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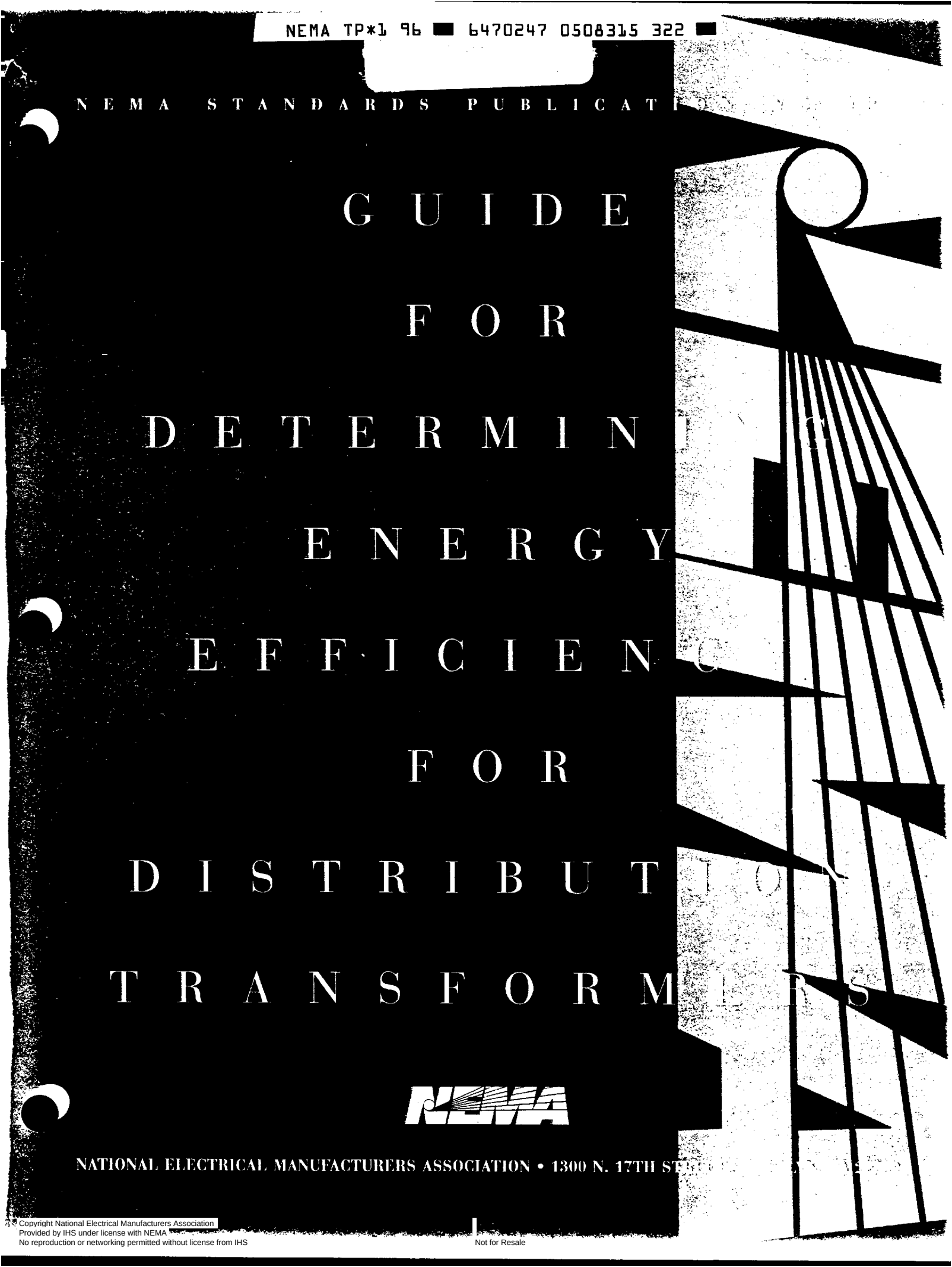
NEMA STANDARDS PUBLICATION

GUIDE FOR DETERMINING ENERGY EFFICIENCY FOR DISTRIBUTION TRANSFORMERS



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NEMA STANDARDS PUBLICATION TP 1-1996

Guide for Determining Energy Efficiency for Distribution Transformers

Published by

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Foreword

This standard has been developed by the Transformer section and has been approved for publication by the National Electrical Manufacturers Association. It is available for use by the electrical industry to promote the use of high efficiency transformers and to assist users in the selection of such transformers.

