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IEEE Guide for Metric Conversion of Transformer Standards

IEEE Power Engineering Society

Sponsored by the
Transformers Committee

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IEEE Guide for Metric Conversion of Transformer Standards

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Abstract: A consistent and accurate method of converting dimensions and quantities in transformer standards to SI units is provided in this guide.
Keywords: conversion, dimensions, metric, transformers, units

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Introduction

(This introduction is not part of IEEE Std C57.144-2004, IEEE Guide for Metric Conversion of Transformer Standards.)

In 1995, IEEE implemented a new metric policy (IEEE Policy 9.20), which directed that all IEEE publications undergo a transition from U.S. Customary (or inch-pound) units of measure to metric or Le Systéme International d'Unités (SI). The metric or SI system is the standard for science and engineering and in common usage in nearly all countries of the world except for the United States. The IEEE Policy directed that standards published after January 2000 were to be expressed solely in metric units.

Subsequently, the IEEE-SA Standards Board modified the policy on 11 September 2003 to allow some latitude in conversion from U.S. Customary to metric units. The revised policy is identified as Policy 9.19. The new policy states that standards should use metric units exclusively in the normative portions of the standard, but the use of metric units with parenthetical inch-pound units are also permitted.

Working groups and subcommittees of the IEEE Transformers Committee tried to make these conversions, but when the work of one body was compared with another, it was found that conversions were often made either inconsistently or incorrectly. The existing guide, IEEE/ASTM SI 10™-2002 and its predecessor, IEEE Std 268™-1992, were not being used as intended. Both documents are listed here because some important information regarding conversion of toleranced values has been omitted from the more recent guide. The Transformers Committee formed a Metric Conversion Task Force to address the problems encountered by the working groups in revising their standards. The Task Force presented tutorials for Transformers Committee members and is hereby creating an IEEE guide to create a better understanding of metric usage and of conversion methods as they apply to Transformer Standards.

Notice to users

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When the IEEE-SA Standards Board approved this guide on 24 June 2004, it had the following membership:

Contents

IEEE Guide for Metric Conversion of Transformer Standards

1. Overview

1.1 Scope

The intent of this guide is to assist the working groups within the IEEE Transformers Committee; thus, specific examples were taken from the transformer-related standards. It should be recognized that identification of general principles and procedures could have broader application.

1.2 Purpose

The purpose of this guide is to assist Transformer Working Groups in the interpretation of IEEE/ASTM SI 10™-2002[1] and other appropriate standards as they convert their documents to the use of SI units. This guide is concerned only with the conversion of existing standards, where a manufacturer's product that meets the existing standard's limits in U.S. Customary units will always meet the new standard's limits in SI units. With the exception of a few very specific examples in A.3, there has been no attempt to make the metric values more rounded or more convenient. Making such changes to a standard may affect the qualification of existing designs and should come only from a consensus of the interested parties in the appropriate working groups.

2. References

This guide shall be used in conjunction with the following standard.

IEEE/ASTM SI 10-2002, American National Standard for Use of the International System of Units (SI): The Modern Metric System.[2]

[1]Information on references can be found in Clause 2.

[2]IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

3. Guidelines

3.1 Application of converted values

Ensure converted values do not suggest a precision (repeatability or confidence interval) that you do not need or cannot measure. For example, the precision of a tape measure or other manual measuring method is limited to about 1/32 in (0.031 in) or 1 mm (0.039 in).

3.2 “Hard” and “soft” conversion

Although the use of these terms is not recommended, the concepts should be understood: “Soft” conversion is a statement of mathematical identity, without regard to significant digits. For example, a soft conversion of 100 ft = 30.480 m. A “hard” conversion, on the other hand, will be rounded to a more convenient value that is easy to work with, such as 100 ft = 30.5 m. Hard conversions may maintain a consistent number of significant digits in both values, but the definition does not specifically state this possibility (see Smith [B4]).[3]

3.3 Use convenient numbers

Overall, 16.5 L/s is handier than 1.65 E-02 m^3/s. The liter (or litre) is equal to 0.001 m^3 and is recommended for common volumes where the use of m^3 is unwieldy. For such volumes, use the symbols “L,” “mL,” and “µL” only. Do not use units such as “cm^3”.

