IEEE Std 295-1969

IEEE Standard for Electronics Power Transformers

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FOREWORD

The Electronics Transformer Technical Committee for several years has been working towards the generation of a Standard for electronics purpose power transformers even while under AIEE auspices. Earlier attempts seemed to parallel the distribution and power transformer Standards too closely, and hence missed the point of departure of how electronics transformers needed, at least in part, a different, treatment than power distribution transformer Standards. After the completion of the Wide-Band Standards Nos. 111 and 264 by the committee, a pattern was established that could be followed in the Power Transformer Standard to achieve the desired results. This proposed Standard can be well considered to be the product of the merger of AIEE and IRE people into the new blend of IEEE as it represents concessions oil the part of each to the other at various points.

Some interesting problems had to be resolved in the process. For example, in the use of solid-state rectifiers it is necessary to provide fast and sensitive protection for the easily destroyed diodes in the event of faulting. This, in turn, led to a new definition of transformer inrush current, which we found was not previously defined satisfactorily. Also, the extensive use of combined alternating and direct voltages and currents in electronics transformers made it necessary to resolve certain insulation testing problems that have plagued the industry for years. Yet to say that these problems are resolved is an oversimplification of the situation. Nevertheless, a good start has been made in this regard.

We have attempted to give guidance and direction in the sensitive area of corona testing without foreclosing on the adoption of new Standards and understandings on the subject.

For all sizes of electronics purpose power transformers, it is expected that this Standard will supersede the use of USA C57 Standards.

PURPOSE

The character and applications of transformers used in electronic circuits are enough different from other categories so that none of the existing Standards does a satisfactory job. Much confusion and conflict has obtained in the past several years because of this lack, with different people having a wide variety of opinion relative to many aspects of specification and testing.

This Standard is intended to control by exception in the areas where conflict and disagreement have been most noticeable. Other well-known Standards are listed that should be used in areas where general agreement exists.

ACKNOWLEDGMENT

The Institute wishes to acknowledge its indebtedness to those who have so freely given of their time and knowledge, and have conducted experimental work on which many of the IEEE publications are based.

This publication was prepared by the Electronics Power Transformer Subcommittee of the Electronics Transformers Committee of the IEEE Parts, Materials, and Packaging Group. The membership of the Subcommittee was:

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CLAUSE PAGE

IEEE Standard for Electronics Power Transformers

1. SCOPE

This Standard pertains to power transformers and inductors that are used in electronic equipments and supplied by power lines or generators of essentially sine wave or polyphase voltage. Guides to application and test procedures are included. Appendices contain certain precautions, recommended practices, and guidelines for typical values. Provision is made for relating the characteristics of transformers to the associated rectifiers and circuits.

Certain pertinent definitions relating to transformers and transformer applications, which have not been found elsewhere, are included with appropriate discussion. Attempts are made to alert the industry and profession to factors that are commonly overlooked.

This Standard includes, but is not limited to, the following specific transformers and inductors.

Rectifier supply transformers for either high- or low-voltage supplies.
Filament and cathode heater transformers.
Transformers for alternating current resonant charging circuits.
Inductors used in rectifier filters.
Autotransformers with fixed taps.

1.1 Related and Reference Standards

a) USA Standard C57: Transformers, Regulators and Reactors.
USA Standard C57: 12.00—1965, General.
USA Standard C57: 12.20—1964, Overhead-Type
Distribution Transformers, 67 000 Volts and Below, 500 kVA and Smaller.
USA Standard C57: 12.80—1958, Terminology.
USA Standard C57: 12.90—1965, Test Code.
USA Standard C57: 18—1964, Pool-Cathode Mercury-Arc Rectifier Transformers, Requirements, Terminology and Test Code.
USA Standard C57: 31—1948, Guide for Operation of Transformers at Altitudes Greater Than 1000 Meters.
USA Standard C57: 32—1948, Guide for Operation of Transformers, Regulators and Reactors.

b) USA Standard C42.
USA Standard C42.25—1956, Definitions of Electrical Terms (Industrial Control Equipment).
USA Standard C42.65—1957, Definitions of Electrical Terms (Communications).

c) IEEE Standards Publication No. 111, Low-Power Wide-Band Transformers.
d) IEEE Standards Publication No. 264, High-Power Wide-Band Transformers.
e) Standards in Preparation.
Corona Test Guide.