This standard consists of two parts, sections 2 and 3, which offer a simplified methodology for the user to apply to determine the equivalent first cost of core and load losses. This information will permit the manufacturer to tailor the transformer design to the unique situation of each user. Section 4 defines the minimum efficiency, based on kVA and voltage considerations, that is recommended if the user elects not to follow the suggested methodology. It must be clearly understood that certain design criteria or conditions of use may preclude the application of this standard. These exceptions are detailed in the body of this document.

User needs and safety have been considered throughout the development of this document. This publication is periodically reviewed by the Transformer section of NEMA for any revisions necessary to keep it up to date with advancing technology. Proposed or recommended revisions should be submitted to:

Vice President, Engineering Department
National Electrical Manufacturers Association
1300 North 17th Street, Suite 1847
Rosslyn, Virginia 22209

This Standards Publication was developed by the Transformer Products Section of the National Electrical Manufacturers Association. At the time it was approved, the Transformer Products Section had the following members.

ABB Power T & D Company—Jefferson City, MO

Acme Electric Corporation—Lumberton, NC

Cooper Power Systems—Waukesha, WI

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General Electric—Hickory, NC

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Section 1
GENERAL

1.1 SCOPE

This standard in intended for use as a basis for determining the energy efficiency performance of the equipment covered and to assist in the proper selection of such equipment.

This standard covers single-phase and three-phase dry-type and liquid-filled distribution transformers as defined in the following table:

Voltage Class	Primary Voltage Secondary Voltage	34.5 kV and Below 600 Volts and Below
Liquid Rating	Single Phase	10–833 kVA
	Three Phase	15–2500 kVA
Dry Rating	Single Phase	15–833 kVA
	Three Phase	15–2500 kVA

Note: Includes all products at 1.2kV and below

Products excluded from this standard include:

a. Liquid-filled transformers below 10 kVA
b. Dry-type transformers below 15 kVA
c. Drives transformers, both AC and DC
d. All rectifier transformers and transformers designed for high harmonics
e. Autotransformers
f. Non-distribution transformers, such as UPS transformers
g. Special impedance, regulation and harmonic transformers
h. Regulating transformers
i. Sealed and non-ventilated transformers
j. Retrofit transformers
k. Machine tool transformers
l. Welding transformers
m. Transformers with tap ranges greater than 15%
n. Transformers with frequency other than 60 Hz
o. Grounding transformers
p. Testing transformers

1.2 REFERENCE STANDARDS

Transformers shall meet the requirements for liquid-filled and dry-type transformers as contained in the latest revision of the following standards:

American National Standards Institute, Inc.
11 West 42nd Street
New York, NY 10036

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

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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*

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*

C57.12.91-1979 *IEEE Standard for Test Code for Dry-Type Distribution and Power Transformers*

National Electrical Manufacturers Association
1300 North 17th Street
Arlington, VA 22209

TR 1-1993 *Transformers, Regulators and Reactors*

ST 20-1992 *Dry-Type Transformers for General Applications*

1.3 DEFINITIONS

1.3.1 EC = Avoided cost of energy ($/kWhr-yr): The levelized avoided (incremental) cost for the next kWh produced by the utility's generating units.

1.3.2 Efficiency tolerance: The nameplate efficiency is the value calculated based on the specified losses of the transformer. A transformer is considered to be within an acceptable tolerance of its nameplate efficiency if its no load and total losses meet the single unit tolerances defined in ANSI standards C57.12.00 or C57.12.01.

1.3.3 FCR(%) = Fixed charge rate: The cost of carrying a capital investment.

1.3.4 HPY (hours): Hours per year (HPY) used in the A- and B-factor equations is generally taken as 8760. However, there may be exceptions, such as transformers connected to irrigation loads. In this case, the transformer may be de-energized a portion of the year and hence, a value less than 8760 would be used for HPY.

