

IEEE Guide for Application of Transformer Connections in Three-Phase Distribution Systems

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Foreword

(This Foreword is not a part of ANSI/IEEE C57.105-1978, American National Standard Guide for Application of Transformer Connections in Three-Phase Distribution Systems.)

In the fall of 1968, a Working Group was formed by the Performance Characteristics Subcommittee of the IEEE Transformers Committee to prepare a user's guide for application of Y-Y transformers considering user systems, manufacturing capabilities, tank heating, ferroresonance and telephone interference. The scope of the proposed user's guide was subsequently expanded to cover the full range of transformer connections commonly used in 3-phase distribution systems with emphasis on those characteristics of connections which distinguish one from another, appear most prominently with asymmetrical system conditions, and affect the selection of connections.

The guide assumes the reader has an educational or practical background equivalent to that of a graduate electrical engineer with some knowledge of transformers and distribution practices. Recognizing from the start, however, that the guide would be most needed by and most useful to the engineer with relatively little experience, the Working Group has incorporated explanatory material where considered to be helpful.

The Institute wishes to acknowledge its indebtedness to those who have given so freely of their time and knowledge to the development of this guide.

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Special acknowledgement is due C. R. French, Chairman of the Performance Characteristics Subcommittee at the time of Working Group formation, who saw the need for this work and contributed substantially to the initial efforts.

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IEEE Guide for Application of Transformer Connections in Three-Phase Distribution Systems

1. Scope

This guide concerns transformer connections in 3-phase distribution systems. Distribution systems are characterized by primary voltages up to and including 34.5 kV, usually have a preponderance of connected transformers with low-voltage windings below 1000 V and furnish electric service to consumers. The characteristics of the various transformer connections and possible operating problems under normal or abnormal conditions are treated.

All combinations of Δ and Y, grounded and ungrounded, T connected, zigzag, and certain special connections are considered. Only two-winding transformers are included.

Phasing procedures and loading practices are not covered. Guides for loading of oil-immersed and dry-type transformers are available in publications of the American National Standards Institute: American National Standard C57.91-1974, Appendix to C57.12.00-1973, Guide for Loading Mineral Oil-Immersed Overhead-Type Distribution Transformers with 55°C or 65°C Average Winding Rise; American National Standard C57.92-1962, Appendix to C57.12 Standards, Guide for Loading Oil-Immersed Distribution and Power Transformers; and American National Standard C57.96-1959, Appendix to C57.12 Standards, Guide for Loading Dry-Type Distribution and Power Transformers, respectively.

2. Electrical Connections

2.1 Primary and Secondary Systems

In general, permissible transformer connections are related to the type of service to be delivered and the type of primary supply.

2.1.1 Types of Service

Three-phase services may be 3-wire or 4-wire. The 3-wire service is quite commonly called “delta” service and consists only of three-phase conductors, having no neutral conductor. The 4-wire service is commonly called a “wye” service

and includes a neutral conductor which is customarily grounded at the service for 208 Y/120 and 480 Y/277 V services and, if the supply originates outside the building served, at one other point on the secondary side of the transformer supplying the system, either at the transformer or elsewhere. Some 4-wire services are derived from a Δ -or open- Δ -connected secondary with the center tap of one leg grounded. This connection is commonly rated 240/120 V, 3-phase, 4-wire, and is also grounded in the manner described.

2.1.2 Types of Sources

The primary supply may be either an ungrounded, effectively grounded, or impedance-grounded source. An ungrounded supply may have a grounded shield wire or cable sheath, but such conductor should not be mistaken for a neutral conductor if it is not intended for such service. The ungrounded supply is frequently called a delta (Δ) source because such systems generally consist of the three phase conductors only.

The effectively grounded distribution system normally includes a solidly grounded neutral conductor derived from the source. Usually the neutral is multigrounded along the feeder. Such systems are referred to as “grounded Y” systems.

The impedance-grounded systems are usually found in industrial plant circuits operating at distribution voltage levels of 4160 V and higher. Such systems may be Y or Δ . If Y, the neutral is derived from the source, but is insulated and grounded through a resistor or reactor. If Δ , the grounding is through a grounding transformer to which an external impedance may or may not be connected. Such systems allow the flow of sufficient ground fault current to afford positive high-speed protective relaying, but limit the ground fault current in order to minimize damage to faulted equipment. Although the impedance-grounded Y systems are sometimes said to have a “floating neutral,” this terminology is misleading. The neutral is actually stabilized at the source, and with fairly well-balanced loads, the neutral voltage remains near ground voltage except during fault conditions.

