IEEE Std C57.109-1993
(Revision of IEEE C57.109-1985)

IEEE Guide for Liquid-Immersed Transformer Through-Fault-Current Duration

Sponsor

Transformers Committee
of the
IEEE Power Engineering Society

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Abstract: Recommendations believed essential for the application of overcurrent protective devices applied to limit the exposure time of transformers to short circuit current are set forth. Transformer coordination curves are presented for four categories of transformers. There is no intent to imply overload capability.
Keywords: liquid-immersed transformer, transformer

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Introduction

(This introduction is not a part of IEEE Std C57.109-1993, IEEE Guide for Liquid-Immersed Transformer Through-Fault-Current Duration.)

This is the first revision of IEEE Std C57.109-1985. Sections 1 (Scope), 2 (Purpose), and 3 (General) have been incorporated as subclauses into a new clause 1, Overview, in order to conform to the 1992 edition of the *IEEE Standards Style Manual*. A new clause on definitions has been added for clarification. The major revision is the definition of short-circuit impedance of a transformer. This definition is intended to make the fault calculations related to the use of these curves consistent with the short-circuit design requirements of Categories III and IV transformers described in IEEE Std C57.12.00-1993. The clause on transformer coordination curves has been modified with more explanation on the curves and the use of system and transformer impedances.

The other changes made in this revision are editorial and related to general updating of the guide. Some of these changes are intended to improve the ease and efficiency of its use.

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Contents

IEEE Guide for Liquid-Immersed Transformer Through-Fault-Current Duration

1. Overview

1.1 Scope

This guide applies to transformers referenced in IEEE Std C57.12.00-1993[1] as Categories I, II, III, and IV.

1.2 Purpose

Protective devices such as relays and fuses have well-defined operating characteristics that relate fault magnitude to operating time. These characteristic curves should be coordinated with a comparable curve(s) applicable to transformers that relate duration and fault magnitude to withstand capability.

This guide sets forth recommendations believed essential for the application of overcurrent protective devices applied to limit the exposure time of transformers to short-circuit currents [see IEEE Std C37.91-1985 (Reaff 1991)]. This guide is not intended to imply overload capability.

1.3 General

The magnitude and duration of fault currents are of utmost importance in establishing a coordinated protection practice for transformers, as both the mechanical and thermal effects of fault currents should be considered. For fault-current magnitudes near the design capability of the transformer, mechanical effects are more significant than thermal effects. At low fault-current magnitudes approaching the overload range, mechanical effects assume less importance, unless the frequency of fault occurrence is high. The point of transition between mechanical concern and thermal concern cannot be precisely defined, but mechanical effects tend to have a more prominent role in larger kilovoltampere ratings, because the mechanical stresses are higher.

2. References

When the following documents referred to in this guide are superseded by an approved revision, the latest revision shall apply:

ANSI C57.12.20-1988, American National Standard for Transformers—Overhead-Type Distribution Transformers, 500 kVA and Smaller: High Voltage, 34 500 Volts and Below; Low Voltage, 7970/13 800Y and Below.[2]

IEEE Std C37.91-1985 (Reaff 1991), IEEE Guide for Protective Relay Applications to Power Transformers (ANSI).[3]

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

[2]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036-8002, USA.

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

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

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

IEEE Std C57.91-1981 (Reaff 1991), 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 (ANSI).

IEEE Std C57.92-1981 (Reaff 1991), IEEE Guide for Loading Mineral-Oil-Immersed Power Transformers Up To and Including 100 MVA with 55 °C or 65 °C Winding Rise (ANSI).

IEEE Std C57.115-1991, IEEE Guide for Loading Mineral-Oil-Immersed Power Transformers Rated in Excess of 100 MVA (65 °C Winding Rise) (ANSI).

3. Definitions

The following definitions reflect usage as understood within the context of this document. The terminology used in these definitions is in accordance with IEEE Std C57.12.80-1978 (Reaff 1992).

3.1 normal base current:[4] Rated current of a transformer corresponding to its rated voltage and rated base kilovoltamperes.

3.2 transformer short-circuit impedance: (1) For Category I and Category II transformers, the transformer impedance, expressed in percent on the transformer's rated voltage and rated base kilovoltamperes. (2) For Category III and Category IV transformers, the sum of transformer impedance and system short-circuit impedance at the transformer location, expressed in percent on the transformer's rated voltage and rated base kilovoltamperes.

