." The high-leg marking is required to be the color orange or other similar effective means and is intended to prevent problems due to the lack of complete standardization where metered and non-metered equipment are installed in the same installation. Electricians should always test each phase relative to ground with suitable equipment to determine exactly where the high leg is located in the system. (12)

ARRANGEMENT OF BUSBARS AND CONDUCTORS

NEC 2002: 408.3 / Support and Arrangement of Busbars and Conductors / (E) Phase Arrangement
The phase arrangement on 3-phase buses shall be A, B, C from front to back, top to bottom, or left to right, as viewed from the front of the switchboard or panelboard. The B phase shall be that phase having the higher voltage to ground on 3-phase, 4-wire, delta-connected systems. Other busbar arrangements shall be permitted for additions to existing installations and shall be marked.

Exception: Equipment within the same single section or multisection switchboard or panelboard as the meter on 3-phase, 4-wire, delta-connected systems shall be permitted to have the same phase configuration as the metering equipment.

FPN: See 110.15 for requirements on marking the busbar or phase conductor having the higher voltage to ground where supplied from a 4-wire, delta-connected system. (9)

NEC 2002 Handbook:
The high leg is common on a 240/120-volt, 3-phase, 4-wire delta system. It is typically designated as "B phase." Section 110.15 requires the high-leg marking to be the color orange or other similar effective means of identification. Electricians should always test each phase to ground with suitable equipment in order to know exactly where this high leg is located in the system.

The exception to 408.3(E) permits the phase leg having the higher voltage to ground to be located at the right-hand position (C phase), making it unnecessary to transpose the panelboard or switchboard busbar arrangement ahead of and beyond a metering compartment. The exception recognizes the fact that metering compartments have been standardized with the high leg at the right position (C phase) rather than in the center on B phase.

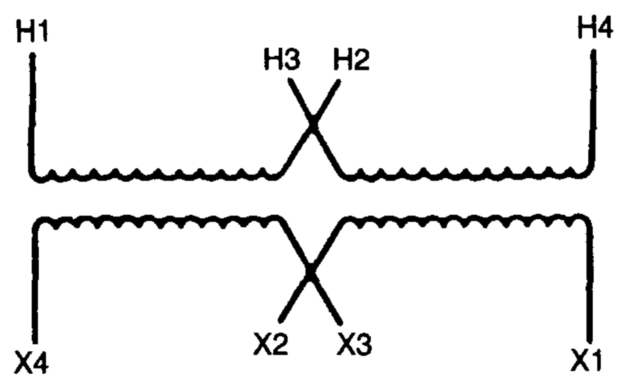
See also 110.15, 215.8, and 230.56 for further information on identifying conductors with the higher voltage to ground. Other busbar arrangements for making additions to existing installations are permitted by 408.3(E). (12)

SINGLE-PHASE

DRY-TYPE 1Ø

DIAGRAM

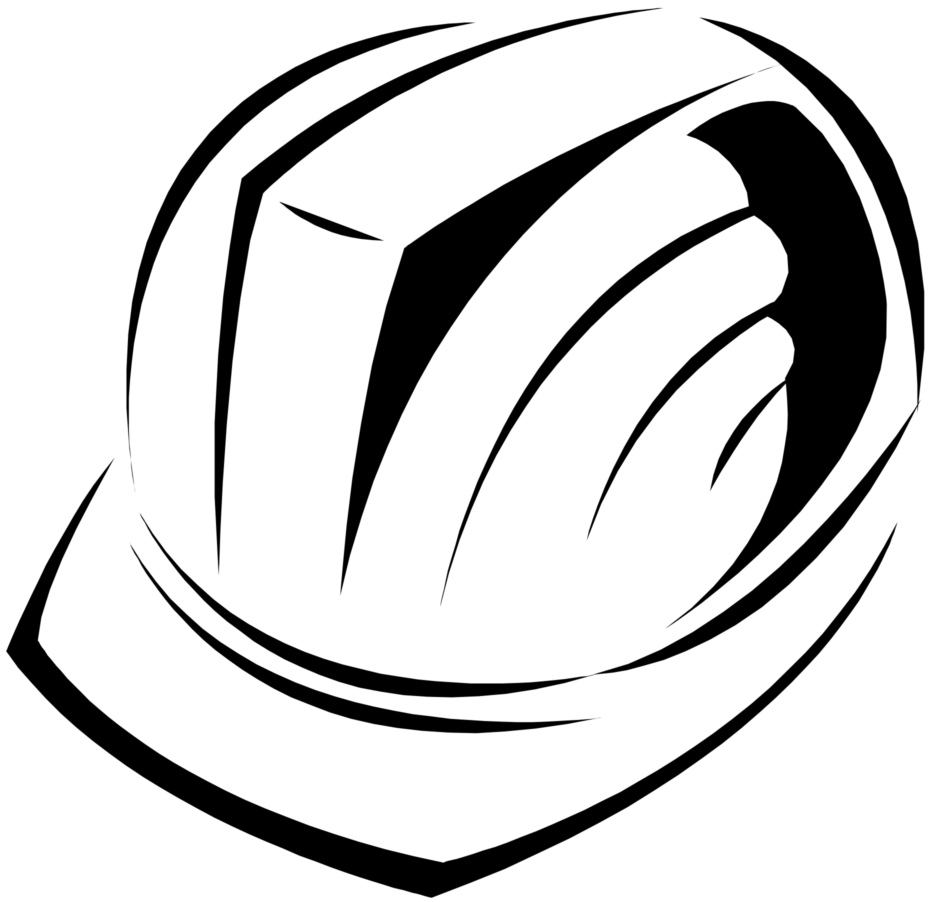
PRIMARY: 120/240 Volts
SECONDARY: 120/240 Volts*



PRIMARY VOLTS	CONNECT PRIMARY LINES TO	INTER-CONNECT	CONNECT SECONDARY LINES TO
240	H1-H4	H2 to H3	—
120	H1-H3 & H2-H4	—	—
SECONDARY VOLTS			
240	—	X1 to X3	X1-X4
120/240	—	X2 to X3	X1-X2-X4
120	—	X1 to X3 X2 to X4	X1-X4

(3)

CHAPTER VIII TRANSFORMER NOTES



GENERAL

MISCELLANEOUS SUBJECTS

OPEN 3Ø BANK CAPACITY

When 1 transformer of a 3-pot bank is disabled in a 3-phase connection, the remaining 2 will operate at 57.7% of the original 3 or 87% of the remaining 2. (6)

YY FOR USE ON A DOWN-HOLE PUMP

In respect to the secondary of an YY connection being purposely isolated from ground for the function of a down-hole pump sensor. The typical connection for YY is grounding both the primary and secondary. The primary must be grounded without exception in the YY configuration. The secondary can float, that is to be isolated from ground. (1)

Some down-hole sensors will function properly with the secondary of a Y-Y grounded, and thus by habit the secondary should initially be grounded unless or until instructed otherwise.