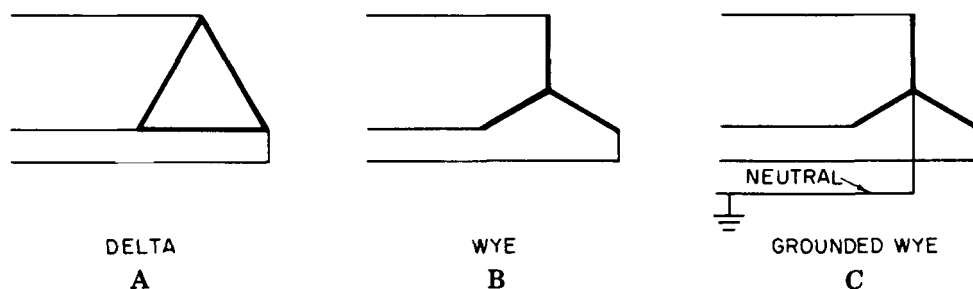


Figure 1— Quasi-Phasor Δ and Y Connection Diagrams
A— Δ , B—Y, C—Grounded Y

In the Y systems, the integrity of the neutral conductor is very important to proper operation and safety.

2.2 Δ and Y Connections

In both 3-phase transformers and banks of three single-phase transformers, the transformer windings are connected either phase-to-phase or phase-to-neutral in all but certain special connections (for example, the T connection). When the windings are connected phase-to-phase as in Fig 1A, the quasi-phasor arrangement of the connection diagram resembles the capital Greek letter delta from which it gets the name and symbol Δ . When the windings are connected phase-to-neutral as in Fig 1B and C, the quasi-phasor connection diagram resembles the letter Y which is used as its symbol. (The Y is inverted in the figure so as to conform to its usual appearance in standard diagrams.) Y connections are also referred to as star connections, a more general term applicable to systems with any number of phases. Y connections may have a grounded or ungrounded neutral. In this guide the term Y and symbol Y will represent the ungrounded neutral connection, and the term Y-grounded and symbol YG will represent the grounded neutral connection.

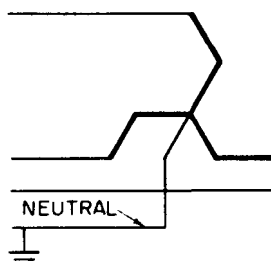


Figure 2— Quasi-Phasor Zigzag Connection Diagram

The primary and secondary windings may be connected in any combination desired. However, certain combinations may be quite undesirable for a particular application. Table 1 shows all combinations of Δ and Y connections and indicates the characteristics of each configuration which relate to its application. The connections which should receive special consideration to avoid misapplication are indicated to be “problem” connections.

2.3 Zigzag-Connected Winding

The zigzag-connected winding has each electrical phase linked equally by two magnetic phases as shown in Fig 2. This winding connection is most commonly used in a single-winding transformer to perform grounding duty. The connection presents a low-impedance path to ground for zero-sequence currents (that is, current components of equal magnitude and phase angle in each leg), and therefore ground current flows with any shift of the system neutral. Grounding transformers may be sized so as to furnish only the magnitude of ground current required for relaying or may be large enough to stabilize the neutral of an otherwise ungrounded system. In the latter case, the grounding transformer supplies the unbalanced phase-to-neutral load as well as ground fault current.