3.4 Convert fractions

Dimensions presently in fractional inches should be expressed as decimals to a reasonable level of precision prior to any conversion. Where a prior conversion from fractions is suspected, an exact conversion may have kept excessive decimal places, overstating the precision attainable. For example, a dimension now shown as 0.1875 in probably originated as 3/16 in and should have been expressed as 0.19 in when first decimalized.

3.5 Determine tolerance

Before any conversion, try to determine the stated, implied, or inherent tolerance on the quantity. This tolerance may depend on the available measurement methods or on the typical manufacturing technology used. For example, the typical manufacturing tolerance for linear dimensions for sand-casting with a copper alloy is ± 1/32 in ~ ± 0.031 in ~ ± 0.8 mm.

3.6 Maintain original minimums and maximums

Do not violate original minimum and maximum values when converting without considering the consequences. For mating parts that must fit together, expanding a tolerance limit can have severe consequences. For situations where mating parts are not involved, the expansion of tolerances by small amounts, e.g., fractions of a millimeter, will probably be inconsequential.

[3]The numbers in brackets correspond to those of the bibliography in Annex C.

3.7 Significant digits should be less than 10% of the overall tolerance

This general rule for “10% accuracy in the rounding of tolerances” is arbitrary, but it works well for the applications considered here. This rule is the basis for Table C.1 in IEEE Std 268™-1992 [B2] used for converting tolerances in inches to millimeters. This table is repeated in B.4 for convenience. The “10% accuracy” chart states that any total tolerance > 0.4 in should produce values rounded to the nearest 1 mm, which is consistent with 3.1.

Another source is F2.4 of CSA Z234.1-2000 [B1], which shows how to calculate the rounding fineness for conversion of any units to any precision. Annex B of this guide has the background for development of “fineness of rounding” limits used herein.

3.8 Method for conversion of toleranced values

Once the “fineness of rounding” is established, the conversion of a toleranced value in one system can be converted to another as illustrated with the following example:

To convert a pressure of 200 ± 15 psi using a 10% accuracy of agreement:

a) Determine total tolerance; total tolerance is ± 15 psi or a total of 30 psi.

b) Find conversion factor: to convert pound-force per square inch (psi) to kilopascal (kPa), multiply by 6.894757.

c) Convert 10% of the total tolerance; 10% of 30 psi is 3 psi. 3 × 6.8948 = 20.68 kPa.

d) To be less than 10%, both the nominal value and the tolerance value must be expressed to the nearest 10 kPa because 100 > 20.68 but 10 < 20.68.

e) Exact conversion of nominal is 200 × 6.8948 = 1378.96 rounded to 1380 kPa (nearest 10 kPa).

f) The tolerance converts from 15 psi to 103.4 kPa, rounded to 100 kPa (nearest 10 kPa).

The converted quantity is 1380 kPa ± 100 kPa.

Note that the rough conversion values of 1276 (185 psi) and 1482 (215 psi) are greater than the range of the finished conversion. Thus, the original limits are not violated. This results from the tolerance being rounded downward from 103.4 to 100 kPa. If the original quantity is 200 ± 17 psi, the conversion becomes about 1379 ± 117 or 1380 ± 120 kPa when the tolerance is rounded up to the nearest 10 kPa instead of downward. Rough conversion produces limits of 1496 (217 psi) and 1262 (183 psi) versus the rounded limits of 1500 and 1260. For these numbers, both original limits are just barely violated. If the original limits must be maintained, then it would be necessary to round the tolerance down to 1380 ± 110 kPa.

3.9 Gauge and absolute pressure

Gauge (or *gage*) and *absolute* pressures must be stated as such or be obvious from the context. There is no metric equivalent to “psia” or “psig”.

3.10 Maintain significant digits

In the absence of other information, at least maintain the same number of significant digits when converting. For example, a torque of 75 pound-force-inches would become 8.5 N · m, maintaining the two significant digits. Given only a quantity such as 1000 kg, it is not clear if precision to 1 kg, 10 kg, or 100 kg is intended. One way to clearly indicate the intended precision is to use scientific notation. If 1000 kg is expressed as 1.00×10^3 kg, the precision is clearly given to three significant digits.