On the other hand, this transformer may remain energized all year but loaded only part of the year. In this case, a reduced equivalent loss factor could be used to account for the unloaded portion of the year while retaining the use of 8760 hours per year in both the A- and B-factor formulas.

1.3.5 LsF (%) – Loss factor: A measure of the annual average load losses to the peak value of load losses on the distribution transformer.

1.3.6 LL: Load Loss watts at rated temperature rise plus 20°C, i.e., 85° C for 65° C rise and 170° C for 150°C rise.

1.3.7 LM – Loss multiplier (%): A measure of system losses from generation through the transmission and distribution system.

1.3.8 Nameplate efficiency: Rounded efficiency to 1/10 of 1 percent. This calculated number which is derived from the parameters of output kVA divided by out put kVA plus losses multiplied by 100% at a given percent load and at specified reference temperature.

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Mathematically, the relationship is as follows:

$$\%E = \frac{100 \times (P \times kVA \times 1000)}{P \times kVA \times 1000 + NL + LL \times P^2 \times T}$$

Where:

P = Per unit load

= 0.35 for low voltage (600 volt class) dry type transformers

= 0.50 for medium voltage liquid and dry transformers

kVA = nameplate kVA rating

NL = No load (core) loss at 20°C in watts

LL = Load loss at its full load reference temperature, consistent with C57.12.00 (liquid) and C57.12.01 (dry) in watts.

T = Load loss temperature correction factor to correct specified temperatures, i.e., 75°C for dry- and 85°C for liquid-transformers.

For liquid-filled transformers, the factor T is 1.0, since efficiency is stated at 85°C. Dry type transformers are significantly affected because 75°C is well below the full load rise. For dry-type transformers, the factor T assumes 10% winding eddy loss, as described in the appendix; however, the actual winding eddy loss may be different than 10%.

1.3.9 P: Per unit load.

1.3.10 PL—Equivalent annual peak load (on the transformer): The average annual peak load seen by the transformer that is equivalent to an initial peak load with an estimated load growth rate and a maximum allowable load before change-out is required.

1.3.11 RF (%)—Peak loss responsibility factor: A measure of the diversity of the load on the transformer.

1.3.12 SC = Avoided cost of system capacity ($/kW-yr): The average avoided (incremental) cost of generation, transmission and primary distribution capacity required to supply the next kW of load to the distribution transformer coincident with the peak load.

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Section 2
EFFICIENCY EVALUATION FOR ELECTRIC UTILITIES

Electric utilities purchase distribution transformers based on a life-cycle cost methodology which accounts for the economic value of electrical losses over the useful life of the transformer. The following is a brief summary of the equivalent first cost (EFC), total owning cost (TOC) method which is most commonly utilized:

$$TOC_{EFC} = \text{Transformer first cost} + \text{Cost of core loss}_{EFC} + \text{Cost of load loss}_{EFC}$$

Transformer first cost = Cost of acquisition

$\text{Cost of core loss}_{EFC}$ = A($/Watt) x core loss watts

$\text{Cost of load loss}_{EFC}$ = B($/Watt) x load loss watts

Where:

A = Equivalent first cost of no load losses ($/Watt)

B = Equivalent first cost of load losses ($/Watt)

The A and B factors are functions of the energy costs and the capacity costs associated with the transformer no-load losses and load losses (including financial costs).

Avoided costs are generally used in the calculation of total owning cost (TOC) evaluations for distribution transformers. As previously described, components of TOC are the costs to the utility to supply distribution transformer core (no load) and load losses, commonly referred to as the A- and B-factors. These distribution transformer losses represent additional (incremental) load that the utility must serve over the life of the transformer. If the utility's avoided costs reflect its long-range incremental costs taken over the transformer's economic life, they can be used to determine the system capacity and energy cost of the transformer core and load losses.

Most utilities regularly determine their avoided costs of capacity and energy. Assuming that those values reflect the continuing economic impact over the transformer's life, they should be used directly in the loss evaluation process.