Table 1— Application Characteristics of Connections

Connection				Phase Shift High-Voltage to Low-Voltage (Note 1)	Subject to Primary Grounding Duty	Triple Harmonic Primary Line Currents Suppressed	“Problem” Connections (Note 2)
Primary	Secondary	Suitable for Ungrounded Source	Suitable for 4-Wire Service				
Δ	Δ	Yes	No	0°	No	Yes	
	Y	Yes	No	-30°	No	Yes	
	Z	Yes	Yes	-30°	No	Yes	
Y	Δ	Yes	No	-30°	No	Yes	
	Y	Yes	No	0°	No	Yes	
	Z	Yes	No	0°	No	Yes	Note 3

Table 1— Application Characteristics of Connections (Continued)

Connection				Phase Shift High-Voltage to Low-Voltage (Note 1)	Subject to Primary Grounding Duty	Triple Harmonic Primary Line Currents Suppressed	“Problem” Connections (Note 2)
Primary	Secondary	Suitable for Ungrounded Source	Suitable for 4-Wire Service				
		Note 4	No	−30°	Yes	Yes	Note 4
		No	No	0°	No	No	
		No	Yes	0°	No	No	Note 5
		Yes	No	Note 6	No	No	
		Yes	Yes	Note 6	No	No	
		Note 4	No	Note 6	Yes	No	Note 4
		Note 4	Yes	Note 6	Yes	No	Note 4
		Yes	Yes	0°	No	Yes	
		Yes	Yes	−30°	No	Yes	
		No	Yes	−30°	No	No	

NOTES:

1 — Based on standard connections and phasor diagrams.

2 — “Problem” connections are those connections which should receive special consideration to avoid misapplication.

3 — This connection is incapable of furnishing a stabilized neutral, and its use may result in phase-to-neutral overvoltage on one or two legs as a result of unbalanced phase-to-neutral load.

4 — Connections designated act as primary grounding transformers and should not be used unless intended for such duty.

5 — The 3-phase transformer of 3-legged core-form construction is susceptible to tank heating with unbalanced phase-to-neutral loads or ground faults.

6 — The T connections in this table represent either similar or rotated orientation. The connection can be made to simulate any of the Δ and Y combinations.

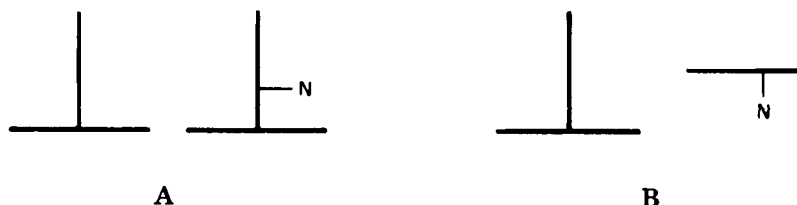


Figure 3— Orientation of Windings in T Connection
A—0° or Similar Orientation Simulates Y-Y,
B—90° or Rotated Orientation Simulates Δ-Y

The zigzag winding is also combined with either Y or Δ connections in two-winding transformers in order to provide a desired phase relation with grounded neutral.

In this guide the symbol ZZ will indicate the zigzag connection, and the symbol ZZG will indicate that the neutral is grounded. Table 1 shows application characteristics of transformer banks with zigzag-grounded secondaries.

2.4 T-T Connections

Some 3-phase distribution transformers consist of two single-phase transformers in a common tank with the interconnection of the two primaries and two secondaries in the manner shown in Fig 3, the end of one winding connecting to the midpoint of the other to form a configuration similar to the letter T. The crossbar of the T is called the main winding, and the stem is called the teaser winding. Voltages of the main and teaser coils are such that balanced 3-phase voltages are obtained. The neutral point is at one third of the teaser coil from the main. Although not actually a symmetrical connection, the 3-phase T-connected transformer simulates the symmetrical Y and Δ connections.

Basically only two configurations are possible, although the designation of terminals (see 2.5.1) so as to simulate standard Δ-Y, Y-Δ, Δ-Δ, and Y-Y may seem to increase the number of connections possible to four. One basic arrangement is shown in Fig 3A with both primary T and secondary T oriented similarly. This connection simulates Δ-Δ or Y-Y. The other basic connection is shown in Fig 3B with one T rotated 90° relative to the other. This connection simulates Δ-Y or Y-Δ. T-connected transformers may be paralleled with Δ and Y combinations provided the usual requirements for paralleling are met (see 2.5.3).

The T connection has two very interesting properties. First, if the neutral is grounded, a T-connected winding presents a low impedance to zero-sequence current and permits the flow of such currents independently of the other winding. The implication of this fact is that the primary should not be grounded since the transformer will then act as a grounding transformer (see 2.6), but it still is capable of providing a 4-wire grounded service even with an ungrounded primary, and it may do so regardless of relative orientation of the windings. The symbol TG will be used in this guide to represent a T-connected winding with neutral grounded.