By experience, there have been times that the primary ground in a Y-Y has created adverse effects on a down-hole sensor and field personnel have been asked to remove the primary ground connection. Field personnel should never take it upon themselves to remove the primary ground of a Y-Y. Field personnel must relay such a request to their immediate supervisor. The supervisor, in turn, must contact the owner of the down-hole equipment and clearly explain the request to remove a ground and the potentially excessive damage this action might have on transformers, drives or motors.

After clearly explaining the dangers of an isolated YY primary connection to a client and the client insists on having the ground removed, then one would comply only with the safety addition of a “chain ground” (a fourth or neutral cutout) to be temporally closed prior to closing the three power cutouts to avoid adverse ferroresonance effects. After the three power cutouts are closed, then the chain ground cutout would be opened.

In coordinating with a pump technician, concerning an improperly functioning down-hole sensor, a transformer connection should not be readily assumed to be the cause of the problem over a faulty or incorrectly installed sensor.

There is some evidence, based on field experience, that some multi-tap transformer brands connected Y-Y and used on down-hole pumps, do not adversely affect sensors while other multi-tap transformer brands installed in conjunction with the same equipment and parameters, will adversely affect sensors.

An ungrounded primary on a Y-Y will pass ground-fault current from the primary system to the secondary. An ungrounded primary on a Y-Y may also develop excessive voltages on the secondary side. (6)

It is necessary that the primary neutral be available when this connection is used, and the neutrals of the primary system and of the bank are tied together as shown. If the three-phase load is unbalanced, part of the load current flows in the primary neutral. Also the third-harmonic component of the transformer exciting current; flows in the primary neutral. For these reasons, it is necessary that the neutrals be tied together as shown. If this tie were omitted, the line to neutral voltages on the secondary would be very unstable. That is, if the load on one phase were heavier than on the other two, phases would rise. Also, large third-harmonic voltages would appear between lines and neutral, both in the transformers and in the secondary system, in addition to the 60-Hz component of voltage. This means that for a given value of RMS voltage, the peak voltage would be much higher than for a pure 60-Hz voltage. This overstresses the insulation both in the transformers and in all apparatus connected to the secondaries. (11)

3rd HARMONIC PHONE SYSTEM INTERFERENCE

"Although early day operations were forced to abandon the idea of grounding the wye in most cases, because the third harmonic caused so much trouble with telephone systems, today's telephone systems are usually so well shielded that this is no longer a cause for concern." (4)

Third harmonic interference with telephones is in reference to grounded primary wye connections. Interference can occur in both the closed and open primary wye banks. Present day telephone systems are not as susceptible to interference due to the shielding of telephone cables. (6)

FERRORESONANCE

This one word describes a circuit condition that is probably more responsible for the renewed interest today in the wye-wye connection than any one other single factor.

Any time we energize a three phase bank, without its neutral grounded, whether it consists of one three phase transformer of three single phase units, by closing single phase switches or fused cutouts, one at a time, we are energizing an inductance in series with a capacitance. If the value of the line capacitance and the transformers own built in capacitance approaches the inductive value of the transformer's winding, a resonant condition will result in which the capacitive reactance will effectively cancel out the inductive reactance of the circuit. During this condition, only the fairly low resistance of the transformer and the primary cable will limit the current, which can then become very large. This current will flow through the capacitive reactance of both the transformer and the cable and the inductive reactance of the transformer, developing extremely large voltages across them. It is these high voltages that can cause damage to the entire system. Since transformer inductance is proportional to the square of the line voltage and inversely proportional to the KVA size, whereas line capacitance increases very slightly as the voltage increases its value is going to increase very rapidly as the line voltage increases and the ration of inductance to capacitance will approach the range where ferroresonance is likely on higher system voltages. It is for this reason that ferroresonance was unknown on 2400/4160 volt systems and rather uncommon on 7200/12470 volt systems switched from fairly short overhead feeders. The problem really becomes acute if the system voltage is 14400/24940 volts or higher or if a 7200/12470 volt bank is fed from underground shielded primary cable or extremely long overhead lines.

The simplest and most foolproof method of avoiding ferroresonance is to solidly ground the transformer bank neutral. This eliminates the series LC path and makes it impossible to put the circuit in a resonant condition. Since, as we have previously pointed out, good operating practices do not usually allow grounding of primary on a wye-delta bank (or a delta-delta), our only alternative, if we are looking for a foolproof solution to the problem of ferroresonance, is to turn to a wye-wye connection with both primary and secondary neutrals tied together and grounded solidly to the system neutral. Although early day operations were forced to abandon the idea of grounding the wye in most cases, because the third harmonic caused so much trouble with telephone systems, today's telephone systems are usually so well shielded that this is no longer a cause for concern. (4)

Ferroresonance is unlikely at 7,200/12,470 VAC or lower but can be a potential problem at 14,400/24,900 V AC and higher. Smaller transformers are more susceptible to ferroresonance problems than larger transformers. If while installing the first cutout, or more likely the second cutout, you hear a rumbling or growling coming from the transformers then a ferroresonance problem exists. A "chain ground" (a fourth or neutral cutout) would be required in the case of ferroresonance to ground the secondary system while closing in the phase cutouts. After the phase cutouts are closed then the chain ground should be opened back up. (1)

Negative affects of ferroresonance are potentially present on non-grounded primary wye connections. There is more danger at 14,400/24.900 VAC and higher. There is more danger with smaller transformers.
A rule-of-thumb concerning negative ferroresonance effects is that transformers 25 KVA and smaller at 14,400/24,900 are susceptible to damage. 30 KVA and larger transformers are relatively safe from adverse ferroresonance effects at 14,400/24,900. Higher voltages than 14,400/24,900 would necessitate larger transformers than 30 KVA to be considered inherently safe from adverse ferroresonance effects.