Avoided costs of energy and generating capacity that are used in evaluating distribution transformers should be determined on a long-range incremental cost basis, using generation production costing and expansion planning. The long-range incremental cost factors include the utility load characteristics, projected peak loads (demand), existing and future generation capability and availability, generation maintenance, generation reliability, costs associated with construction of new generation plants, current and projected fuel prices, short-range purchase/sale contracts and long-range purchase/sale contracts. The generation expansion includes planning reserve margins sufficient to maintain system reliability at a high level based on objective criteria.

The application of the TOC methodology using A- and B-factors, as described above, is common place in the electric utility industry.

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Section 3
EVALUATION PARAMETERS FOR COMMERCIAL AND INDUSTRIAL TRANSFORMERS

3.1 INTRODUCTION

While many aspects of the TOC for industrial or commercial placed transformers parallels that used by the utility, there are, nonetheless, differences that require the use of a different procedure. This procedure would at least provide a differentiation among designs that reflect the users constraints.

The following is a review of the equivalent first cost TOC method:

TOC_{EFC} = Price + cost of core loss + cost of load loss

Cost of core $loss_{EFC}$ = A($/watt) x core loss watts

Cost of load $loss_{EFC}$ = B ($/watts) x load loss watts

Where:

A = Equivalent First Cost of No Load Losses

= PW(IS) (EL) (HPY) / 1000

Where:

PW(IS) = Present worth of an inflation series

$$= \frac{1 - \left[\frac{1+a}{1+i}\right]^n}{i-a}$$

a = per unit inflation index
i = per unit interest rate
n = number of years

Where:

EL = purchasers cost of electricity ($/kWh)

B = Equivalent first cost of load losses

= $A \times P^2 \times T$

An alternative approach to specific no load and load losses of a transformer is to measure energy efficiency at the specific load which is most typical of how it will be used. The general expression for energy efficiency is:

%Efficiency = 100 (output load)/(output load + losses)

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This expression can be tailored to the commercial/industrial segment as:

$$\%E = \frac{100 \times (P \times kVA \times 1000)}{P \times kVA \times 1000 + NL + LL \times P^2 \times T}$$

Where:

P = Per unit load

= 0.35 for low voltage (600 volt class) dry type transformers

= 0.50 for medium voltage liquid and dry transformers

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Section 4
TABLES OF ENERGY EFFICIENCY

The following tables of energy efficiencies would define the minimum efficiency to be categorized as NEMA class 1 efficiency, per this standard. These efficiencies apply to both the utility and the commercial/industrial segment, that do not use evaluation parameters as defined in either Section 2, for utility transformers, or Section 3, for commercial/industrial transformers.

Table 4-1
NEMA CLASS 1 EFFICIENCY LEVELS FOR LIQUID-FILLED DISTRIBUTION TRANSFORMERS

Reference Condition	Temperature	% of Nameplate Load
Load Loss	85°C	50%
No Load Loss	20°C	50%

kVA	Single Phase Efficiency	kVA	Three Phase Efficiency
10	98.3	15	98.0
15	98.5	30	98.3
25	98.7	45	98.5
37.5	98.8	75	98.7
50	98.9	112.5	98.8
75	99.0	150	98.9
100	99.0	225	99.0
167	99.1	300	99.0
250	99.2	500	99.1
333	99.2	750	99.2
500	99.3	1000	99.2
667	99.4	1500	99.3
833	99.4	2000	99.4
		2500	99.4

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Table 4-2
NEMA CLASS I EFFICIENCY LEVELS FOR DRY-TYPE DISTRIBUTION TRANSFORMERS

Reference Condition	Temperature	% of Nameplate Load
Low Voltage	75°C	35%
Medium Voltage	75°C	50%

Single Phase Efficiency			Three Phase Efficiency		
kVA	Low Voltage	Medium Voltage	kVA	Low Voltage	Medium Voltage
15	97.7	97.6	15	97.0	96.8
25	98.0	97.9	30	97.5	97.3
37.5	98.2	98.1	45	97.7	97.6
50	98.3	98.2	75	98.0	97.9
75	98.5	98.4	112.5	98.2	98.1
100	98.6	98.5	150	98.3	98.2
167	98.7	98.7	225	98.5	98.4
250	98.8	98.8	300	98.6	98.5
333	98.9	98.9	500	98.7	98.7
500	—	99.0	750	98.8	98.8
667	—	99.0	1000	98.9	98.9
833	—	99.1	1500	—	99.0
			2000	—	99.0
			2500	—	99.1