3.11 The precision of a value

The precision of a value may be taken as ± 0.5 of the last significant digit.

3.12 Trade sizes

Dimensions that appear in the names of trade sizes are usually only nominal and are not converted, which includes pipe threads, "1.0 in NPT," and screw threads, "1/2 in -13 UNC." Other examples are "2/0 AWG" for the standard conductor size and "2 by 4" for dimensional lumber.

3.13 Standard for rounding

Both the IEEE Std 268™-1992 [B2] and CSA Z234.1-2000 [B1] references cited recommend rounding a value ending in "exactly 5" to a last significant digit that is always even. Modern computer software and calculators do not do this rounding, but instead they will always round 0 to 4 down and 5 to 9 up. Therefore, it is more consistent with modern practice to always round "exactly 5" up to the higher significant digit; e.g., 44.45 rounds to 44.5.

3.14 Conversion math

In conversion math, significant digits are limited by the number with the least number of digits, except that 25.4 mm per inch is not limiting because 25.4 is the exact conversion. Other examples of exact conversions are Joule/kilogram (J/kg) = British thermal unit$_{IT}$/pound (Btu$_{IT}$/lb) × 2326 and J/kg = calorie$_{th}$/gram (cal$_{th}$/g) × 4184.

3.15 Writing unit symbols

Metric quantities are properly written with a space between the value and the unit symbol, e.g., "35 mm." Temperature differences or rises can be expressed as either "°C" or "K". Although some guides prefer no space, e.g., in "65°C," IEEE/ASTM SI 10-2002 recommends the use of the space, e.g., "65 °C" for consistency. Plane angles are still expressed with no space, as in "an angle of 30°."

3.16 Capitalization

The first letter of symbols for units of measure that memorialize the proper names of persons are capitalized. Examples are newton (N), pascal (Pa), hertz (Hz), watt (W), volt (V), ampere (A), and so on. When written out in full, these units are not capitalized, as in 100 watts or 10 kVA = 10 kilovoltamperes. Notable exceptions are Celsius (°C) and the liter or litre, which uses L to distinguish from the numeral 1.

3.17 Units of force and mass

The use of pounds, kilograms, and other units of mass as measures of force or weight has caused a considerable amount of confusion. In the U.S. Customary system, the discrepancy has been improved somewhat with the more accurate term "pounds-force" or "lbf". In common usage, weight and mass are synonymous because we often use the acceleration of gravity to measure them. To say that "My weight is 80 kg" and that "The mass of the apparatus is 1900 kg and lifting it will require a crane capacity of 2000 kg or more" is entirely correct. The SI unit of mass is the kilogram, and the unit of force is the newton. The newton is defined as the force that accelerates a mass of 1 kg at 1 m/s^2, where acceleration may be caused by gravity or any other effect. If we use a spring scale to vertically suspend a 1 kg mass, it is drawn to earth by a force equal to its mass (1 kg) times the acceleration due to gravity of 9.8 m/s^2. The scale will indicate a force of 9.8 N. The same scale with the same mass will measure a force of 1.6 N due to gravity on the moon.

3.18 Specifying a quantity with a tolerance

The *IEEE Standards Style Manual* [B3] prefers that both the nominal value and its tolerance be given units when they are presented together. The example is 150 m ± 5 mm, but it also could have been given as 150 000 ± 0.005 m. Although examples can be found both ways in different Metric Practice Guides, such as 50.80 ± 0.02 mm or 1380 kPa ± 100 kPa, there seems to be less chance for error if both values are given units as long as it does not result in excessive clutter.

3.19 Dual dimensioning

When dual dimensioning, group each value and its tolerance together. It may be easier to understand when each unit is given only once.

Examples:

50.80 ± 0.02 mm (2.000 ± 0.001 in)

or

1380 kPa ± 100 kPa (200 psi ± 15 psi)

3.20 Temperature conversion

Temperatures converted from an integer value of Fahrenheit to Celsius are rounded to the nearest 0.5 °C.