2. DEFINITIONS

Electrical terms used in this Standard shall be in accordance with those given in USA Standard C42 “American Standard Definitions of Electrical Terms” insofar as they apply except as herein stated.

The IEEE Dictionary, when issued, shall be applicable and included as a part of this Standard and shall take precedence over USA Standard C42 in case of conflict.

2.1 Additional Definitions

2.1.1 Turns Ratio: shall be preferably defined in terms of the primary turns as the number of turns of a given secondary divided by the number of primary turns. Thus a ratio less than one (1) is a step-down transformation, a ratio greater than one (1) is a step-up transformation, and a ratio equal to one (1) is unity ratio.

2.1.2 Loaded Voltage Ratio: shall be equal to the secondary voltage divided by the primary voltage. (See paragraph 2.1.1.) For linear loads, the ratio shall be stated for a specified load current and power factor. For rectifier loads, the ratio should be given for the specified circuit configuration, including the filters, and the rated direct-current load. Unless otherwise stated, the ratio shall be given for rated conditions, line voltage, frequency, load, and stabilized temperature. Primary voltages shall be given as line to line and secondary voltages as leg values (terminal to neutral or center tap if used) unless otherwise indicated.

2.1.3 No-Load Loss: (excitation loss) is the input power, expressed in watts, to a completely assembled transformer that is excited at rated terminal voltage and frequency, but not supplying load current.

2.1.4 Full-Load Losses:

2.1.4.1 Core Loss: is the measured power loss, expressed in watts, attributable to the material in the core and associated clamping structure, of a transformer that is excited, with no connected load, at a core flux density and frequency equal to that in the core when rated voltage and frequency is applied and rated load current is supplied.

2.1.4.2 Winding Loss: (copper loss) is the power losses of all windings involved, expressed in watts, in an inductor or transformer with the values measured at or corrected to the rated load current, frequency, and waveshape an stabilized at the maximum ambient temperature.

2.1.4.3 Stray Losses: are those occurring in the core and case structure that result from the leakage flux and stray flux of a transformer when supplying rated load current.

2.1.5 Graded Insulation: is the selective arrangement of the insulation components of a composite insulation system to more nearly equalize the voltage stresses throughout the insulation system

2.1.6 Inrush Current: is the maximum root-mean-square or average current value, determined for a specified interval, resulting from the excitation of the transformer with no connected load, and with essentially zero source impedance, and using the minimum primary turns tap available and its rated voltage. (See Annex V.)

2.1.7 Peak Inrush Current: is the peak instantaneous current value resulting from the excitation of the transformer with no connected load, and with essentially zero source impedance, and using the minimum turns primary tap and rated voltage.

2.1.8 Essentially Zero Source Impedance: implies that the source impedance is low enough so that the test currents under consideration would cause less than five (5) percent distortion (instantaneous) in the voltage amplitude or waveshape at the load terminals. (See Annex V.)

3. SYMBOLS

The proposed IEEE Standards Publication No. 276 "Letter and Graphic Symbols for Electronics Transformers" or revisions shall apply.

4. TRANSFORMER ELECTRICAL TESTS

Transformer terminals normally grounded in service should be grounded during these tests or connected as otherwise required or noted in the following test description.

4.1 Electrical Tests

(values not recorded) It is recommended that the following electrical tests be made on all transformers.

Ratio, polarity, terminal marking tests.
No-load excitation; exciting current (amperes), loss (watts).
Corona test (when specified).
Induced voltage.
Electric strength of insulation.

4.2 Characteristic Tests

(may be performed on a limited basis unless otherwise specified).

Inrush current (when specified).
Winding loss, impedance, regulation.
Leakage inductance.
Impulse (when specified).
Temperature rise, winding resistance.

5. ELECTRICAL TESTS

5.1 Electrical Strength Tests

(see paragraph 5.3 for retesting). Applied high-voltage tests to major insulation systems should be made with windings shorted. Windings and shields on one side of the insulation should be connected to frame and ground while windings or shields on the other side should be connected together. Sine wave test voltages having a frequency in the operating range of the transformer and having adequate current capacity for the application is applied between the two sets of terminals in the manner set forth herein. All voltages should be defined in the same terms; e.g., root mean square, peak, average.