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Appendix A
TEMPERATURE CORRECTION FACTOR FOR DRY TYPE TRANSFORMERS

A.1 ASSUMPTIONS

a. Stray and eddy losses—10% of load loss
b. Conductor material—copper and aluminum
c. Candidate full load temperature rises 80, 115, 150
d. 20°C Ambient

A.2 ALGORITHMS

a. Electrical resistance at 75°C vs. full load reference

$$\frac{R_{75}}{R_{ref}} = \left[\frac{F+75^{\circ}C}{F+T_{rise}+Ambient}\right]$$

Where:

F = thermal coefficient of resistance
$F_{aluminum}$ = 225
F_{copper} = 234.5
Ambient = 20°C

Full Load Rise	Aluminum	Copper
80	0.9231	0.9253
115	0.8333	0.8376
150	0.7595	0.7651

b. Temperature correction factor

$$T_F = (L_I)\frac{R_{75}}{R_{ref}} + L_E\frac{R_{ref}}{R_{75}}$$

L_I = PU load loss due to d - c resistance = 0.9
L_I varies directly with temperature

L_E = PU load loss due to strays and eddies = 0.1
L_E varies inversely with temperature

$$\therefore T_F = 0.9\frac{R_{75}}{R_{ref}} + 0.1\frac{R_{ref}}{R_{75}}$$

Full Load Rise	Aluminum	Copper
80	0.9391	0.9408
115	0.8700	0.8732
150	0.8152	0.8193

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Appendix B
BIBLIOGRAPHY

C57.12.10-1988 — *American National Standard for Transformers – 230 KV and below, 833/958 through 8333/10417kVA, single phase, and 750/862 through 60000/80000/100000kVA, Three Phase without Load Tap Changing; and 3750/4687 through 60000/80000/100000 kVA with Load Tap Changing – Safety Requirements.*

C57.12.20-1988 — *American National Standard for Transformers — Overhead-Type Distribution Transformers, 500 kVA and Smaller; High Voltage, 34500 and Below; Low Voltage, 7970/13800Y and Below*

C57.12.22-1989 — *American National Standard for Transformers – Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers with High Voltage Bushings, 2500 kVA and Smaller; High Voltage, 34500GrdY/19920 Volts and Below; Low Voltage, 480 Voltages and Below – Requirements*

C57.12.23-1993 — *IEEE Standard for Transformers – Underground-type, Self-Cooled, Single-phase Distribution Transformers with Separable, Insulated, High Voltage Connectors; High Voltage (24940 GrdY/14400 V and Below) and Low Voltage (240/120 V, 176 kVA and Smaller)*

C57.12.24-1988 — *American National Standard for Transformers – Underground-type, Three-Phase Distribution Transformers, 2500kVA and Smaller; High Voltage 34500 GrdY/19920 Volts and Below; Low Voltage, 480 Volts and Below – Requirements*

C57.12.25-1990 — *American National Standard for Transformers – Pad-Mounted, Compartmental-type, Self-Cooled, Single-Phase Distribution Transformers with Separable Insulated High Voltage 34500 GrdY/19920 Volts and Below; Low Voltage, 240/120 Volts; 167 kVA and Smaller – Requirements*

C57.12.26-1992 — *IEEE Standard for Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers for Use with Separable Insulated High-Voltage Connectors (34500 GrdY/19920 V and Below; 2500 kVA and Smaller*

C57.12.40-1992 — *American National Standard for Transformers – Subway and Vault Types (Liquid Immersed) – Requirements*

C57.12.50-1981 — *American National Standard Requirements for Ventilated Dry-Type Distribution Transformers, 1 to 500 kVA, Single-Phase, and 15 to 500 kVA, Three-Phase, with High Voltage 601 to 34500 Volts, Low-Voltage 120 to 600 Volts*

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 34500 Volts, Low Voltage 208Y/120 to 4160 Volts*

C57.12.52-1987 — *American National Standard Requirements for Sealed Dry-Type Power Transformers, 501 kVA and Larger, Three-Phase, with High Voltage 601 to 34500 Volts, Low-Voltage 208Y/120 to 4160 Volts*