Example:

70 °F = 21 °C,   80 °F = 26.5 °C

3.21 Default tolerances

Some IEEE Transformers Committee Working Groups have suggested that a default tolerance of ± 2 mm be adopted. Any default tolerance or other tolerances for specific dimensions should be stated whenever they are needed.

3.22 Convenience and drawing clarity

The desire to move toward more rounded, more convenient values should not be done at the expense of drawing clarity. For example, the typical vertical spacing between bushings on single-phase pad-mount transformers is 5.0 ± 0.25 in. The straightforward conversion will be to 127 ± 6 mm. If the nominal value is rounded to 130 mm, then the tolerance will have to be +3 mm, –9 mm. Adding a skewed tolerance such as this to each dimension on an already crowded drawing will further hinder the clarity of the drawing. If all bushing locations are given a common tolerance such as ± 6 mm, then drawing clarity is maintained by rounding each nominal value only to the nearest 1 mm.

3.23 Separate + and – tolerances

Occasionally, skewed dimensions having separate positive and negative tolerances will be used. The intent of such dimensioning is to call attention to the ideal (nominal) value, but to permit as much leeway as possible larger and smaller, although they are not both the same. The fineness of rounding applies to these dimensions as well, with each limit treated separately and the values rounded according to the sum of the positive and negative tolerances. The issue of drawing clarity discussed in 3.22 must be considered also.

3.24 Safety issues

The conversion of units of measure in standards is a major step toward creating familiarity with units associated with the product. Some quantities, such as the mass of the apparatus listed on the nameplate, can have safety implications. The introduction of a nameplate mass given in kilograms may, at first, confuse some workers who handle, install, or maintain the equipment. Consideration should be given to dual listing, such as having mass given in both kilograms and pounds on a nameplate or other label. Dual listing may be necessary for a period of time until the nameplate mass in kilograms is more easily related to a crane or other lifting or carrying device whose capacity rating may be given in pounds, tons, kilograms, or metric tons.

Annex A

(normative)

Conversion of quantities common to transformer standards

A.1 Linear dimensions

As discussed in this guide, the majority of linear dimensions on front panels and other tank parts can be expressed to the nearest millimeter with a tolerance of ± 2 mm.

A.2 Four-hole terminal connector

The typical four-hole terminal connector for use on transformers is described by a pattern that consists of four 9/16 in diameter holes arranged in a square pattern with 1-3/4 in between centers. The pattern can be recognized in a variety of current NEMA and IEEE standards and should be converted to metric dimensions as follows.

For terminals that are made by sandcasting with a copper alloy, the typical manufacturing tolerance for linear dimensions is ± 0.031 in. This tolerance is consistent with the need to successfully fit nominal 0.5 in hardware through the holes even if the diameter is undersize by 0.031 in and the spacing is off by 0.031 in.

Using 3.8, the original hole diameter is 0.5625 ± 0.031 in. Total tolerance is 0.062 in, so rounding fineness is 0.1 mm. Converted limits are 15.0749 mm and 13.5001 mm, and nominal is 14.2875 mm. After rounding, the converted dimension is 14.3 ± 0.8 mm.

The distance between centerlines is 1.75 ± 0.031 in. Converted limits are 45.2374 and 43.6626 mm, whereas the nominal converts to exactly 44.45 mm. Rounding 44.45 mm to 0.1 mm according to the modern rule produces 44.5 mm. If the limits are rounded to 0.1 mm, the result is 45.2 and 43.7 mm. This produces 44.5 + 0.7 – 0.8 mm. If the tolerance is extended to a more convenient ± 0.8 mm, then the upper limit of 45.3 mm violates the original limit by 0.0626 mm, but it is unlikely to cause fit problems. Therefore, the four-hole terminal dimensions convert to four holes of 14.3 ± 0.8 mm diameter spaced in a square pattern on 44.5 ± 0.8 mm centers.