Second, the flow of triple-harmonic excitation currents in the windings and in the lines is not suppressed regardless of whether the primary or secondary is grounded or not, and these harmonics may flow on the phase conductors only. Harmonic voltages and currents and their effects are discussed in Section 4.

Table 1 shows the application characteristics of T-connected transformers.

2.5 Terminal Markings, Phase Relations, and Paralleling

2.5.1 Terminal Designation

American National Standard C57.12.20-1974, Requirements for Overhead Type Distribution Transformers 67 000 Volts and Below, 500 kVA and Smaller, and American National Standard C57.12.70-1964 (R 1971), Terminal

Markings and Connections for Distribution and Power Transformers, are the standards which specify the terminal markings and connections for distribution and power transformers. The user should obtain copies of these standards because this guide is not intended to supplant or to unnecessarily repeat application information from the standards.

In general, however, the terminals of two-winding transformers and autotransformers without tertiaries are designated by the alphabetic symbols H and X for the high voltage and low voltage, respectively, with numerical subscripts to distinguish the winding ends and taps. Neutral terminals of 3-phase transformers are designated by the subscript 0; that is, H_0 , X_0 , and, for the case of a common neutral, H_0X_0 . The three leads which connect to full phase windings of a 3-phase transformer are designated H_1 , H_2 , H_3 and X_1 , X_2 , X_3 .

Single-phase transformers do not have the 0 subscript marking, but have markings of all leads brought out of the case in a subscript sequence 1, 2, 3, 4, 5, etc so that the lowest and highest numbers indicate the full winding. Most transformers have only two high-voltage leads brought out of the case, and if one of the two terminals is intended to be grounded, it is designated as H_2 , the other being, of course, H_1 . This convention also applies to low-voltage terminals X_1 and X_2 , when only the two leads are brought out. However, the low-voltage leads brought out of the case of a single-phase transformer may number from 2 to 4 in commonly used ratings and are so designated that consecutive subscript values must indicate progress along the windings when connected in series.

2.5.2 Phase Relations

In a single-phase transformer conforming to the standard, the phase of H_1 and X_1 coincide. In a standard 3-phase transformer, the phase of H_1 and X_1 coincides if the connection is Y-Y, Δ - Δ , ZZ- Δ , or Δ -ZZ. If the connection is Y- Δ , Δ -Y, Y-ZZ, or ZZ-Y, then the phase of X_1 lags that of H_1 by 30° . Fig 4 shows the phasor relationship of these connections. This figure is taken from ANSI C57.12.00-1973 with the addition of the Y-ZZ combinations. The T-T windings are marked to simulate the Δ and Y combinations as indicated in Fig 3.

American National Standard C57.12.70-1964 (R1971) has a complete set of diagrams for the banking of three single-phase transformers and for the connection of 3-phase transformers in all combinations of Δ and Y. Also, connections for other angles of phase shift than 0° and 30° lagging are shown.

2.5.3 Paralleling

Four requirements must be met for paralleling transformers: (1) the phase relations on high-voltage and low-voltage sides must be the same, (2) the voltage ratios line-to-line must be equal or nearly so, (3) if connected for 4-wire service to phase-to-neutral loads, the voltages to neutral must also agree in ratio and phase, and (4) the impedances of the transformers in percent on transformer base must be equal or nearly so.

Requirement (1) is met if standard transformers with connections which give the same phase shift between H_1 and X_1 are used and if leads of similar marking on each transformer are connected together; that is, H_1 to H_1 , X_1 to X_1 , etc.

Requirements (2), (3), and (4) are necessary to maintain satisfactory load division between transformers and to avoid large circulating currents. Requirement (3) is not intended to mean that the Δ - Δ connection may not be paralleled with YG-YG, for example, but in such a circumstance, only the YG-YG transformer will supply the unbalanced phase-to-neutral load.

Calculation of load division or no-load circulating current is quite lengthy if exact methods are used. Approximate methods can be quite rapid and satisfactory. The assumptions of the method are (1) that transformer impedance is approximately the leakage reactance and (2) that the effect of load losses may be neglected. The method is best illustrated by an example.

Assume two transformers delivering 750 kVA at 480 V and 85% power factor with data as follows: