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ANSI/IEEE C57.18-1964)

IEEE Standard Practices and Requirements for Semiconductor Power Rectifier Transformers

Sponsor

**Transformers Committee
of the
IEEE Power Engineering Society**

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Abstract: Practices and requirements for semiconductor power rectifier transformers for dedicated loads rated single-phase 300 kW and above and three-phase 500 kW and above are included. Static precipitators, high-voltage converters for dc power transmission, and other nonlinear loads are excluded. Service conditions, both usual and unusual, are specified, or other standards are referenced as appropriate. Routine tests are specified. An informative annex provides several examples of load loss calculations for transformers when subjected to nonsinusoidal currents, based on calculations provided in the standard.

Keywords: eddy current losses, harmonic load losses, single-phase transformers, three-phase transformers, three-winding transformers, transformer load losses, two-winding transformers

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Introduction

(This introduction is not part of IEEE Std C57.18.10-1998, IEEE Standard Practices and Requirements for Semiconductor Power Rectifier Transformers.)

Early editions of ANSI C57.18 were written for transformers used with pool cathode mercury arc rectifiers. The last revision date for ANSI C57.18 was 1964. That standard did not reflect the practices that have developed with the use of semiconductor rectifying or converting devices, nor did it reflect the latest transformer technology. As a result, much of it is inconsistent with current practices and with other related standards, such as ANSI C34.2^{*}, that deal with semiconductor converters. This new standard is the result of the decision to write a new rectifier transformer standard instead of revising the old standard. Suggestions for improvement of these practices will be welcomed.

Basic impulse level (BIL) ratings for windings connected to converters are not specified by this standard. There are many practical reasons why windings connected to converters need not have a BIL test or rating. These windings are often high-current, low-voltage windings that will not produce ANSI standard waveforms when tested. Interleaved windings cannot be impulse tested easily. Usually the converter and the transformer are close coupled in a throat connection and not subject to lightning strikes. The converter usually cannot withstand normal transformer BIL ratings for the winding voltages to which they are connected. These conditions aren't always true, however. If a user wishes to have a BIL rating or test, this may be arranged through commercial negotiations and technical specifications that may override this standard. This should also be acknowledged by the transformer manufacturer during the bidding process.

Hottest-spot winding temperatures are referred to in this standard. These are not tested values. Hottest-spot temperatures cannot be measured from a practical standpoint on production units. Therefore, average winding temperatures plus a hottest-spot increment may be used. There is continuing work in other standards groups on this matter.

The methods of rating the transformer kVA and currents in previous editions of ANSI C57.18 were based on the rms equivalent of a rectangular current wave shape based on the dc rated load commutated with zero commutating angle. This is the rms kVA and current method. All of the tables in Clause 10 are based on this traditional method. A new approach is to base the transformer kVA and currents on the rms value of the fundamental current and kVA. This is the fundamental kVA and current method. The fundamental kVA method is in use in IEC standards. This approach needs to be reflected in ANSI C34.2 and ANSI C34.3 as well as in this standard. The traditional tables are retained in Clause 10 to maintain its method. Both kVA values will be shown on the nameplate to accommodate either method. Specifying engineers should clearly define whether they are specifying the traditional rms kVA or the fundamental kVA so as to avoid confusion. RMS kVA is beneficial to users who utilize their primary metering on the transformer to monitor load. The fundamental kVA is related directly to the real power used by the rectifier or convertor. The rms kVA can be determined when the fundamental kVA is given along with the harmonic spectrum for the load. The specifying engineer is always obligated to supply the harmonic spectrum in order to properly rate and design the transformer. The specifying engineer has overall system responsibility; definition of the harmonic spectrum is not the transformer manufacturer's responsibility. The difference between the two methods should result in only a small percentage error in kVA sizing, but in some cases it may be determined to be critical. Future coordination with ANSI C34.2 and ANSI C34.3 working groups should give a final direction with regard to kVA rating method.

Two cautionary notes are in order regarding testing.

First, errors may result when measuring losses on transformers with low power factors. Care must be exercised in making the loss measurements for rectifier transformers with high reactance and low losses. Test tol-

^{*}A new working group has been formed to revise ANSI C34.2.

erances should be held to 3% throughout the ranges of reactance and losses so as to accurately measure stray losses for the harmonic calculations. There is ongoing work on this subject within the Loss Measurement Working Group of the Performance Characteristics Subcommittee.

Second, other errors regarding resistance readings for losses or temperature rise tests are possible on low-voltage, high-current windings having very low resistance, often with bolted joints. Connection losses may alter normal resistance measurements. Work on this topic should be undertaken in the future.

The exact methodology for temperature rise testing using service losses enhanced with harmonics needs to be more fully developed. After this standard has been in use, it is expected that manufacturers and users will develop more detailed preferred methods. Experience will also provide insight as to whether there are any serious shortcomings in these methods. It is hoped that they will be found to be safely conservative. It is believed that some development time is necessary with the new approach before exact methods are prescribed.

Work should be done on future revisions to this standard to develop more detailed methods of interphase transformer loss testing. More precise methods for determining losses for commercial guarantee purposes, as well as thermal and magnetic capability, are needed. These were not attempted in this standard revision due to lack of time.

This standard was developed by a Working Group of the Subcommittee on Performance Characteristics of the IEEE Transformer Committee. The Working Group had the following membership:

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IEEE Standard Practices and Requirements for Semiconductor Power Rectifier Transformers

1. Overview

1.1 Scope

This standard includes semiconductor power rectifier transformers for dedicated loads rated

- Single-phase 300 kW and above
- Three-phase 500 kW and above

The scope of this standard excludes

- Static precipitators
- High-voltage converters for dc power transmission
- Other nonlinear loads

1.2 Mandatory requirements

When this standard is used on a mandatory basis, the words “shall” and “must” indicate mandatory requirements, and the words “should” and “may” refer to matters that are recommended and permitted, respectively, but not mandatory.

2. References

When the following standards and guides referred to in this standard are superseded by an approved revision, the latest revision shall apply.

ANSI C34.3-1973 (IEEE Std 444-1973), IEEE Standard Practices and Requirements for Thyristor Converters for Motor Drives.¹

¹This standard has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.

ANSI C57.12.10-1988, American National Standard for Transformers—230 kV and Below 833/948 through 8333/10 417 kVA, Single-Phase, and 750/862 Through 60 000/80 000/100 000 kVA with Load Tap Changing—Safety Requirements.

ANSI C57.12.51-1981, American National Standard Requirements for Ventilated Dry-Type Power Transformers 501 kVA and Larger, Three-Phase, with High-Voltage 601 to 34 500 Volts, Low-Voltage 208Y/120 to 4160 Volts.

ANSI C57.12.70-1978 (Reaff 1993), American National Standard Terminal Markings and Connections for Distribution and Power Transformers.

IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronics Terms, Sixth Edition.²

IEEE Std 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.

IEEE Std 995-1987, IEEE Recommended Practice for Efficiency Determination of Alternating-Current Adjustable-Speed Drives, Part 1—Load Commutated Inverter Synchronous Motor Drives.³

IEEE Std C57.12.00-1993, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.01-1989, IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those with Solid Cast and/or Resin-Encapsulated Windings.⁴

IEEE Std C57.12.80-1978 (Reaff 1992), IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.12.90-1993, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and IEEE Guide for Short Circuit Testing of Distribution and Power Transformers.

IEEE Std C57.12.91-1995, IEEE Standard Test Code for Dry-Type Distribution and Power Transformers.

IEEE Std C57.91-1995, IEEE Guide for Loading Mineral-Oil-Immersed Transformers.

IEEE Std C57.96-1989, IEEE Guide for Loading Dry-Type Distribution and Power Transformers.

IEEE Std C57.110-1986 (Reaff 1992), IEEE Guide for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents.

3. Definitions

Terms used in this document, other than those described below, are defined in IEEE Std 100-1996⁵. Some terms are restated here for emphasis because of the special application.

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

³IEEE Std 995-1987 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.

⁴IEEE Std C57.12.01-1989 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.

⁵Information on references can be found in Clause 2.

3.1 commutating impedance (rectifier transformer): The impedance that opposes the transfer of current between two secondary winding terminals of a commutating group, or a set of commutating groups.

3.2 percent impedance (rectifier transformer): The percent of rated primary winding voltage required to circulate current equivalent to rated kilovoltamperes in the primary winding with all secondary winding terminals short-circuited.

4. Symbols

D_x	Commutating reactance transformation constant (applies only to the first mode of operation after the light load transition)
E_d	Average dc voltage under load
E_{do}	Theoretical dc voltage (average dc voltage at no load or light transition load assuming no overlap, no phase control, and zero forward voltage drop)
E_L	Alternating-current system line-to-line voltage (rms)
E_n	Alternating-current system line-to-neutral voltage (rms)
E_r	Direct voltage drop caused by resistance losses in transformer equipment
E_s	Transformer secondary winding line-to-neutral, open-circuit no-load voltage (rms)
E_x	Direct voltage drop caused by commutating reactance
f	Frequency of ac power system
F_{HL-OSL}	Other stray loss harmonic loss factor
F_{HL-WE}	Winding eddy current harmonic loss factor
h	Order of harmonic
I_h	Harmonic component of current of the order indicated by the subscript h
I_L	Alternating line current (rms)
I_p	Equivalent thermal test current on primary windings
I_{pL}	Alternating line current corresponding to the current in the primary winding during load loss test
I_s	Equivalent thermal test current on secondary windings
I_T	Equivalent thermal test current on tertiary windings
I'_p	Rated current for the primary windings
I'_s	Rated current for the secondary windings
I'_T	Rated current for tertiary windings
P_{EC}	Total winding eddy current and circulating current loss under test conditions
P_{EC-p}	Primary winding eddy current and circulating current loss under test conditions
P_{EC-s}	Secondary winding eddy current and circulating current loss under test conditions
P_{EC-T}	Tertiary winding eddy current and circulating current loss under test conditions
P_{OSL}	Total other stray loss under test conditions
P_{OSL-p}	Primary winding other stray loss under test conditions
P_{OSL-s}	Secondary winding other stray loss under test conditions
P_{OSL-T}	Tertiary winding other stray loss under test conditions
P_r	Transformer load losses in watts (including resistance and eddy current losses)
P'_{OSL}	Total other stray loss expected at rectifier operation
P'_{OSL-p}	Primary winding other stray loss expected at rectifier operation
P'_{OSL-s}	Secondary winding other stray loss expected at rectifier operation
P'_{OSL-T}	Tertiary winding other stray loss expected at rectifier operation
P'_{EC}	Total eddy current and circulating current loss expected at rectifier operation
P'_{EC-p}	Primary winding eddy current and circulating loss expected at rectifier operation
P'_{EC-s}	Secondary winding eddy current and circulating loss expected at rectifier operation
P'_{EC-T}	Tertiary winding eddy current and circulating loss expected at rectifier operation
PU	Per unit of some defined base
q	Pulse number of rectifier or number of rectifier phases
R_c	Line-to-neutral commutating resistance in ohms for a set of commutating groups

R_{cn}	Equivalent line-to-neutral commutating resistance in ohms for a set of commutating groups, referred to the primary winding of a rectifier transformer
R_p	Total ohmic resistance of primary windings at τ
R_s	Total ohmic resistance of secondary windings at τ
R_T	Total ohmic resistance of the tertiary winding at τ
t	Turns ratio (primary to secondary)
τ	Rated winding temperature rise plus 20 °C
X_c	Line-to-neutral commutating reactance in ohms for a set of commutating groups
X_{cn}	Equivalent line-to-neutral commutating reactance in ohms for a set of commutating groups referred to the primary winding of a rectifier transformer ($X_{cn} = D_x X_c$)
Z_c	Line-to-neutral commutating impedance in ohms for a set of commutating groups
Z_{cn}	Equivalent line-to-neutral commutating impedance in ohms for a set of commutating groups referred to the primary winding of a rectifier transformer
Z_g	Line-to-neutral commutating impedance in ohms for a single commutating group

5. Service conditions

5.1 Usual service conditions

5.1.1 General

Usual service conditions shall be as defined in IEEE Std C57.12.00-1993 for liquid-immersed rectifier transformers and in IEEE Std C57.12.01-1989 for dry-type rectifier transformers, except where clearly not applicable to rectifier transformers or where otherwise specified herein.

5.1.2 Operation above or below rated voltage or frequency

Rectifier transformers shall be capable of

- Operating continuously above rated voltage or below rated frequency, at maximum rated kVA for any tap, without exceeding the limits of observable temperature rise in accordance with 6.12 when both the secondary voltage and volts per hertz do not exceed 105% of rated values and the operating frequency is at least 95% of rated value.
- Operating continuously above rated voltage or below rated frequency, on any tap at no load, without exceeding limits of observable temperature rise in accordance with 6.12 when neither the voltage nor volts per hertz exceeds 110% of rated values.

5.1.3 Voltage harmonics

Rectifier transformers shall be capable of operating under load with voltage harmonics present, but within the limits established by IEEE Std 519-1992.

5.2 Unusual service conditions

5.2.1 General

Conditions other than those described in 5.1 are considered unusual service conditions and, when prevalent, should be brought to the attention of those who are responsible for the design and application of the transformer.

5.2.2 Loading at other than rated load

5.2.2.1 Liquid-immersed rectifier transformers

IEEE Std C57.12.00-1993 and IEEE Std C57.91-1995 define loading for other than rated load conditions for liquid-immersed rectifier transformers.

5.2.2.2 Dry-type rectifier transformers

IEEE Std C57.12.01-1989 and IEEE Std C57.96-1989 define loading for other than rated load conditions for dry-type rectifier transformers.

5.2.3 Unusual temperature and altitude conditions

Rectifier transformers may be used at a higher or lower ambient temperature or at higher altitudes than those specified in 5.1, but special consideration must be given to these applications. For unusual temperatures, the appropriate guides referenced in IEEE Std C57.12.00-1993 and IEEE Std C57.12.01-1989 apply. For altitude, Table 1, Table 2, and Table 3 in Clause 10 may serve as a guide.

5.2.4 Other unusual service conditions

Other unusual service conditions include the following:

- a) Damaging fumes or vapors, excessive or abrasive dust, explosive dust or gases, steam, salt spray, excessive moisture or dripping water, etc.
- b) Abnormal vibration, shocks, or tilting.
- c) Unusual transportation or storage conditions.
- d) Unusual space limitations.
- e) Unusual operating duty, frequency of operation, difficulty of maintenance, poor wave form, unbalanced voltage, special insulation requirements, high source impedance, etc.
- f) The presence of any dc current in transformer windings either from load or supply side.

5.2.5 Transformers energized from a convertor/inverter

Transformers energized from a convertor/inverter are often subject to considerably distorted voltages. Generally, voltage harmonics are considered to be low with regard to loss correction and negligible in thermal design considerations. If voltage distortions are known to be above the specified limits in IEEE Std 519-1992, information shall be given in the specification with details of the service conditions.

Variable frequency applications are generally considered to be constant volts per hertz, unless noted otherwise. If the volts per hertz is variable, the degree of variation shall be given in the specification. The amplitude of the flux density in the core is the most important factor, not the maximum value of the nonsinusoidal voltage.

6. Rating data

The kVA rating of a rectifier transformer shall be the kVA drawn from the line.

6.1 Taps on rectifier transformers

If taps are provided they shall be considered to be, unless otherwise specified, only a means of adjusting for sustained departures in alternating supply voltage. These shall be rated kVA primary taps.

When taps are provided in the rectifier transformer for adjusting the output voltage, the taps providing output voltages above rated voltage shall be rated kVA taps, and the output current shall be reduced in proportion to the increase in output voltage, thereby maintaining rated kilowatt output. The taps providing output voltages below rated voltage shall be reduced kVA taps, the output currents shall not exceed the current specified, and voltage variation shall not exceed $\pm 10\%$.

6.2 Cooling classes of transformers

Use “Cooling Classes of Transformers” in IEEE Std C57.12.00-1993 and “Limits of Temperature Rise” in IEEE Std C57.12.01-1989.