A.3 Pressure relief valve

A typical specification of a pressure relief valve is as follows. At issue:

a) “0.25 in NPT (or NF)” is a standard pipe or machine thread trade size and requires no conversion.

b) “25 lb-force” converts to 25 × 4.448 222 = 111.205 555 N. By context, this is an implied minimum value. Rounding up yields 112 N.

c) “100 lb-force” is also a minimum and converts and rounds up to 445 N.

d) “Cracking pressure of 10 ± 2 psig” ≥ 68.9476 ± 13.79 kPa. For accuracy of 10%, the full tolerance of 27.46 × 10% = 2.75; thus, values will be rounded to ± 1 kPa. The result after rounding to the inside of the tolerance is 69 ± 13 kPa (gauge).

e) “Resealing pressure of 6 psig minimum,” assuming accuracy of 10%, yields 6 × 6.894757 = 41.368 and rounded up is 42 kPa (gauge) minimum.

f) "Zero leakage from resealing pressure to –8 psig." Convert to –55.16 kPa and round down to –56 kPa (gauge).

g) "Flow at 15 psig: 35 SCFM minimum." (SCFM = standard cubic feet per minute at a pressure of 14.7 psi and 21.1 °C). There is really no such thing as "standard CFM." SCFM is defined differently for each application. The standard temperature of 21.1 °C appears to have been created by an inappropriate prior conversion from 70 °F and should have been 21 °C. After conversion, this can be restated as "Flow at 103 kPa (gauge): 16.5 L/s minimum of air at standard temperature and pressure. Standard temperature is 21 °C, and standard pressure is 101 kPa (absolute)."

The conversion to the following more convenient numbers will also be satisfactory, as assured by a major manufacturer of distribution transformer pressure relief devices:

— Venting Pressure: 70 ± 15 kPa gauge
— Sealing Pressure: 40 kPa gauge minimum
— Zero leakage: from reseal pressure to –55 kPa
— Flow at 100 kPa gauge: 16.5 L/s, corrected for air pressure of 101 kPa absolute and air temperature of 21 °C

A.4 Tank fittings

The following conversion examples apply to three-phase pad-mount transformers and illustrate how the conversion principles are to be applied:

a) "The vertical clearance for a jack shall be 38 mm minimum, 165 mm maximum." U.S. Customary dimensions were 1.5 in minimum and 6.5 in maximum. Conversions are rounded to the nearest millimeter.

b) "To withstand a gauge pressure of 50 kPa without permanent distortion; and 104 kPa without rupturing or affecting cabinet security." U.S. Customary dimensions were 7 psig and 15 psig, respectively. In conversion, 48.3 kPa is rounded up for a more convenient minimum, and 103.4 kPa minimum is rounded up the nearest 1 kPa.

c) "A 1 in NPT." No conversion is required for these standard threads.

d) "Two steel pads, each with a 1/2 inch – 13 UNC tapped hole, minimum thread depth of 11 mm shall be provided." Thread specifications are not converted, but the linear depth, formerly 7/16 in or 0.44 in is changed to millimeters.

e) "Copper-faced steel or stainless steel pads, 51 mm × 89 mm each with two holes spaced on 44.5 ± 0.8 mm centers and tapped for 1/2 inch – 13 UNC thread…thickness of the copper facing shall be 0.38 mm. Minimum thread depth of the holes shall be 13 mm." U.S. Customary dimensions were 2 × 3.5 in with two tapped holes spaced 1.75 in apart (NEMA spacing). Copper facing thickness was 0.015 in minimum.

f) "Provisions for surge arresters shall consist of 6 steel pads with 1/2 inch – 13 UNC tapped holes 11 mm deep, or 1/2 inch – 13 UNC studs, 25 mm long." Thread depth and length are converted to the nearest millimeter from 0.44 in and 1.0 in.

g) Figures and others similar—cable accessory parking stand inside width is 200 mm (7.85 in min) while inside height is 19.1 +3.2 mm, –0.0 mm. Inside height was 3/4 + 1/8 in – 0 in, or 0.75 + 0.13 in– 0 in. As total tolerance is 0.13 in, then fineness of rounding is 0.1 mm for both nominal value and tolerances:

    1) Tolerance on dimensions that were ± 0.25 in are now ± 6 mm.

    2) Fineness for tolerance ± 0.5 in is to nearest 1 mm; therefore, tolerance is ± 13 mm on charted dimensions.