5.1.1 Method Voltage

should be increased at a convenient uniform rate of not greater than 2000 volts per second, from zero to the specified value, maintained for the specified period (unless breakdown occurs) then decreased to zero at the same rate.

5.1.2 Primary Windings

with rated voltagex *over* 600 volts line to line should be tested in accordance with USAS C57.12 as amended or revised (see Annex IV).

5.1.3 Primary Windings

with rated voltages 600 volts *or less* line to line should be tested with sine wave alternating voltage equal to twice the rated voltage of the highest voltage tap, plus 1000 volts and held at that value for the duration of 3600 cycles.

5.1.4 Connections

for windings not under test should be specified so that unwarranted stresses will not occur during the electric strength tests. Windings with relatively low working voltage to ground should be grounded during the test of other windings to prevent the lower voltage insulation from being damaged through capacitive coupling.

5.1.5 Secondary Windings

that have no special test voltage specified should be tested with applied alternating voltage equal to twice the rated voltage of the highest voltage tap, plus 1000 volts and held at that value for the lesser time of 3600 cycles or one minute.

5.1.6 Secondary Windings or Inductor Windings

that may have a specific operating direct or alternating voltage derived elsewhere, unless otherwise specified, should be tested at twice the working volts plus 1000 volts for the lesser of one minute or 3600 cycles and using the same type and frequency of voltage as the working stress. High alternating voltage should not be substituted for direct current unless specifically authorized by the manufacturer.

5.1.7

When the voltage insulation strength is not the same at both ends of a winding, an induced voltage test may be substituted in lieu of the applied voltage test.

5.2 Induced Voltage Tests

5.2.1 Secondary Windings and Inductors

employing *graded insulation systems* may be tested as described herein in lieu of other high-voltage electric strength tests.

NOTE — Many high-voltage rectifier windings have a distinctly different voltage stress to adjacent windings on one end of a winding when compared with the stress on the other end. Not only can the voltage stress be different in magnitude, but also in waveform. An alternating voltage stresses the insulation much more than a direct voltage of the same peak value. For example, a three-phase winding wye connected for a system using three-phase bridge rectifier will have a direct voltage to ground at the neutral equal to one-half of the bridge output, whereas the rectifier terminals will have an alternating voltage excursion from zero to twice the peak voltage of one leg. It is not necessary or desirable to use the same kind and amount of insulation at the neutral as at the rectifier terminals, yet it is desirable to test both insulations at twice the normal working voltage and with a waveform similar to that of the working voltage. In *this* test, apply a direct voltage between neutral and ground equal to twice the working voltage of the neutral, and at the same time excite the transformer windings with a voltage equal to twice the normal induced voltage, thus placing a double voltage stress in kind at each major insulation interface, and at the same time check out the intrawinding withstand capability. See paragraph 5.2.2.1 for restrictions on frequency of applied voltage.

5.2.1.1

First apply the bias voltage to the lower voltage rated terminal, using a voltage source having a waveform similar to the working voltage and a peak value equal to twice the maximum rated voltage of that terminal. The voltage reference should be the adjacent winding voltage and ground. Maintain this voltage during the following sequence.

5.2.1.2

The input currents should be monitored during the test to check for erratic variations in value. A normal excitation test made subsequently should not show a change in value from that of a previous test (see paragraph 4.1).

5.2.1.3

During this test, all windings should be connected in the normal relationship to each other and to ground. Three-phase transformers should be tested using three-phase induced voltage excitation. It is desirable to have the neutral terminal of a wye connected secondary available for this test, to which the bias or other direct voltage may be applied. If no neutral is available, the rectifiers may be connected instead (providing they have adequate voltage rating) with the direct current output grounded on one terminal.

5.2.2 Induced Voltage Test

is performed on transformers *not tested under paragraph 5.2.1*. The procedure is the same as paragraph 5.2.1 except that the bias voltage is not employed as in paragraph 5.2.1.1.

5.2.2.1

Apply voltage, as in normal excitation, to the primary terminals (see paragraph 5.1.1). The voltage should be increased to a value equal to twice the maximum induced rating and held for the duration of 7200 cycles and then returned to zero. The induced voltage should be of a frequency between two and ten times the minimum rated frequency for the transformer.