6.3 Frequency

The frequency of rectifier transformers covered by this standard shall be 60 Hz unless otherwise specified.

6.4 Phases

See Table 9 for selection of number of primary and secondary phases.

6.5 Rated kVA

6.5.1 Line kVA rating

The line kVA rating of a rectifier transformer shall be the kVA assigned to it by the specifier corresponding to the kVA drawn from the ac system at rated ac voltage and rated dc volts and dc amperes on the rectifier, not including auxiliary power.

6.5.2 RMS kVA rating

The traditional rms kVA ratings are shown in the tables and figures in Clause 10. These values are based on the rms equivalent of a rectangular current wave shape based on the dc rated load commutated with zero commutating angle. The rms kVA can also be calculated by calculating the rms value of the sum of the fundamental line current plus all of the associated harmonic line currents. The equivalent thermal test current will be used for testing thermal capability.

6.5.3 Fundamental kVA rating

The fundamental kVA rating is based on the rms value of the fundamental current and the fundamental line-to-line voltage. The fundamental kVA rating and line current shall be used for commercial loss guarantees.

6.6 Compensation on rectifier transformers

The specifier shall take the following aspects into account while arriving at the specification. In order to obtain rated direct output voltage at rated current on the rectifier unit, the winding turns ratio of the rectifier transformer may be changed to compensate for either or both of the following:

- a) Momentary reduction in alternating supply voltage or prolonged operation at reduced alternating voltage without a tap change.
- b) Voltage drop resulting from ac system impedance. When compensation is required, the following shall be specified:
 - 1) Minimum alternating supply voltage at which the rectifier unit shall deliver rated direct voltage and current with the transformer on a specified voltage tap.
 - 2) Maximum system impedance for which compensation is required. The impedance shall be given in ohms or in terms of short-circuit kVA or amperes available at the terminals of the primary winding of the rectifier transformer. The total number, capacities, and transformer connections of all rectifiers to be supplied by the same ac system shall also be specified.

NOTE—A rectifier transformer that is compensated by decreasing the winding turns ratio has an increased kVA rating.

It is the responsibility of the specifying engineer to provide the transformer manufacturer with the proper compensations. The specifying engineer must provide the values of E_s , transformer kVA, and transformer impedance.

6.7 Rated current

6.7.1 RMS rated current method

The rated current of a rectifier transformer is the rms equivalent of a rectangular current wave shape based on the dc rated load commutated with zero commutating angle.

6.7.2 Fundamental current method

The rated current of a rectifier transformer is the rms equivalent of the fundamental component of the line current.

6.8 Connections

Rectifier transformer connections may be selected from Table 9 of Clause 10 as required.

6.9 Polarity, angular displacement, and lead markings

6.9.1 Polarity of single-phase rectifier transformers

All single-phase rectifier transformers shall have subtractive polarity.

6.9.2 Angular displacement between voltages for polyphase transformers

Figures 1, 2, and 3 show angular displacements for circuits 46, 45, and 53, respectively. These examples may be expanded to include all circuit configurations.

6.9.3 Connection and marking of terminals for rectifier transformers

Rectifier transformer terminal markings shall be as follows:

- a) The terminals of the primary windings of rectifier transformer equipment shall be marked “H” with subscripts.

- b) The terminals of the secondary windings of rectifier transformer equipment shall be marked “R” with subscripts. If there is more than one group of secondary windings in the same phase position, successive groups shall be marked “S,” “T,” “U,” “V,” and “W” and auxiliary windings shall be “A.” The corresponding phases shall have the same numerical subscripts. The neutral terminals of secondary windings shall be marked “N” with subscripts.

6.10 Impedance

6.10.1 Percent impedance of a rectifier transformer

See 3.2.

6.10.2 Commutating impedance

See 3.1 and 8.8.1.

This value is defined as one-half the total impedance in the commutating circuit expressed in ohms referred to the total secondary winding. For wye, star, and multiple wye circuits, this is the same value as derived in ohms on a phase-to-neutral voltage basis; while with diametric and zig-zag circuits it must be expressed as one-half the total due to both halves being mutually coupled on the same core leg or phase.