On a floating Y-Δ connection, temporarily ground the primary neutral when closing or opening primary fuses to avoid adverse ferroresonance effects. A "chain ground" (a fourth or neutral cutout) should be installed and closed while closing or opening the power cutouts and then re-opened after all of the power cutouts are closed.

Configurations used to avoid ferroresonance are an open Y-Δ with a solidly grounded primary Y or a Y-Y with a solidly grounded primary and secondary Y connection. (6)

CORNER-OF-THE-DELTA GROUNDED

Open or closed-delta systems may be operated grounded by connecting one of the secondary-phase wires to ground. The neutral is displaced thereby raising the phase-to-ground stress on the other two phases by a factor of 1.73. From an operational standpoint, this system will perform as a grounded system.

With an overhead open-wire system, some shielding from lightning is obtained by selecting the top wire as the ground wire; however, the basic impulse level of low-voltage systems is not high enough for shielding to be effective. Grounding the corner of the delta is good insurance against arcing grounds; however, to improve the protection from lightning of any particular motor on the system, arresters should be properly applied with a metallic connection from the arrester to the machine frame and a low-resistance ground connection made at both the machine and the arrester. (2)

In some areas of the country the term "widow maker" is used as slang in reference to corner grounding a phase. (6)

STATIC DISCHARGE

Potentially present on a non-grounded primary wye connection. A high, excessive voltage results on a 3-phase Y-Δ connection on the secondary line to ground when one leg of the primary is open. The voltage present is static with no power and bleeds off when taken to ground. This static can damage a volt-ohm meter. The static is greater when the secondary feeder is short and lesser when the secondary feeder is long. The static problem is resolved by grounding one phase or the center tap of one transformer on the secondary side, but this usually requires special KWH metering. This static condition is present only when a primary line is open, not the secondary. This static condition can occur on an open (2-transformers) or closed (3-transformers) bank. This static condition can occur with any primary voltage. (6)

POLARITY

POLARITY GENERAL INFORMATION

The polarity of a transformer refers to the voltage vector relations of the leads, as brought outside the case. Bushing locations and designations are such as to indicate the polarity as being subtractive or additive. This is illustrated in Fig. 3-8.

Primary and secondary leads are said to have the same polarity when current enters the primary lead in question and leaves the secondary lead in question in the same direction as though the two leads formed a continuous circuit.

To determine by test the lead polarity of a single-phase transformer, connect one high-voltage lead and the adjacent low-voltage lead and apply a voltage to one of the windings. The lead polarity is additive if the voltage measured across the other two leads (one high-voltage and one low-voltage lead) is greater than the high-voltage winding alone. The lead polarity is subtractive if this voltage is less than the high-voltage winding alone.

Insofar as polarity is concerned, single-phase additive and subtractive polarity transformers may be paralleled or operated in three-phase banks provided leads of like designation are connected as though they were of the same polarity. In other words, disregard the relative position of the leads and connect the transformers according to lead designations (H1, H2, and X1, X2). This point is illustrated in Fig. 3-9.

Additive polarity is standard for all single-phase transformers, 200 KVA and below, having a high-voltage rating of 8,660 volts and below. Subtractive polarity is standard for all other single-phase transformers. (2)

POLARITY FIELD APPLICATION

Additive or subtractive polarity is marked on transformer nameplates. If transformers in a bank are identical then there is no question concerning polarity as long as all of the H bushings and X bushings are connected the same. If a replacement transformer has a different polarity than the existing bank of transformers, then the H bushings and X bushings of that transformer alone would be connected opposite of the others.

See the note on impedance for additional cautions on replacement transformers. (6)

POLARITY DIAGRAM (1)

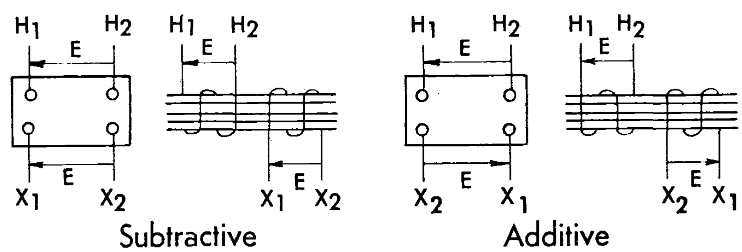


Fig. 3-8—Standard polarity for two-winding transformers.

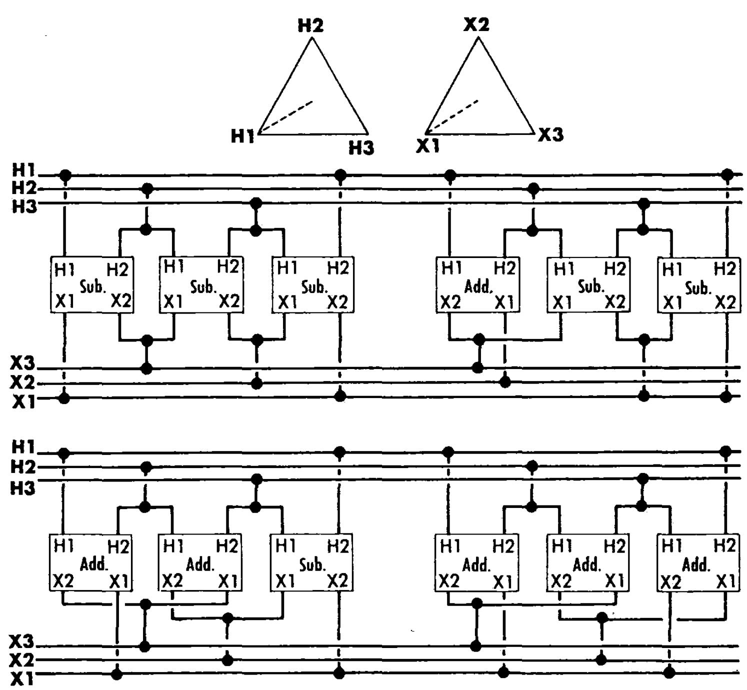


Fig. 3-9—Additive and subtractive polarity transformers in the same bank.

(2)

Transformer polarity is an indication of the direction of current flow through the high-voltage terminals with respect to the direction of current flow through the low-voltage terminals at any given instant in the alternating cycle.