5.2.2.2

The input currents should be monitored during the test to check for erratic variations in value. A subsequent excitation test should not show a change in value from that of a previous test.

5.2.2.3

During this test (paragraph 5.2.2), all windings should be connected in the normal relationship to each other and to ground. Three-phase transformers should be tested using three-phase induced voltage excitation.

5.3 Repeated Electric Strength Testing

Since the application of test potentials may impair the strength of the transformer insulation, any test made per paragraphs 5.1–5.2.2 should, if repeated, be made at not more than 90 percent of the specified test potential and for the same time interval, or for less time if specified.

5.4 Corona Tests

When specified, transformers and inductors should be free from corona under all operating conditions. “Free” may be interpreted as within the allowable tolerance of corona display as provided in the Corona Test Specification.

5.4.1

Transformers and inductors having peak alternating voltages under 1000 volts may be exempt from tests.

5.4.2 Corona Test Voltage

Windings and terminals shall meet the corona test requirement when the test voltage is reduced to 115 percent of rated voltage from a higher value not in excess of 150 percent. This test may be performed at a frequency higher than the rated frequency. The intent herein is that the corona extinction level will be the criterion; therefore, the applied or excitation voltage should be increased until a corona condition is observed, but not in excess of 150 percent of maximum rated voltage.

5.4.3 Corona Test Conditions

Test voltages for corona detection should be of the same nature and waveform as those occurring in actual operation. Sine wave testing should not be substituted for direct current. The frequency of the test voltages should be within one octave of the rated frequency. The corona detection circuits and constants shall be suitable for the frequency and waveshape used in the test.

5.4.4 Induced Voltage Corona Testing

should be used when the rated induced winding voltage is in excess of 1000 volts crest. A combination of applied direct voltage and induced alternating voltage should be used when both are present in the operating circuit.

5.4.5 Applied Voltage Corona Testing

with winding terminals shorted together should be used when the lowest rated major insulation alternating voltage of the winding is in excess of 1000 volts crest, unless the unit has been tested under paragraph 5.2.1.

5.5 Corona Test Methods

Refer, when issued, to Corona Test Guide under preparation by the Insulation System Subcommittee of the IEEE Electronics Transformer Technical Committee.

5.6 Temperature Rise Tests

5.6.1 Linear Load

Units designed for linear loads or where the primary and secondary kilovoltampere ratings are the same may be tested using the standard methods described in USA Standards, such as C57.12.00, C57.12.20, and C57.12.90.

5.6.2 Nonlinear and Rectifier Loads

Units designed for nonlinear or rectifier loads where winding currents are not sinusoidal and/or the primary voltamperes may not be equal to secondary voltamperes, need to be tested using special loading circuits. Correct and accurate testing of many rectifier transformers will require the use of the rectifiers in conjunction with the transformers and the resultant direct current loading of the system. When the rated power load test using the rectifiers is impractical because of excess power consumption over a period of time, full current loading at a fraction of the rated voltage may be employed. Adjustment of final test results (temperature rise) may be made, approximately, by extrapolation of the temperature-rise versus loss data considering the added losses due to the difference between full-load core loss and actual core loss.

5.6.3 Winding Resistance

The standard reference temperature for reporting direct current resistances is 25 °C.

Annex I Definitions Relating to Transformer-Rectifier Systems (Informative)

1 Input Impedance

of a transformer-rectifier system is its internal impedance in ohms at rated frequency, when the rectifier is supplying rated direct current into a short circuit. It may be measured at the primary terminals by taking the ratio of the primary voltage and the primary current under the conditions stated above.

1.1 Output Impedance

of a transformer-rectifier system is its internal impedance in ohms measured at the direct current terminals when the rectifier is continuously providing direct current to a load. This impedance is preferably expressed as a curve of impedance in ohms versus frequency, over the frequency range of interest to the application.

1.2 Regulation

of a transformer-rectifier system is the change in output voltage as the load current is varied. It is usually expressed as a percentage of the rated load voltage when the load current is changed by its rated value.

$$\text{Percent regulation} = 100\,\frac{(E_1 - E_2)}{E_2}$$

where E_1 is the no-load voltage and E_2 is the voltage at rated load current and the line voltage is held constant at rated value.

1.3 Switch-On Overshoot

of a transformer-rectifier system is the transient voltage on the output direct voltage following the completion of capacitor charging in the direct current circuit. It may be expressed as a percentage of excess over the steady-state direct voltage.

1.4 Switch-Off Overshoot

of a transformer-rectifier system is the transient output voltage pulse occurring as the result of deenergization of the core on switch-off.

1.5 Short-Circuit Current

of a transformer-rectifier system is the steady-state value of the input alternating current that flows when the output direct current terminals are short-circuited and rated line alternating voltage is applied to the line terminals. This current is normally of interest when using current limiting transformers or checking current limiting devices.

1.6 Transient Suppression Networks

consist of capacitors, resistors, or inductors so placed as to control the discharge of stored energy banks. They are commonly used to suppress transients caused by switching.

Annex II Transformer Terminal Marking Guide (Informative)

1 General

Terminals should be so marked that a person familiar with this Standard can determine which terminals are a part of the same winding and which are primary and secondary terminals without having the terminal plan at hand. Furthermore, he should be able to determine the polarity of the winding by referring to the terminal markings alone. If a winding has a specific voltage relationship to ground, the terminal marking should indicate which is the high or low voltage to ground. This convention requires that all terminal numbers will have two digits or more.

1.1

Different windings will be identified by the tens column digit, with the lowest numbers always referring to the primaries. Thus a number 10 to 19 is always the primary or input winding. If there are two primary windings, then the second will be terminals 20 to 29, and for a third primary the numbers 30 to 39.

1.2

Winding terminals will be identified by a number in the units column.

1.3

No. (0) will always refer to a terminal that is common to two or more other terminals. Thus the common terminal of a tapped primary may be No. 10 and the center tap of a filament winding might be No. 40 while the beginning and ending are No. 41 and No. 42.

1.4

Polarity marking may be indicated without additional marks by making the lowest numbered ends of all windings have the same instantaneous polarity. Thus a series aiding connection may be made by connecting the lower numbered terminal of one winding to the higher numbered terminal of another winding. Parallel connections are more safely made with two similar windings by connecting like numbered terminals together; for example, (11, 21) and (12, 22) where the unit numbers are the same. The terminal number sequence should follow the voltage sequence.

1.5 Relative Insulation Level

Another convention is possible with an orderly terminal numbering system; namely, identify the high-voltage and low-voltage ends of a winding if there is a difference of importance. Starting with a winding having a relatively high voltage or impedance that is not balanced to ground or adjacent windings, and designating the low-voltage (insulation level) terminal with the lowest number for that winding series, then, of course, the higher numbered terminal will also be the higher voltage. The polarity of the other windings can then follow suit.

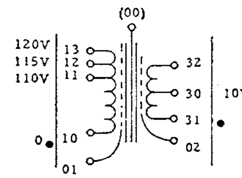


Fig. 1

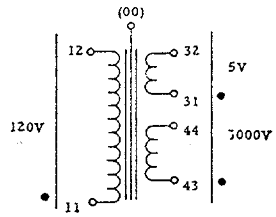


Fig. 2

1.6 Ground, Frame, Faraday Shields

Terminals for nonwindings may be designated in the tens column by (0). Thus a frame or core ground terminal would be (00). A primary shield may be designed (01) and a secondary shield may be (02), etc. This convention permits the marking (G) to mean a terminal that is connected to ground.

2.0 Single-Phase Transformers

Single-phase transformers will have one or two primary windings and rarely more; if two separate windings, they will usually be designed for series or parallel connections. If the windings are not intended for parallel operation, the terminal markings should inhibit this possibility by not using the same unit numbers on each, such as (Primary A No. 11, 12) (Primary B No. 23, 24).

2.1 Primary Windings

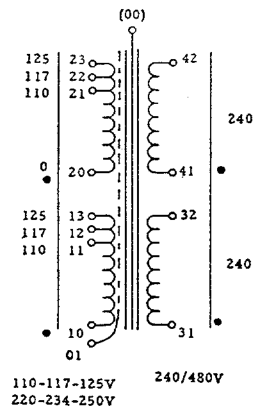
The first or only primary winding will use the tens digit (1), and the second primary (if any) will use the tens digit (2). Often one primary terminal is preferred near ground or grounded. If no other reason prevails (see paragraph), this terminal should have the smaller terminal number, indicating a ground preference.