6.11 Losses

Use losses described in IEEE Std C57.12.00-1993 for liquid-immersed rectifier transformers and in IEEE Std C57.12.01-1989 for dry-type rectifier transformers.

6.12 Temperature rise and insulation system capability

“Temperature Rise and Insulation System Capability” in IEEE Std C57.12.01-1989 and “Temperature Rise and Loading Conditions” in IEEE Std C57.12.00-1993 shall be used for this standard.

CAUTION

The application of some types of hottest-spot temperature measuring equipment to a rectifier transformer is complicated by the effect of residual dc magnetomotive forces due to various abnormal operating conditions of the rectifier. When hottest-spot temperature measuring equipment is provided, it is subject to inherent error due to abnormal operating conditions.

6.13 Nameplates

A nameplate shall be attached to each rectifier transformer. It shall be made of corrosion-resistant material with permanent easily visible engraved or stamped lettering.

6.13.1 Nameplate information

The minimum information shown on the nameplate shall be as specified below:

- a) Serial number.

NOTE—The height of letters and numerals showing the serial number shall be a minimum of 4.0 mm (5/32 in). The height of other letters and numerals shall be at the manufacturer’s discretion.

- b) Cooling class. In some cases, it may be desirable to include the type or form, or both, in addition to the cooling class.
- c) Number of primary winding phases.
- d) Frequency.
- e) kVA (line rating). Both the rms kVA rating and the fundamental kVA rating will be shown.
 - 1) The height of letters and numerals showing kVA shall be 4.0 mm (5/32 in). The height of other letters and numerals shall be at the manufacturer's discretion.
 - 2) Where the cooling class of a transformer involves more than one kVA rating, such as forced cooled class or future forced-cooling class, the kVA rating should be the line kVA corresponding to rated kW of rectifier. Supplemental rectifier transformer ratings, if specified, should be indicated by a note on the nameplate.
- f) Voltage ratings.
 - 1) The height of letters and numerals showing voltage ratings shall be a minimum of 4.0 mm (5/32 in), whether engraved or stamped. The height of other letters and numerals shall be at the manufacturer's discretion.
 - 2) The primary winding voltage rating shall be the primary line voltage and circuit connection, and the secondary winding voltage rating shall be the voltage anode to neutral or line-to-line with reference to the circuit employed. *Example:* 13 800 Y-745 anode to neutral, double Y.
- g) Tap voltages.
 - 1) The tap voltage of a winding shall be designated by listing the winding voltage of each tap separated by a slant, or it shall be in tabular form. The rated voltage of each tap shall be shown in volts.
 - 2) The rated rms currents of all windings at rms kVA corresponding to the rated dc amperes of the rectifier shall be shown.
- h) Temperature rise, °C.
- i) Polarity (single phase) or phasor diagram (polyphase).
- j) Percent impedance at line kVA rating.
- k) Commutating reactance in ohms, phase-to-neutral referred to total dc winding.
- l) The following statement: "For use with a _____ phase⁶, _____ kW, _____ volts, dc, single, or double way, rectifier for _____ service" (electrochemical, industrial, light traction, mining, or heavy traction, extra heavy traction) Circuit # _____.
- m) Approximate weights. The approximate weights in pounds (or kilograms) shall be shown as follows:
 - Core and coils
 - Tank and fittings
 - Liquid
 - Total weight
 - Untanking weight (heaviest piece)
- n) Connection diagram.

⁶Refers to secondary winding phases. (Quantity *q* in the list of symbols; see Clause 4.)

All leads brought outside the tank and all windings shall be identified on the nameplate or connection diagram. (Show connections as viewed facing the transformer from the side on which the nameplate is attached or as otherwise described.)

A schematic view shall be included to show the relative location of external and internal terminals. In general, the schematic view should be arranged to show the secondary winding at the bottom and the H1 primary winding terminal at the top left. (The arrangement may be modified in particular cases, such as multiwinding transformers equipped with terminal chambers, potheads, or having terminal locations not conforming to the suggested arrangement if the modification is explained.)

All internal leads and terminals that are not permanently connected shall be designed or marked with numbers or letters in a manner which will permit convenient reference and will obviate confusion with terminal and polarity markings.

- o) Patent numbers (at the manufacturer's discretion).
- p) Name of manufacturer.
- q) Reference to instruction book or sheet.
- r) The words "rectifier transformer" and "dry-type" or "liquid-immersed."
- s) Type of liquid if liquid-immersed or class of insulation if dry-type.
- t) Number of gallons of liquid. The number of gallons of insulating liquid shall be shown for the main tank and for each liquid-immersed compartment.
- u) Basic impulse level (BIL). BIL rating in kV of line terminals of windings shall be designated as the following example:

Primary winding 110 kV BIL
Secondary winding 45 kV BIL
- v) Conductor material.
- w) Date of manufacture.

6.13.2 Additional information

In addition to the information specified in 6.13.1, the following shall be included on the nameplate, when applicable:

- a) Indication of provision for future forced-cooling equipment.
- b) Indication of potential transformers, potential devices, current transformers, winding temperature devices, etc.
- c) Polarity and location identification of current transformers to be shown if used for metering, relaying, or line-drop compensation. (Polarity need not be shown if current transformers are used for winding temperature equipment or fan control.)
- d) Maximum operating pressures of liquid preservation system, kPa (or lbf/in²) positive and _____ kPa (or lbf/in²) negative.
- e) Tank designed for _____ cm (inches) mercury vacuum.
- f) Liquid level below top surface of the highest point of the highest manhole flange at 25 °C, _____ cm (inches). Liquid level changes _____ cm (inches) per 10 °C in liquid temperature.
- g) Core and coils braced for _____ times normal load current.

7. Construction

Use IEEE Std C57.12.00-1993 for construction specifications for liquid-immersed rectifier transformers, and IEEE Std C57.12.01-1989 for dry-type rectifier transformers in this standard except as follows.

7.1 Mounting and location

7.1.1 Portable mining-type rectifier transformer

A portable mining-type rectifier transformer shall be suitable for transporting on skids or wheels in the restrictive areas of mines.

7.1.2 Lifting, jacking, and/or skidding

Rectifier transformers shall be supplied with lifting, jacking, and/or skidding attachments. Special requirements for handling must be specified.

7.2 Tanks

7.2.1 Finish

The finish normally furnished by a manufacturer shall be supplied except as required by this subclause or as specified. Metallic flake paints, such as aluminum and zinc, etc., have properties which increase the temperature rise of the transformers except in direct sunlight. Temperature limits and tests are based upon the use of a pigment paint finish.

7.2.2 Bracing

Transformers shall be braced sufficiently to withstand normal forces experienced in shipping, maintaining, and operating.

7.3 Method of coolant preservation

Refer to ANSI C57.12.10-1988 for approved methods of coolant preservation.

7.4 Grounding

Grounding of case and core on liquid-immersed rectifier transformers shall be done as described in IEEE Std C57.12.00-1993. For dry-type rectifier transformers, grounding of case and core shall be done as described in IEEE Std C57.12.01-1989.

7.5 Connections for shipping

Unless otherwise specified, connection specifications in IEEE Std C57.12.00-1993 for liquid-immersed and IEEE Std C57.12.01-1989 for dry-type rectifier transformers shall apply.

7.6 Accessories

Accessories may include any or all of the following:

7.6.1 Liquid-immersed transformers

Liquid level gauge with alarm contact; cooling medium temperature gauge with one- or two-point alarm contacts; sudden pressure relay; gas-fault relay; pressure relief device with alarm; liquid flow switch with alarm; pressure-vacuum gauge with high and low alarm and bleeder; nozzles with valves for filling, draining, sampling, and liquid filtering; pump; manholes; weather-protected covers for controls and wiring terminal compartments; heat exchangers; radiators; and other. These shall be specified as required.

7.6.2 Dry-type transformers

Temperature detection device; fan and fan control circuit; space heater; ground protection relays; etc. These shall be specified by users.

8. Testing and calculations

Unless otherwise specified, tests shall be made at the factory only.

8.1 Routine tests

The following routine tests shall be made on all rectifier transformers. The numbers shown do not necessarily indicate the sequence in which the tests shall be made. All tests shall be made in accordance with the test code in IEEE Std C57.12.90-1993 for liquid-immersed transformers and the test code in IEEE Std C57.12.91-1995 for dry-type transformers.

- a) Resistance measurements of all windings on the rated voltage connection of each identical unit and in case of a production run, at the tap extremes of one unit of a given rating when produced by one manufacturer at the same time.
- b) Ratio tests on the rated voltage connection and on all tap connections.
- c) Polarity and phase relation tests on the rated voltage connection.
- d) Excitation loss at rated voltage on the rated voltage connection.
- e) Excitation current at rated voltage on the rated voltage connection.
- f) Impedance and load loss at rated current on the rated voltage connections of each unit (except as modified by 8.6) and on the tap extremes of one unit of a given rating when produced by one manufacturer at the same time.
- g) Temperature test or tests shall be made on one unit when one or more units of a given rating are produced by one manufacturer at the same time, except that these tests shall be omitted when a record of a temperature test, made in accordance with these standards, on a duplicate or essentially duplicate unit, is available. The temperature test is a design test, not a routine test.

Subject to the limitation of the preceding paragraph, when a rectifier transformer is supplied with auxiliary cooling equipment to provide more than one kVA rating, temperature tests shall be made in accordance with Table 14 of IEEE Std C57.12.00-1993.

- h) Applied potential tests.
- i) Induced potential tests.

8.2 Symbols used in tests

Symbols listed in Clause 4 as used in routine tests may be modified by additional subscripts to indicate phase, line, transformer, etc. (i.e., X_c , X_{c2} , X_{c3} , X_{c1} , X_{ct}). Additional symbols will be identified as used.

8.3 Resistance measurement

Use resistance measurement as described in IEEE Std C57.12.90-1993 for liquid-immersed and in IEEE Std C57.12.91-1995 for dry-type rectifier transformers as part of this standard.

8.4 Dielectric tests

Unless otherwise specified, dielectric tests shall be made in accordance with IEEE Std C57.12.90-1993 for liquid-immersed rectifier transformers and IEEE Std C57.12.91-1995 for dry-type rectifier transformers. Dielectric tests on rectifier transformer secondaries will be made using voltages given in Tables 4 and 5 in Clause 10 of this standard.

8.5 Excitation losses

Use excitation loss measurement as described in IEEE Std C57.12.90-1993 for liquid-immersed, and IEEE Std C57.12.91-1995 for dry-type transformers as part of this standard.

8.6 Load losses

Load losses of rectifier transformers shall be determined by the methods given in IEEE Std C57.12.90-1993 for liquid-immersed and in IEEE Std C57.12.91-1995 for dry-type units, with special considerations listed below. The measurement of load losses shall be performed with sinusoidal rated transformer current. The load loss guarantee is based on the sinusoidal loss measurement, for commercial purposes.

Actual service load losses for the expected harmonic spectrum provided in the specification supplied to the transformer manufacturer with the inquiry may also be calculated and submitted for information in the bid proposals. These losses are not subject to guarantee, but shall be calculated according to accepted methods, an example of which is described in the remainder of 8.6, or by the use of an advanced mathematical modeling technique.

8.6.1 General

The difference in kVA capabilities of the primary and secondary windings of many rectifier transformers makes it impractical to circulate rated current in all windings when making load loss tests. Furthermore, the load loss is dependent on the magnitude and wave form of the current flowing in the windings. The current wave form is influenced by the circuit employed, by transformer reactance, and by the supply lines. Involved calculations are necessary to accurately include the effects of all these factors. Investigations have demonstrated, however, that tests made with sine wave currents having the same rms values as the expected rectangular current waves, together with calculations based thereon, permit load losses, accurate to within satisfactory limits, to be obtained. When making load loss tests on rectifier transformers, external interphase transformers, if present, shall be excluded from the test circuits in any manner that precludes their contributing to the losses measured. Internal interphase transformers shall be tested in accordance with 8.6.4.

8.6.2 Test and calculations required for load loss tests

- a) Measure all winding resistances on a per winding basis and correct to τ .