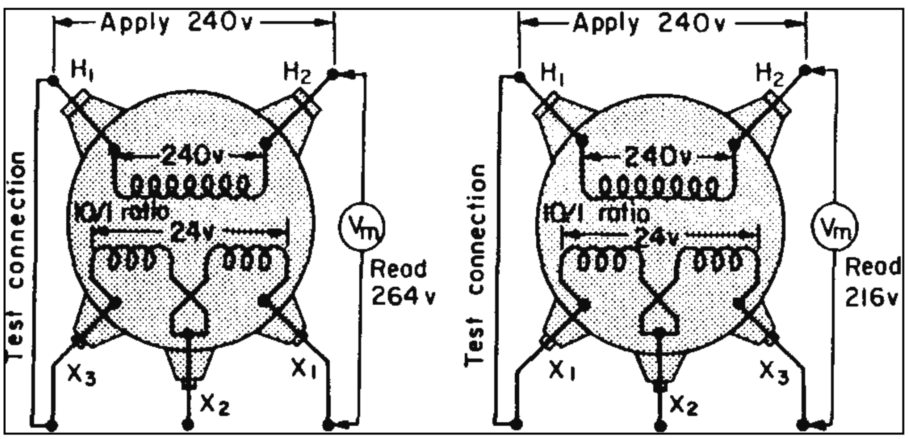
The polarity of a single-phase distribution transformer may be additive or subtractive. A simple test for polarity is to connect two adjacent terminals of the high and low-voltage windings together and apply a moderate voltage to either winding.

The polarity is additive if the voltage across the other two leads of the windings in question is greater than that of the high-voltage winding alone (Fig. A).

The polarity is subtractive if the voltage across the other two leads of the windings in question is less than that of the high-voltage winding alone (Fig. B).

By industry standards, all single-phase distribution transformers 200 KVA and smaller, having high voltages 8660 volts and below (winding voltage) have additive polarity. All other single-phase transformers have a subtractive polarity.
(5)

POLARITY DIAGRAM (2)



(5)

POLARITY MARKINGS FOR 1Ø AND 3Ø

By Industry Standards, the high-voltage terminal marked HI is brought out at the right-hand terminal of the high-voltage group as seen when facing the high voltage side of the case, and other "H" terminals are brought out in numerical order from right to left. The H0 terminal of three-phase transformers, if present, is located to the right of the H1 terminal as seen when facing the highest voltage side of the case.

For single-phase transformers, the low-voltage Xl terminal is on the right, when facing the low-voltage side of the transformer, for additive polarity (HI is diagonally located with respect to XI) and the low-voltage Xl terminal is on the left for subtractive polarity (HI and Xl are adjacent).

For three-phase transformers, the X1 terminal is brought out as the left-hand terminal of the "X" group as seen when facing the "X" winding side of the case. The X_2 and X3 terminals are brought out so that the three terminals are arranged in numerical order reading from left to right when facing the "X" winding side of the case. The Xo terminal, if present, is located to the left of the XI terminal as seen when facing the "X" winding side of the case. X_4 designates a tap in one of the secondary windings to supply a 120-volt, single-phase circuit between XI and X_4. (5)

FAULT RATING

FAULT CURRENT RATING

Fault Close Rating - The ability of a switching device to close into a fault current of a specific magnitude without excessive arcing.

Over-current protective devices, such as fuses and circuit breakers, have time/current characteristics that determine the time it takes to clear the fault for a given value of fault current. Selectivity occurs when the device closest to the fault opens before the next device upstream operates. For example, any fault on a branch circuit should open the branch circuit breaker rather than the feeder over-current protection. All faults on a feeder should open the feeder over-current protection rather than the service over-current protection. When selectivity occurs, the electrical system is considered to be coordinated.

Most electrical distribution systems can deliver high ground-fault or short-circuit currents to components such as conductors, service equipment, and the like. These components may not be able to handle short-circuit currents; they may be damaged or destroyed, and serious burn-downs and fires could result. Properly selected current-limiting over-current protective devices, such as the ones shown in Exhibit 240.1, limit the let-through energy to within the rating of the components, in spite of high available short-circuit currents. A current-limiting protective device is one that cuts off a fault current in less than one-half cycle. It thus prevents short-circuit currents from building up to their full available values.

With coordinated over-current protection, the faulted or overloaded circuit is isolated by the selective operation of only the over-current protective device closest to the over-current condition. This isolation prevents power loss to unaffected loads. (7)

FAULT CURRENT

Fault Current - The current from the connected power system that flows in a short circuit.

Full load current X 100 X impedance (Z) =amp short circuit (ASC) or fault current (the “100” factor removes the decimal). Example: 416 x 100 / 25 =1,664

ASC is the amount of current that can flow through a breaker before it trips. If the current exceeds the breakers ASC rating, then the breaker will be damaged. An example is a cup of water held upright and quickly turned upside down and back upright again. The amount of water lost is determined by the speed of returning the cup upright. If the cup is moved quickly enough, little or no water (current) will be lost; but if the cup is moved slowly, a sizable amount of water (current) would be spilled.

Caution should be taken when changing out a single-phase or 3-phase transformer with different impedance. A replacement transformer with lower impedance will increase the ASC rating of the transformer. This rating could potentially damage a breaker if the breaker is not rated with a matching ASC.

Example:

416 x 100 / 25 =1,664

416 x 100 / 20 =2,080

416 x 100 / 30 =1,386

The impedance rule of thumb when changing out 1 single pot transformer on a 2 or 3 pot bank is not to exceed a difference of 10% in impedance. A difference in impedance creates additional current.

Example:

One transformer burns up on a 3 pot bank and it must be replaced. The only transformer available has the same KVA rating but a different impedance rating.

The good transformers have an impedance of 25. 10% of 25 are 2.5. The replacement transformer should have an impedance of no less than 22.5 (25-2.5) or no more than 27.5 (25+2.5).

Any difference in impedance will create an increase in current. A difference in impedance exceeding 10% will create an excessive current. (7)

INTERRUPTING RATING

NEC 110-9 Interrupting Rating (9)

Equipment intended to interrupt current at fault levels shall have an interrupting rating sufficient for the nominal circuit voltage and the current that is available at the line terminals of the equipment.

Equipment intended to interrupt current at other than fault levels shall have an interrupting rating at nominal circuit voltage sufficient for the current that must be interrupted.