2.2 Secondary Windings

The first or only secondary winding will use the tens digit of (3) so that an untapped winding would be numbered (31, 32) and a tapped winding with a common terminal would have (30, 31, 32, 33 …). A second secondary would use (40, 41, 42, 43 …), if they were alike and could be connected in parallel. However, a second secondary obviously not alike and marked (40, 45, 46) would not be parallel.

2.3 Graphic Examples and Interpretations

Fig. 3



3.0 Three-Phase Transformers

3.1 Phase Rotation Identification

Three-phase transformer terminals should be so numbered that the phase rotation of the primary windings and secondary windings is progressive. Thus, if terminal numbers 11, 21, 31 represent the starts of the three primary windings, and 41, 51, 61, the respective terminals of the secondaries, then the lowest of each series should be on the same phase coil; e.g., No. 11 and No. 41 thereafter No. 21, No. 51 on the next phase and also No. 31, No. 61 on the third phase coil. Accordingly, one would know that winding 41, 42 would be in phase with winding 11, 12 and so on. Furthermore, connecting terminal No. 41 to No. 12 would make the windings series aiding if this were desired.

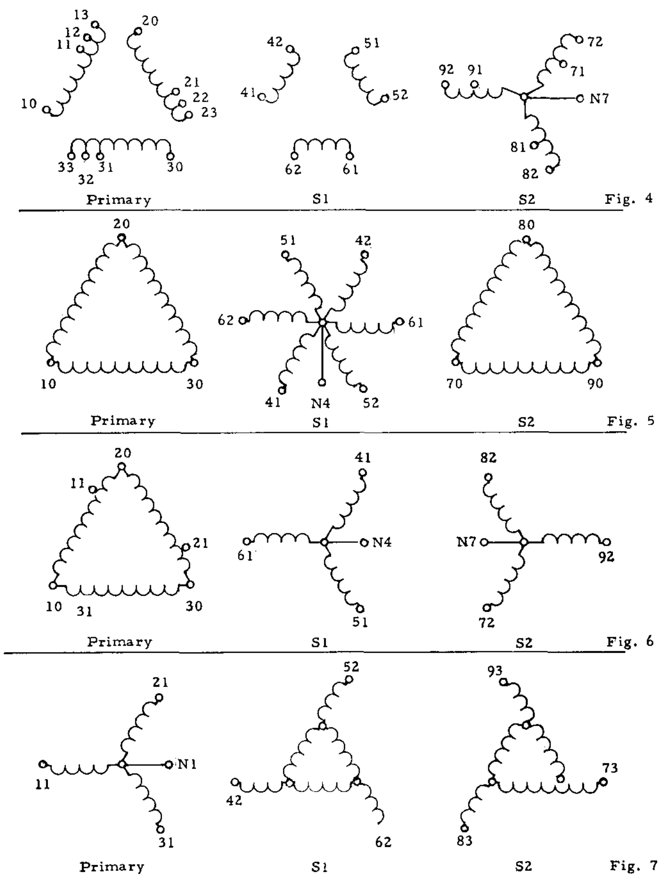
3.2 Primary Winding

Number series 10, 20, 30 is reserved for the primary windings. The rules under paragraph 1.0 otherwise apply.

3.3

Since a neutral terminal requires distinctive designation to avoid misunderstandings, it will be designated in the tens column by letter (*N*). This will indicate a common connection of three or more windings in proper phase relationship. There may be more than one neutral on a given transformer, so further identification is needed. Borrow the lowest winding number associated with that group of windings and use it in connection with the (*N*); e.g., (*N*7) for windings with terminals marked 71, 81, 91.