    3) Fineness for tolerance + 1.0 – 0 in is to nearest 1 mm; therefore, + 25 – 0 mm on charted dimensions.

Annex B

(normative)

Guideline background and development

B.1 Accuracy and precision

The terms *accuracy* and *precision* are often used interchangeably and are easily confused. Accuracy describes how close a measurement comes to the actual value. Precision describes the reproducibility of multiple measurements. It is possible to have good precision but poor accuracy. Picture a target shooter that produces a tight pattern far away from the bull's eye. It is also possible to have good accuracy but poor precision. The target shooter in this case would have a widely dispersed pattern that surrounds the bull's eye. In the conversion of values, repeatability or precision would seem to be the only issue. Subclause 3.1 can be restated by saying that one should not specify a physical quantity with great precision where no practical means exists to accurately measure that quantity (see Tissue [B5]).

B.2 Precision or fineness of rounding

Tolerance values for any dimension may be converted to any other system of measurement and rounded to any arbitrary degree of accuracy using the relationship (from CSA Z234.1-2000, Subclause F2.4 [B1]):

$$r \leq Tcp/100$$

where

- r is the precision or fineness of rounding (1, 0.1, 0.01, 0.001, etc.),
- T is the overall tolerance in the original units of measurement,
- c is the conversion factor from old to new units,
- p is the percentage accuracy required of the converted and rounded tolerance with respect to the original tolerance.

Example:

A dimension with a total tolerance of 0.035 in, when converted to millimeters to agree with an accuracy of 12%, will be rounded to 0.1 mm:

$$Tcp/100 = 0.035 \text{ in} \times 25.4 \times 12/100 = 0.107 > 0.1 \text{ mm}$$

B.3 Creating values for rounding tolerance

The relationship in B.2 is the basis for Table C.1 in IEEE Std 268-1992 [B2] for rounding when converting from inches to millimeters. For example, using the 10% accuracy in the rounding of tolerances per 3.7:

a) A total tolerance of 0.04 in on a dimension converted to millimeters with 10% accuracy will be rounded to 0.04 × 25.4 × 10/100 = 0.102 mm (considered = 0.10 mm).

b) A total tolerance of 0.4 in; the value is 0.4 × 25.4 × 10/100 = 1.016 mm (considered 1.0 mm).

Thus, for $0.04 \leq T < 0.4$ and a 10% accuracy of rounding, the nominal value and tolerance in millimeters should be rounded to the precision value greater than or equal to 0.10 mm and less than 1.0 mm, that is, rounded to the nearest 0.1 mm.

B.4 Table for conversion of tolerances

The following example demonstrates the method for rounding presented in B.3 applied to transformer components. Bushing spacings are given as 6.5 in, 4.5 in, and 6.0 in, with a standard tolerance of ±0.25 in. The total tolerance is 0.5 in, which implies a fineness of 1 mm, according to Table B.1.

Table B.1—Inches to millimeters for agreement within an accuracy of 10%[a]

Original tolerance (in)		**Fineness of rounding (mm)**
At least	**Less than**	**Round converted values**
0.000 04	0.0004	0.0001
0.0004	0.004	0.001
0.004	0.04	0.01
0.04	0.4	0.1
0.4	—	1

[a]From IEEE Std 268-1992, Table C.1 [B2].

The converted limits of 6.5 ± 0.25 in are 158.75 mm and 171.45 mm. The nominal value converts to exactly 165.1 mm with a tolerance of ± 6.35 mm. When rounded to 1 mm, the conversion yields 165 ± 6 mm. In this case, the tolerance is rounded down so the original limits are not exceeded. Similarly, 4.5 ± 0.25 in = 114 ± 6 mm and 6.0 ± 0.25 in = 152 ± 6 mm. In this last example, the lower limit, 146 mm, is 5.7480 in, which is 0.002 in outside the original lower limit. This small discrepancy is unlikely to cause any problem.

Annex C

(informative)

Bibliography

[B1] CSA-Z234.1-2000, Canadian Metric Practice Guide.[4]

[B2] IEEE Std 268-1992, American National Standard for Metric Practice.[5, 6]

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