Example:
Full Load Amps = (KVA x 1000) / (Volt x 1.732 for 3 phase)

150 KVA at 208 volts
(150 x 1000) / (208 x 1.732 150,000 / 359.84 = 416 FLA

(FLA x 100) / Z = Fault Current

(416 x 100) / 20 (independence of old transformers) = 2,080 Fault Current
(416 x 100) / 2 (independence of most transformers) = 20,800 Fault Current
(416 x 100) / .5 (independence of transformers coming out soon) = 83,200 Fault Current
(7)

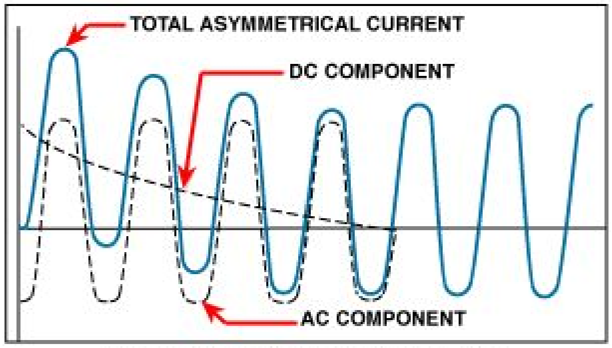
SHORT-CIRCUIT CALCULATION

Determining the available short-circuit Amperes or KVA values is one of the most important aspects of the electrical power distribution system design. Short-circuits must be expected, and since no one knows just where in the system they will occur, every part of the system must have adequate interrupting capacity (IC). Inadequate devices subjected to severe faults can fail to clear the fault and become hazardous to persons and equipment. On the other hand, arbitrarily oversized protective devices are needless extra cost. A realistic estimate of the short circuit current protection is necessary.

The short-circuit current that a low-voltage protective device (600-V or less) must interrupt on the low-voltage (secondary) side of a transformer originates from two sources:

1. The major portion comes through the transformer from the primary system. This current is limited by the impedance of the transformer and the short-circuit capacity of the primary system.
2. The second source of current flowing through the protective device into the short-circuit comes from any motors connected to the low-voltage buss through other feeders. These motors act as current generators for a short while after the short circuit occurs, taking energy from the spinning motor and converting it into electrical energy.

The protective device must interrupt the current flowing through it at the instant that its contacts part after the fault. This depends upon the speed of operation, as shown here.

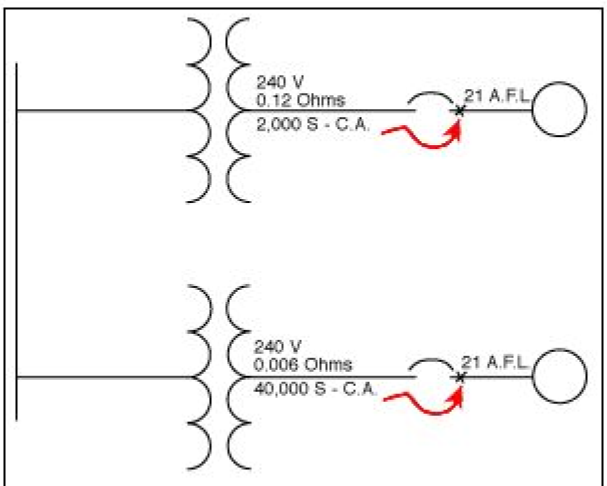


SHORT CIRCUIT CURRENT COMPONENTS

This figure shows the short-circuit current to be made up of two components:

1. The symmetrical alternating current component.
2. The direct-current component which decays with time.

This total current as pictured is called "the asymmetrical current." If the contacts are prevented from separating until the DC component has dropped to a low value (as is sometimes done with power circuit breakers), the AC component is what is used to define the interrupting duty. This is called "the symmetrical short-circuit current." It is determined by the AC voltage and the impedance of the system as shown in the figure.



OHM'S LAW – NOT LOAD CURRENT – SETS SHORT CIRCUIT AMPERES

The magnitude of the DC component depends upon the exact point in the voltage wave corresponding to the instant the short-circuit happened. Obviously, this cannot be predicted; but the worst case condition can be, and the system should be designed to withstand that. This worst case (maximum value) DC component is 1.41 times the peak value of the symmetrical sine wave. This gives a value for the peak asymmetric current of 2.3 times the RMS symmetric short-circuit current when the system X/R ratio is 6.6 to 1.0. The rate of decay of the DC component is slowed when the X/R ratio is high.

When a fault occurs, the system voltage is pulled down by the short circuit, and the induction and synchronous motors act as amperage generators because their magnetic fields persist for some time while they continue to rotate. These motors deliver current to the short-circuit in an amount about equal to the combined starting currents for all of the motors running at the time of the short-circuit. This only lasts for a short time, about three cycles for typical induction motors and a few seconds for synchronous motors. This motor contribution is significant if the circuit breaker contacts begin to separate before the current decays. Many circuit breakers begin to open in less than one cycle. Therefore, this motor contribution and the DC contribution both need be considered when determining the maximum possible short-circuit current.

Since the short-circuit can occur at any time, it is not possible to know how many motors will be running. For estimating purposes, some rules of thumb are:

1. For systems predominantly supplying motor power at 240-Volts or higher, assume the KVA of running motors to be equal to the transformer nameplate KVA.
2. For 240-Volt systems predominantly supplying lighting, assume the motor KVA to be 50% of the transformer capacity.
3. For 208-Volt systems, assume the motor load to be 50% of the transformer installed capacity.

These values should be modified to fit the particular conditions in the plant.

Motor contributions to short-circuit requirements generally assume an impedance of 25%. This means that the motors contribute four KVA to the short-circuit current for each KVA of motor load as calculated by the rule of thumb given above.

Frequently, the symmetric short-circuit current that a protective device must clear is calculated with only a single transformer as the limiting impedance, and the power system plus connected running motors considered as the sources of current. This will result in a pessimistic, and somewhat exaggerated estimate of the interrupting duty required, but errs on the side of safety and is certainly easy to calculate. If a circuit breaker or fuse has an IC adequate for this current, it could be used. If this calculation calls for use of a huskier and more costly device, the designer should complete the calculation which includes the impedance of circuit elements and conductors upstream of that point. This more precise analysis might show that another device with lower IC and lower cost could be safely used.

These more precise calculations require that an impedance diagram be drawn showing the resistances and reactance of all significant elements of the system upstream of the point in question. The process is outlined in the protection handbook and in the IEEE Buff Book (and other sources). The Buff Book* lists three tables for "Available Three-Phase Symmetrical RMS Fault Currents" for 208-Volts, 240-Volts, and 480-Volts, based on the size of the transformer and typical conductor layouts.

*IEEE Std. 242-1975: Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (10)

SURGE ARRESTERS

SURGE ARRESTERS GENERAL

Adequate lightning protection of distribution systems depends upon three major considerations:

1. Selection of distribution equipment with basic insulation as proposed by EEI-NEMA and ANSI.
2. Proper selection of arresters.
3. Effective installation of arresters.

Selection of Arresters:
The proper arrester rating for use on any distribution system depends on maximum system voltage. The table below lists appropriate system voltages and arrester ratings. (5)

SURGE ARRESTER CHART

Nominal System Line-to- Line Voltage (See Note I)	Recommended Arrester Rating (See Note 2)		
	4-Wire Multi-Grounded Neutral Systems	Spacer Cable & Uni-Ground Systems	Delta or Ungrounded Wye Systems
4,160	3	6	6
8,320	6	9	9
12,000	9	10	12
12,470	9	12	15
13,200	10	12	15
13,800	10	12	15
20,780	15	18	21
22,860	18	21	27
24,940	18	27	27
34,500	27		

Note 1: ANSI C84.1-"Voltage Ratings for Electric Power Systems and Equipment."
Note 2: IEEE Committee Paper 71TP542 PWR-"Voltage Rating Investigation for Application of Lightning Arresters on Distribution Systems." (5)

SURGE ARRESTERS INSTALLATION

For adequate lightning protection, the arresters should limit the lightning voltage stresses on distribution transformers to a value well below the standard impulse-test level. This level should take into account the deterioration effect of repeated lightning stresses on solid-and-oil insulation as well as operating conditions such as overloads, absence of periodic maintenance, etc. To meet this protection requirement, arresters should have the lowest practicable spark-over and IR discharge voltage.

Arresters not already integrally mounted on the transformer should be mounted as close as possible to the apparatus to be protected. Leads should be kept as short as possible. The arrester ground should be interconnected to the secondary neutral and to the transformer tank either directly or through a tank-isolating gap. To minimize primary-fuse blowing at the transformer fuses smaller than 12k should be placed on the transformer side of the arrester so that the lightning-discharge current passing through the arrester does not pass through the fuse. (5)

FUSING

FUSING OF DISTRIBUTION TRANSFORMERS

Fuses perform the following functions:

Protect the transformer from
(a) Secondary short circuits.
(b) Damaging overloads.

Protect the system from
(a) Transformer failure.
(b) Power outages in adjacent areas, by isolating the faulted transformer.

Simplify trouble shooting by isolating the faulted transformer.

EEI-NEMA has established time current characteristics as well as heating requirements for standard fuses. These standard links are shown below with "rule of thumb" fusing practices for single or three-phase transformers. (5)

FUSING FACTOR CHART

Fusing Factor*	EEI-NEMA Solid-head Links Std Length 24-in. Type K (Fast) Model No.	EEI-NEMA Solid-head Links Std Length 24-in. Type T (Slow) Model No.	For Use in Cutouts Rated
1	9F51CBK001	9F51CBH201	100 amp
2	002	202	
3	003	203	
5	—	—	
8	006	9F51CBT006	
10	008	008	
15	010	010	
20	012	012	
25	015	015	
30	020	020	
40	025	025	
50	030	030	
60	040	040	
75	050	050	
100	065	065	100 amp
125	080	080	
150	100	100	
200	—	—	200 amp
240	140	140	
320	200	200	

(5)

FUSING FACTOR

The "fusing factor" is used to determine the K, or T fuse link rating that will strike a suitable balance between operation on secondary fault currents and operation on expected overload currents, such as motor starting currents. It is obtained by using a rule of thumb such as one of the following: (The current obtained by the selected rule of thumb becomes the "fusing factor.")

1. 1.5 times the rated full-load current of the transformer (Generally used on transformers 25 kva and larger where motor starting currents are not the controlling factor)

2. 2.0 times the rated full-load transformer current

3. 2.4 times the rated full-load transformer current (This rule is frequently expressed as, "1 ampere per kva rating of transformers at 2400 volts, ½ ampere per kva at 4800 volts, and 1/3 ampere per kva at 6900 to 7600 volts.")

4. 3.0 (or above) times the rated full-load transformer current.

Example:
If the selected rule of thumb is 2.4 times rated full-load current, the system voltage is 4800 volts and the transformer is rated 50 kva, what fuse link should be used?

Rated full-load current = 50,000 / 4800 = 10.4 amperes (see "Load Current Tables" on pages 98 and 99).
2.4X10.4 = 24.9 amperes. Use a fusing factor of 25
Suggested fuse link from table: 15K or 15T.
(5)

FUSE LINKS

In adapting standard links to a transformer, the following items should be considered and evaluated:

Is the fuse link rated?

(a) Small enough to clear secondary short circuits quickly to protect the transformer?

(b) Large enough to reduce unnecessary fuse blowing from motor starting current or lightning?

(c) To carry short-time overloads which are permissible on the transformer but which might deteriorate the strength of the fuse-holder below that required for safely interrupting short circuit?

(d) To co-ordinate with sectionalizing fuses or reclosers so as to indicate positively the location of the troubled transformer? (5)

FUSE TROUBLESHOOTING

When repeated fuse-blowing occurs at the same installation with no apparent damage to transformers, look for the following causes:

1. The primary arrester ground not interconnected to the secondary neutral.

2. Un-protectable impulse level of transformers (such as damaged bushings flashing over, leads too close to tank or cover, low oil level, etc.)

3. Flashover from line conductors or leads to transformer tank or hanger.

4. blowing on magnetizing inrush if fuse is less than 15 times full load current of the transformer for 0.1 seconds. (5)

FUSE SIZING

OKLAHOMA GAS AND ELECTRIC COMPANY DISTRIBUTION STANDARD D351

MAR 1984

TO OBTAIN FUSE SIZE FROM TABLE:

1. Select Table I or Table II based on the lightning arrester location from fuse.
2. Find the single or three phase transformer size or sizes being used.
3. Moving to the right, select the fuse size from Column "A" or "B" under the transformer's primary voltage rating in accordance with instructions below.

FUSE CHART / ARRESTER MOUNTED ON SOURCE SIDE

Arrester Mounted On Source Side of Fuse

LIGHTNING ARRESTER MOUNTED ON SOURCE SIDE OF FUSE

TRANSFORMER SIZE ①	TRANSFORMER PRIMARY VOLTAGE RATING													
	2400		4160		7200		12470 thru 14400				Y 24940 Δ			
	A	B	A	B	A	B	A Y	CL	B Δ	CL	A	CL	B	CL
	Fuse Rating in Amperes													
2	3	5	2	3	1									
3	5	7	3	5	2		1	12	2					
5	5	7	3	5	2		1	12	2					
8	7	10	5	7	3		2	12	3					
10	7	15	5	7	3		2	12	3		1	12	2	12
15	10	20	7	10	5		3	12	5		1	12	3	12
25	20	30	10	20	7		5	12	7		2	12	5	12
38	30	50	15	30	10		5	12	10		3	12	5	12
50	30	50	20	30	10		7	12	10		5	12	7	12
75	50	80	30	50	15		10	12	15		5	12	10	12
100	65	100	40	65	20	Not Applicable	15	12	20	Not Applicable	7	12	15	12
150	100	150	50	100	30		20	25	30		10	12	20	12
167	100	200	65	100	40		20	25	40		10	12	20	25
200	125	200	80	125	40		25	25	40		15	12	25	25
250	150	250*	100	150	50		30	40	50		15	12	30	+
333	200	300*	125	200	65		40	40	65		20	25	40	+
500	300*	400*	150	300*	100		50	+	100		30	+	50	+

* Note 2

TABLE I

FUSE CHART / ARRESTER MOUNTED ON LOAD SIDE

Lightning Arrester Mounted On Load Side of Fuse

LIGHTNING ARRESTER MOUNTED ON LOAD SIDE OF FUSE

TRANSFORMER SIZE	TRANSFORMER PRIMARY VOLTAGE RATING									
	7200		14400		19920		24940			
	A	B	A	CL	A	CL	A	CL	B	CL
	Fuse Rating in Amperes									
10	5	Not Applicable	5	12	5	12	5	12	5	12
15	5		5	12	5	12	5	12	5	12
25	7		5	12	5	12	5	12	5	12
38	10		5	12	5	12	5	12	5	12
50	10		7	12	5	12	5	12	7	12
75	15		10	12	7	12	5	12	10	12
100	20		15	12	10	12	7	12	15	12
150	30		20	25	10	12	10	12	20	25
167	40		20	25	15	12	10	12	20	25
200	40		25	25	15	12	15	12	25	25
250	50		30	40	20	25	15	12	30	+
333	65		40	40	25	25	20	25	40	+
500	100		50	+	40	+	30	+	50	+

(1) Size shown is for single phase transformers, for three phase transformers select fuse size according to:

$$\frac{\text{Name plate kVA}}{3}$$

TABLE II

INSTRUCTIONS

Column "A" should be used for:
a. One single phase transformer station.
b. Two single phase transformers where the primaries are connected "Open-Y"; fuse each transformer according to its size.
c. Two single phase transformers where the primaries are connected "Open-Delta"; fuse each transformer according to its size, except the primary common to both transformers should be fused in accordance with column "B" for the largest transformer.
d. Three single phase transformers where the primaries are connected "Y"; fuse each transformer according to its size.
e. One three phase transformer where the primaries are connected "Y"; all three fuses will be the same. See (1) above.

Column "B" should be used for:
a. One three phase transformer where the primaries are connected "Delta"; all three fuses will be the same size. See (1) above.
b. Three single phase transformers where the primaries are connected "Delta"; fuse sizes are to be determined based on the largest transformer to which each primary is connected.

Column "CL" (current limiting) should be used for:
a. A back-up current limiting fuse used in series with expulsion fuses shown in columns "A" and "B"
b. + = No back-up CL fuse available for these application.

Note: All transformer fuses shall be smaller than the line fuses between the transformer and source. (8)

FULL-LOAD RATING

3Ø - TRANSFORMER FLA CHART

Kva Rating	Rated Line Voltage					
	120	208	240	480	600	2400
15	72.17	41.64	36.09	18.04	14.43	3.61
* 22½	108.26	62.46	54.13	27.06	21.65	5.41
30	144.34	83.27	72.17	36.09	28.87	7.22
45	216.51	124.91	108.26	54.13	43.30	10.83
75	360.85	208.19	180.43	90.21	72.17	18.04
*100	481.14	277.58	240.57	120.28	96.23	24.06
112½	541.28	312.28	270.64	135.32	108.26	27.06
150	721.71	416.37	360.85	180.43	144.34	36.09
*200	962.28	555.16	481.14	240.57	192.46	48.11
225	1082.56	624.56	541.28	270.64	216.51	54.13
300	1443.42	832.74	721.71	360.85	288.68	72.17
500	2405.70	1387.90	1202.85	601.42	481.14	120.28
750	3608.55	2081.85	1804.27	902.14	721.71	180.43
1000	4811.39	2775.80	2405.70	1202.85	962.28	240.57
1500	7217.09	4163.71	3608.55	1804.27	1443.42	360.85

Kva Rating	Rated Line Voltage					
	4160	4800	7200	8320	12000	12470
15	2.08	1.80	1.20	1.04	0.72	0.69
* 22½	3.12	2.71	1.80	1.56	1.08	1.04
30	4.16	3.61	2.41	2.08	1.44	1.39
45	6.25	5.41	3.61	3.12	2.17	2.08
75	10.41	9.02	6.01	5.20	3.61	3.47
*100	13.88	12.03	8.02	6.94	4.81	4.63
112½	15.61	13.53	9.02	7.81	5.41	5.21
150	20.82	18.04	12.03	10.41	7.22	6.95
*200	27.76	24.06	16.04	13.88	9.62	9.26
225	31.23	27.06	18.04	15.61	10.83	10.42
300	41.64	36.09	24.06	20.82	14.43	13.89
500	69.40	60.14	40.09	34.70	24.06	23.15
750	104.09	90.21	60.14	52.05	36.09	34.73
1000	138.79	120.28	80.19	69.40	48.11	46.30
1500	208.19	180.43	120.28	104.09	72.17	69.45
2000	277.58	240.57	160.38	137.79	96.23	92.60
2500	346.98	300.71	200.47	173.49	120.28	115.75
3750	520.46	451.07	300.71	260.23	180.43	173.63
5000	693.95	601.42	400.95	346.98	240.57	231.50

Kva Rating	Rated Line Voltage					
	13200	14400	22900	34400	43800	67000
15	0.66	0.60	0.38	0.25	0.20	0.13
* 22½	0.98	0.90	0.57	0.38	0.30	0.19
30	1.31	1.20	0.76	0.50	0.40	0.26
45	1.97	1.80	1.13	0.76	0.59	0.39
75	3.28	3.01	1.89	1.26	0.99	0.65
*100	4.37	4.01	2.52	1.68	1.32	0.86
112½	4.92	4.51	2.84	1.89	1.48	0.97
150	6.56	6.01	3.78	2.52	1.98	1.29
*200	8.75	8.02	5.04	3.36	2.64	1.72
225	9.84	9.02	5.67	3.78	2.97	1.94
300	13.12	12.03	7.56	5.04	3.95	2.59
500	21.87	20.05	12.61	8.39	6.59	4.31
750	32.80	30.07	18.91	12.59	9.89	6.46
1000	43.74	40.09	25.21	16.78	13.18	8.62
1500	65.61	60.14	37.82	25.18	19.77	12.93
2000	87.48	80.19	50.43	33.57	26.36	17.23
2500	109.35	100.24	63.03	41.96	32.95	21.54
3750	164.02	150.36	94.55	62.94	49.43	32.32
5000	218.70	200.47	126.06	83.92	65.91	43.09

For other KVA ratings or voltages:

$$\textbf{Amperes} = \frac{\textbf{KVA} \times \textbf{1000}}{\textbf{Volts} \times \textbf{1.732}}$$

* No longer on EEI-NEMA standard.

(5)

1Ø - TRANSFORMER FLA CHART

Kva Rating	Rated Line Voltage					
	120	240	480	600	2400	4160
* 1½	12.50	6.25	3.12	2.50	.62	.36
3	25.00	12.50	6.25	5.00	1.25	.72
5	41.67	20.83	10.42	8.33	2.08	1.20
* 7½	62.50	31.25	15.63	12.50	3.12	1.80
10	83.33	41.67	20.83	16.67	4.17	2.40
15	125.00	62.50	31.25	25.00	6.25	3.60
25	208.30	104.20	52.10	41.67	10.42	6.01
37½	312.50	156.30	78.10	62.50	15.63	9.01
50	416.70	208.30	104.20	83.30	20.83	12.02
75	625.00	312.50	156.30	125.00	31.25	18.03
100	833.00	416.70	208.30	166.70	41.67	24.04
*150	1250.00	625.00	312.50	250.00	62.50	36.06
167	1392.00	696.00	348.00	278.50	69.60	40.15
*200	1667.00	833.00	416.70	333.30	83.34	48.10
250	2083.00	1042.00	521.00	416.70	104.20	60.10
333	2775.00	1388.00	694.00	555.00	138.80	80.00
500	4167.00	2083.00	1042.00	833.00	208.30	120.20

Kva Rating	Rated Line Voltage				
	4800	7200	7620	12000	13200
* 1½	.31	.21	.20	.12	.11
3	.62	.42	.39	.25	.23
5	1.04	.69	.66	.42	.38
* 7½	1.56	1.04	.98	.62	.57
10	2.08	1.39	1.31	.83	.76
15	3.12	2.08	1.97	1.25	1.14
25	5.21	3.47	3.28	2.08	1.89
37½	7.81	5.21	4.92	3.12	2.84
50	10.42	6.94	6.56	4.17	3.79
75	15.63	10.42	9.84	6.25	5.68
100	20.83	13.89	13.12	8.33	7.57
*150	31.25	20.83	19.68	12.50	11.36
167	34.80	23.20	21.93	13.92	12.68
*200	41.67	27.78	26.24	16.67	15.14
250	52.10	34.73	32.81	20.83	18.94
333	69.40	46.30	43.70	27.75	25.23
500	104.20	69.40	65.60	41.67	37.88

Kva Rating	Rated Line Voltage				
	14400	22900	34400	43800	67000
* 1½	.10	.06	.04	.03	.02
3	.21	.13	.09	.07	.04
5	.35	.22	.14	.11	.07
* 7½	.52	.33	.22	.17	.11
10	.69	.44	.29	.23	.15
15	1.04	.65	44	.34	.22
25	1.74	1.09	.73	.57	.37
37½	2.60	1.64	1.09	.86	.56
50	3.47	2.18	1.45	1.14	.75
75	5.21	3.27	2.18	1.71	1.12
100	6.95	4.37	2.91	2.28	1.49
*150	10.42	6.55	4.36	3.42	2.24
167	11.60	7.29	4.85	3.81	2.49
*200	13.89	8.73	5.81	4.57	2.98
250	17.37	10.91	7.27	5.71	3.73
333	23.15	14.54	9.68	7.60	4.97
500	34.70	21.83	14.53	11.42	7.46

For other KVA ratings or voltages

$$\text{Amperes} = \frac{\text{KVA} \times 1000}{\text{Volts}}$$

* **No longer an EEI-NEMA standard.**

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STANDARD TRANSFORMER KVA AND VOLTAGES

KVA AND VOLTAGES CHART

KVA's		HIGH VOLTAGES		LOW VOLTAGES	
Single-Phase	Three-Phase	Single-Phase	Three-Phase	Single-Phase	Three-Phase
5	15	2400/4160Y	2400	120/240	208Y/120
10	30			277	240
15	45	4800/8320Y	4160Y/2400	240/480	480
25	75	7200/12470Y			240 x 48
37½	112½	12470 GrdY/7200*	4160Y		408Y/277
50	150		4160		
75	225	7620/13200Y	4800	For certain KVA sizes the following are standard*	
100	300		8320Y/4800		
167	500	13200 GrdY/7620*			
250			8320Y	2400	2400
333		12000		2520	4100Y/2400
500			7200	4800	4800
		13200/22860Y*		5040	
		13200	12000		
		13800 GrdY/7970*	12470Y/7200	6900	12470Y/7200
		13800/23900Y*			
		13800		7200	13200Y/7620
		14400/24940Y*	12470Y	7500	
		16340		7970	
		24940 GrdY/14400*	13200Y/7620		
		34500 GrdY/19920*	13200Y		
		22900			
			13200		
		34400	13800		
			22900		
		43800			
			34400		
		67000	43800		
			67000		

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ANNOTATIONS

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