3.4 Graphic Examples and Interpretations



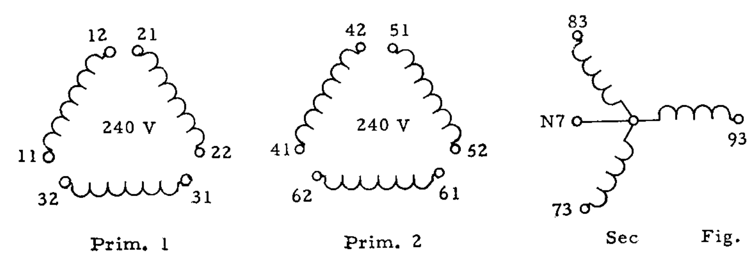


Fig. 8

Figure 8 Interpretation

For 240 volt primary connection:

Connect terminals 12, 21, 42, 51 to Line A
Connect terminals 22, 31, 52, 61 to Line B
Connect terminals 32, 11, 62, 41 to Line C

For 480 volt primary connection:

Connect 12 to 41, 22 to 51, 32 to 61.
Connect terminals 21, 42 to Line A
Connect terminals 31, 52 to Line B
Connect terminals 11, 62 to Line C

Annex III Typical Norms and Tolerances for Transformer Specifications (Informative)

1.0 Regulation

Regulation is also affected by the load power factor, hence the following table is based on 90 to 100 percent PF-60 hertz typical regulation (low to moderate voltage):

kVA	0.01	0.10	1.0	10	100 up
Percent Regulation	10–20	5–7	2–4	2.5	2.0

2.0 Impedance

($R + jw\ Ls$) of primary and secondary windings.

Typical impedance (low to moderate voltage):

kVA	0.01	0.10	1.0	10	100 up
Percent Impedance	15–25	8–12	4–6	2.5–4.5	2–3
Percent Tolerance*	±15	±15	±10	±10	±10

*Recommended tolerance on specified impedance.

3.0 Output Voltage Tolerance

(rated load)

kVA	0.01	0.10	1.0	10	100
Rectifier Winding (percent)	±5	±4	±3	±2	±2
Filament Winding (percent)	±3	±2	±1	±1	x
General (percent)	±3	±3	±3	±3	±2

Annex IV Electric Strength Tests for Transformers Connected to High-Voltage Lines (Informative)

(*Excerpt From "Distribution, Power, and Regulating Transformers"—USA Standard C57.12*)

Table 12-02.110a —DIELECTRIC TESTS FOR OIL-IMMERSED TRANSFORMERS

Nominal System Voltage* Column 1	Basics Impulse Insulation Level (BIL) Column 2	Insulation Class† Column 3	Low-Frequency Test Column 4	Impulse Tests: Chopped Wave Column 5	Impulse Tests: Chopped Wave Column 6	Impulse Tests: Full Wave Column 7
kV	kV	kV	kV	kV Crest	Minimum Time to Flashover (ms)	kV Crest
Distribution levels, transformers 500 kV A and below						
1.2	30	1.2A	10	36	1.0	30
2.4	45	2.5A	15	54	1.25	45
4.8	60	5A	19	69	1.5	60
8.32	75	8.7A	26	88	1.6	75
14.4	95	15A	34	110	1.8	95
Power levels, transformers above 500 kV A						
1.2	45	1.2	10	54	1.5	45
2.4	60	2.5	15	69	1.5	60
4.8	75	5	19	88	1.6	75
8.32	95	8.7	26	110	1.8	95
14.4	110	15	34	130	2	110

*For the insulation class applying to other oil-filled transformers with preferred nominal system voltages, see Table 12-02.110c. Voltage ratings between the listed nominal system voltages are placed in next higher insulation class unless otherwise specified.
†The letter "A" in the insulation class refers specifically to distribution levels, transformers 500 kVA and below.

Table 12-02.110b —DIELECTRIC TESTS FOR DRY-TYPE TRANSFORMERS AND DRY-TYPE SHUNT REACTORS

Nominal System Voltage Column 1	Basic Impulse Insulation Level (BIL) Column 2	Insulation Class Column 3	Low-Frequency Test Column 4	Impulse Tests: Chopped Wave Column 5	Impulse Tests: Chopped Wave Column 6	Impulse Tests: Full Wave Column 7
kV	kV	kV	kV	kV Crest	Minimum Time to Flashover (ms)	kV Crest
1.2	10	1.2	4	10	1.0	10
2.4	20	2.5	10	20	1.0	20
4.8	25	5	12	25	1.0	25
8.32	35	8.7	19	35	1.0	35
14.4	50	15	31	50	1.25	50

Annex V Inrush Current Considerations (Informative)

Two distinctly different definitions (2.1.6) (2.1.7) for inrush current have been offered because one definition cannot serve all the purposes where inrush current is of interest.

Magnetic and thermal cut-out devices usually are not responsive to one-half cycle of energy regardless of magnitude, hence two or more half cycles are needed to define the trip-out characteristics. Furthermore, these devices are not responsive to peak values, but rather to energy content. (I^2 t) becomes the parameter of interest, using root-mean-square current values for fusing characteristics. Relays and magnetic cut-outs are responsive to the average current value. Therefore, when inrush current is cited it should be made clear which of the two values (root mean square) (average) is indicated.

It should be noted that the inrush current of a transformer is seldom the same value as the steady-state exciting current, but is typically larger and decays to steady state after several cycles, depending on the condition of the core, the instantaneous value of applied voltage, etc. It is important to consider this asymmetry of inrush current in the design and use of transformers and particularly in the specification of protective devices for the transformer.

Maximum inrush current values occur when a transformer core that has an existing maximum residual flux is switched on at zero instantaneous voltage so the residual flux and the instantaneous magnetizing flux are additive. Circuits are available using silicon controlled rectifier switching to cause this to happen deliberately. Alternately, random switch-on twenty or more times will usually produce a near maximum value for a single-phase transformer. It may take more times for a three-phase transformer unless all three lines are monitored. For the measurement of root-mean-square or average current it is necessary to use an adequate *X*-axis spread or chart speed so that curve area per cycle can be measured.

Peak inrush current values are of interest in connection with contact welding problems and with devices sensitive to instantaneous current magnitude.

The measurement of true inrush current with any degree of accuracy can be very difficult because of the usual non-availability of zero source impedance power lines for larger systems. This problem can best be circumvented when the installed source capacity is known and specified in terms of impedance and phase angle, and rated capacity. These values can then be used in test or computation to determine the installed inrush characteristics of a system which, of course, is the final value of interest. When inrush current values are presented for conditions other than essentially zero source impedance, the actual source impedance values applicable to the data should also be given.

Annex VI Service Conditions (Informative)

This Appendix illustrates the sort of service conditions that can be specified and are often relevant to the transformers covered by this publication.

1.0 Visual and Mechanical

All units furnished should meet the dimensional and finish requirements of the applicable specifications and be of such construction as to meet the environmental conditions indicated in the specifications.

The units shall be capable of withstanding without damage the normal handling incidental to shipping and installing in the equipment. Terminals and bushings should be of sufficient strength in proportion to the size and weight of the unit.

2.0 Special Environmental Tests

Special environmental tests, including humidity, temperature extremes, altitude, vibration, shock, flammability, tilt, drop, impulse, sand erosion, submersion, salt spray, radiation, and sonic stress should be included in the specifications in a manner plainly evident to the manufacturer and user. Tests for these conditions should be agreed upon between user and manufacturer.

3.0 Acoustical Noise Level

Where the acoustical noise level is important, it shall be suitable for the environment. The use should specify the maximum acoustical noise level, the ambient acoustical noise, and weighting factor.

4.0 Ambient Temperature

Ambient temperature range for air-cooled transformers is normally between 20 °C and 50 °C and with the additional provision that air convection currents on five sides or 70 percent of the case surface should not be restricted. (Further, the radiation from nearby hot surface is not present unless specified. The reflection coefficient of opposite nearby surfaces should not exceed 0.75).

5.0 Liquid-Cooled Units

Water-cooled units shall presume an unlimited supply of liquid below 30 °C and with an available pressure drop of 30 pounds per square inch. The water shall be free from impurities that would be injurious to the materials used in the heat exchanger of the transformer.

6.0 Forced-Air Cooling

Forced-air cooling should be covered in the specifications as to directions, temperature, velocity, and cubic feet per minute.

7.0 Physical Location

Electronic components are usually placed in a protective cabinet where the terminals are not accessible to accidental contact. Any other requirement or condition should be specified.

8.0 Clean and Dry Environment

A clean and dry environment is considered normal for indoor equipment.

9.0 Altitude

Normal maximum altitude, unless otherwise specified, is 1000 meters (3300 feet).