4. Transformer coordination

For purposes of coordinating overcurrent protective devices with transformer short-circuit withstand capability, figures 1 through 4 are presented for Categories I–IV transformers as defined in IEEE Std C57.12.00-1993 and adopted in table 1.

For Categories I and IV transformers, a single curve represents both thermal and mechanical damage considerations.

For Categories II and III transformers, two curves are required. Depending upon the number of fault occurrences in the transformer's lifetime and fault current levels, mechanical damage considerations may be negligible. On the curves that have both a solid and a dashed portion, the solid portion represents the total fault duration beyond which thermal damage to the transformer may occur. The dashed portion represents the total fault duration beyond which cumulative mechanical damage may occur. The increasing significance of mechanical effects for higher-rated transformers is reflected in these curves. Transformers subjected to frequently occurring faults should be represented with the combination of mechanical and thermal portions of the curve, while transformers subjected to infrequently occurring faults are represented with the thermal portion only. The validity of these damage limit curves can not be demonstrated by tests, since the effects are

[4]For multiple-rated transformers, the base kilovoltamperes is the minimum nameplate rating.

Table 1—Transformer categories

Category	Single phase (kVA)	Three phase (kVA)
I*	5 to 500	15 to 500
II	501 to 1667	501 to 5000
III	1668 to 10 000	5001 to 30 000
IV	Above 10 000	Above 30 000

*Category I shall include distribution transformers manufactured in accordance with IEEE Std C57.12.20-1988 up through 500 kVA, single phase or three phase. In addition, autotransformers of 500 equivalent two-winding kilovoltamperes or less, which are manufactured as distribution transformers in accordance with IEEE Std C57.12.20-1988, shall be included in Category I, even though their nameplate kVA may exceed 500.

NOTE—All kilovoltampere ratings are minimum nameplate kVA for the principal windings.

cumulative over the transformer's lifetime. They are based principally on informed engineering judgment and favorable, historical field experience.

ANSI C57.92-1962, American National Standard Guide for Loading Oil-Immersed Distribution and Power Transformers, contained a section entitled *Protective Devices*, which provided information indicating the short-time thermal load capability of oil-immersed transformers as summarized in table 2.

Table 2—Transformer short-time thermal load capability

Time	Times rated current
2 s	25.0
10 s	11.3
30 s	6.3
60 s	4.75
5 min	3.0
30 min	2.0

During the revision of C57.92 it became evident that the *Times Rated Current* capability of transformers as stated therein were thermal limits and did not recognize the mechanical withstand considerations of transformers. Consequently, the *Protective Devices* portion of the loading guide was removed. Later, this thermal capability became part of this guide in an attempt to document the through-fault-current duration capability of transformers in sufficient detail to facilitate coordination of overcurrent protective devices with power transformers.

Low values of 3.5 or less times normal base current may result from overloads rather than faults, and for such cases loading guides may indicate allowable time durations different from those given in figures 1 through 4. See IEEE Std C57.91-1981 (Reaff 1991), IEEE Std C57.92-1981 (Reaff 1991), and IEEE Std C57.115-1991.

The per unit short-circuit currents shown in figures 1, 2, 3, and 4 are the balanced transformer winding currents. The line currents that relate to these winding currents depend upon the transformer connection and the type of fault present. Application engineers shall relate the winding currents to the currents seen by the protective devices in order to protect the transformer within its capability.

Categories I–IV were first established by IEEE Std C57.12.00-1980. This standard was later revised to its present form, IEEE Std C57.12.00-1993, with no major changes to the short-circuit withstand requirements. The standard preceding the 1980 version (1973) contained short-circuit thermal requirements for transformers that were more conservative than those in the 1980 version. The mechanical requirements for transformers have not changed since 1973.

As the scope in this guide indicates, the Categories I–IV protection curves apply to transformers covered by IEEE Std C57.12.00-1993. Based upon the above historical evolution of the short-circuit withstand requirements, these curves should be applicable to transformers built beginning in the early 1970s. However, as a precaution it is recommended that the manufacturer be consulted for confirmation of this, especially for transformers built during the early 1970s. For transformers built prior to the early 1970s, the manufacturer must be consulted for the short-circuit withstand capabilities.

4.1 Category I transformers

The recommended duration limit is based on the curve of figure 1. The curve reflects both thermal and mechanical damage considerations and should be applied as a protection curve for faults that will occur frequently or infrequently.

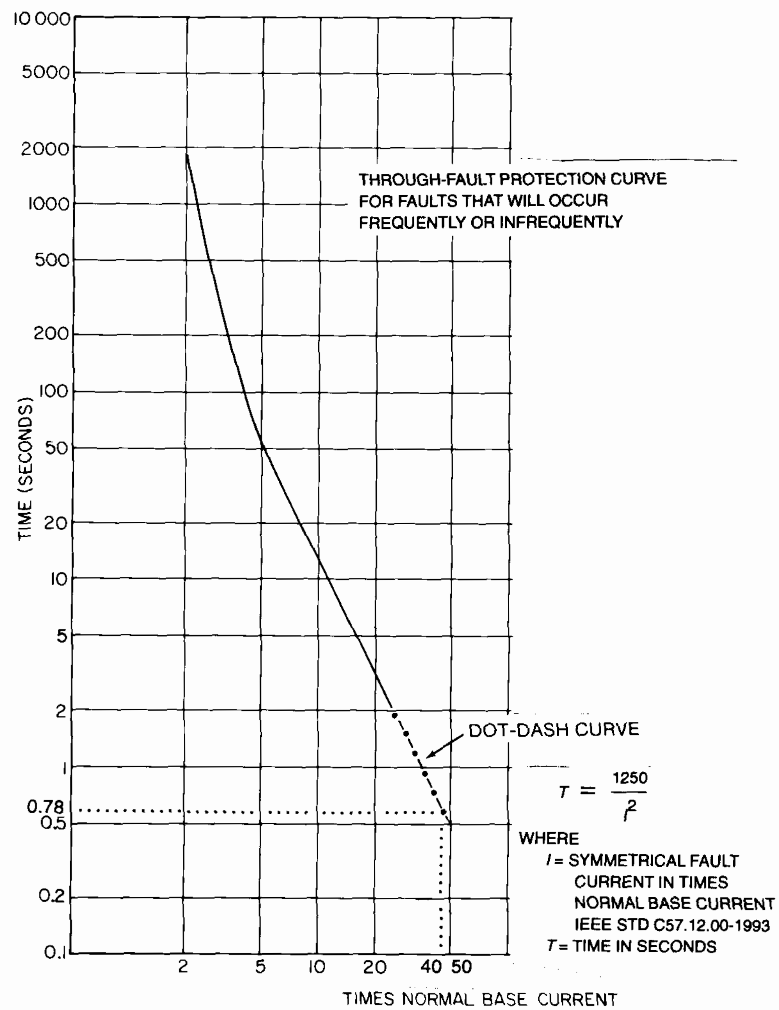
The dot-dash extension of the curve covers the transformer varying short-circuit withstand capabilities required by IEEE Std C57.12.00-1993, adopted in figure 1 and table 3, up to a maximum of 40 times normal current.

Table 3—Distribution transformer short-circuit withstand capability

Single phase (kVA)	Three phase (kVA)	Withstand capability per unit of base current (symmetrical)*
5–25	15–75	40
37.5–100	112.5–300	35
167–500	500	25

*This table applies to all distribution transformers with secondaries rated 600 V and below and to distribution autotransformers with secondaries rated above 600 V. Two-winding distribution transformers with secondaries rated above 600 V should be designed to withstand short circuits limited only by the transformer's impedance. Autotransformers having nameplate kilovoltamperes greater than 500 that are built as distribution transformers in accordance with ANSI C57.12.20-1988 shall have withstand capabilities of 25 per unit of base current (symmetrical).

NOTE—For ratings not covered in the above kVA ranges such as 100 kVA three-phase, contact the transformer manufacturer for the per unit short-circuit withstand capability information.