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C57.12.57-1987	*American National Standard for Transformers – Ventilated Dry-Type Network Transformers 2500 kVA and Below, three-Phase, with High Voltage 34500 Volts and Below, Low-Voltage 216Y/125 and 480/277 Volts – Requirements*
C57.12.59-1989	*IEEE Guide for Dry-Type Transformer Through-Fault Current Duration*
C57.12.70-1978	*American National Standard Terminal Marking and Connections for Distribution and Power Transformers*
C57.12.80-1978	*IEEE Standard Terminology for Power and Distribution Transformers*
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*
C57.12.91-1979	*IEEE Standard Test Code for Dry-Type Distribution and Power Transformers*
C57.91-1981	*IEEE Guide for Loading Mineral-Oil-Immersed Overhead and Pad-Mounted Distribution Transformers Rated 500 kVA and Less with 65°C or 55°C Average Winding Rise*
C57.92-1981	*IEEE Guide for Loading Mineral-Oil-Immersed Power Transformers Up to and including 100 MVA with 65°C or 55°C Average Winding Rise*
C57.96-1989	*IEEE Guide for Loading Dry-Type Distribution and Power Transformers*
C57.109-1993	*IEEE Guide for Liquid-Immersed Transformer Through-Fault Current Duration*
C57.110-1986	*IEEE Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents*

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NEMA STANDARDIZATION BACKGROUND

The purpose of NEMA standards, their classification, and status are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below:

Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process, or procedure with reference to one or more of the following; nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 1)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p. 6)

Categories of Standards

National Electrical Manufacturers Association Standards are of three classes, which have received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture.
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development.
3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, p. 5)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data or other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative.

(Standardization Policies and Procedures, p. 5)

Identification of Status

Standards in NEMA Standards Publications are identified as "NEMA Standard," "Suggested Standard for Future Design," or "Adoptive Standard." These indicate the status of the standard. A statement incorporating the auxiliary verb "shall" indicates that compliance with a requirement is mandatory for compliance with the standard. These classes of standards are identified in the foreword or throughout the text.

The material identified as "Authorized Engineering Information" is designated similarly. Statements incorporating other auxiliary verbs such as "should," "may," etc. refer to the authorized engineering information and not to procedures required for compliance with the standard.

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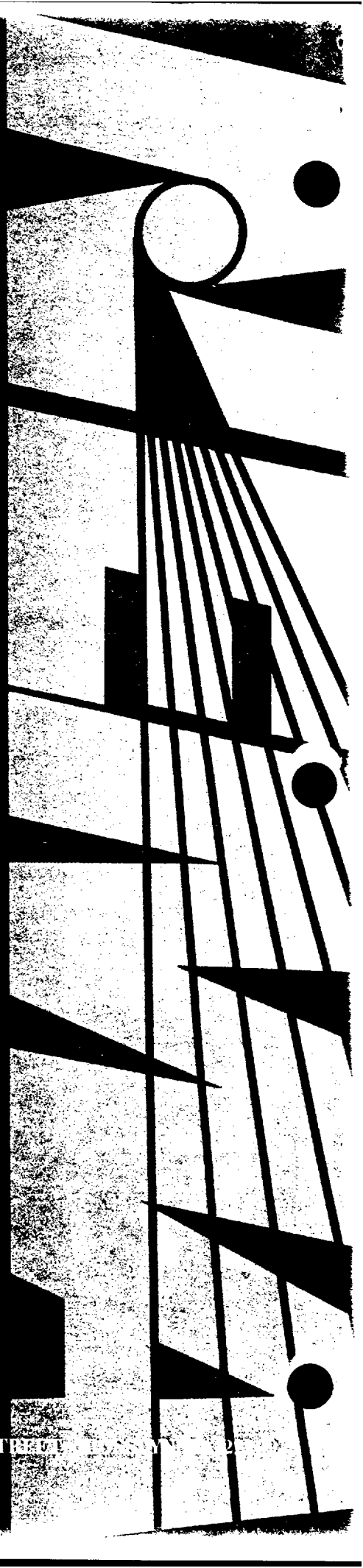

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