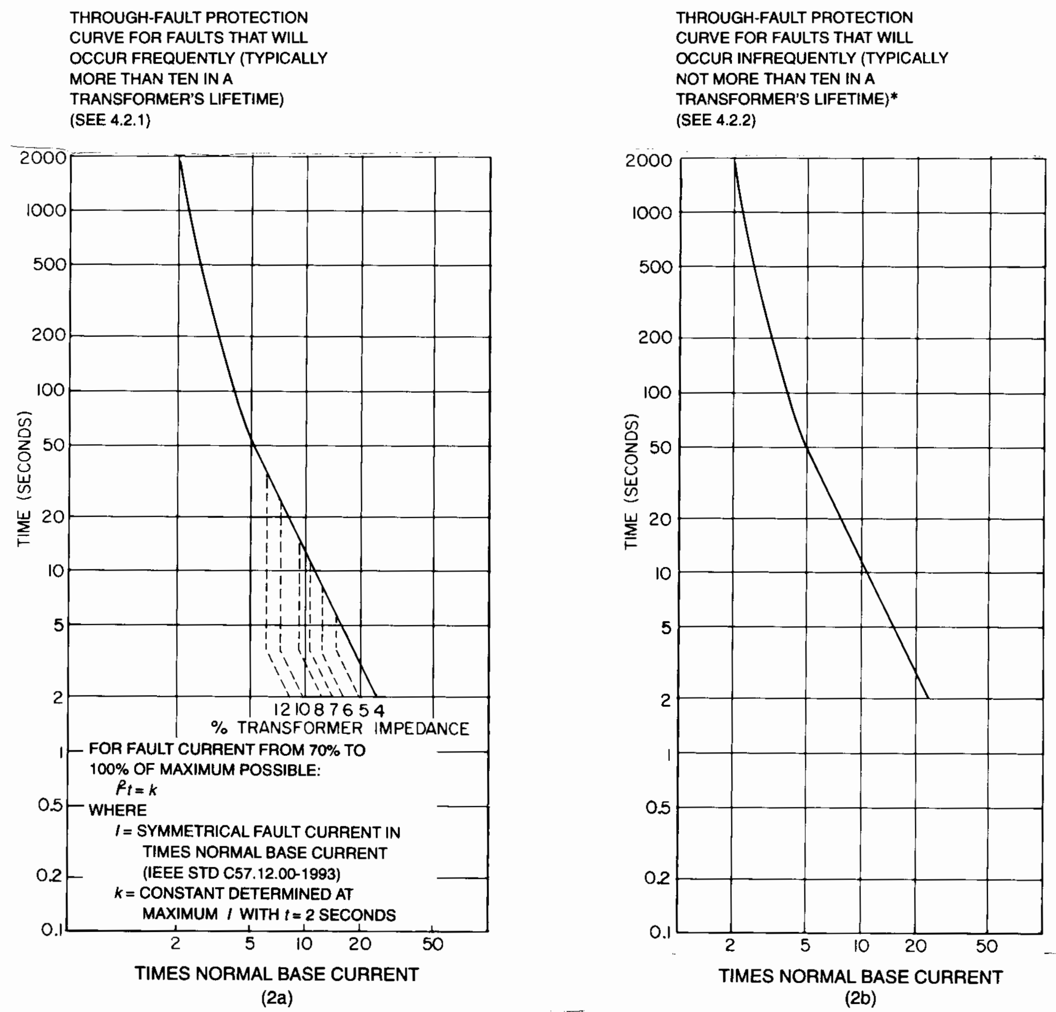


NOTE—Low current values of 3.5 and less may result from overloads rather than faults. An appropriate loading guide should be referred to for specific allowable time durations.

Figure 1—Category I transformers
5 to 500 kVA single-phase
15 to 500 kVA three-phase

4.2 Category II transformers

The recommended duration limits depend upon fault frequency and are based upon the curves of figures 2a and 2b. Fault frequency refers to the number of faults with magnitudes greater than 70% of the maximum possible.



*This curve may also be used for backup protection where the transformer is exposed to frequent faults normally cleared by high-speed relaying.

NOTES

1—Sample $I^2t = k$ curves have been plotted for selected transformer short circuit impedances as noted in 2a.

2—Low current values of 3.5 and less may result from overloads rather than faults. An appropriate loading guide should be referred to for specific allowable time durations.

Figure 2—Category II transformers
501 to 1667 kVA single-phase
501 to 5000 kVA three-phase

4.2.1 Faults that occur frequently

Figure 2a, reflecting both thermal and mechanical damage considerations, should be applied as a protection curve for faults that will occur frequently (typically more than ten in the life of a transformer). Part of the curve is dependent upon the transformer short-circuit impedance for fault currents above 70% of the maximum possible and is keyed to the I^2t of the worst-case mechanical duty (maximum fault current for 2s) as shown by the dashed curves for a few selected impedances. The remaining portion matches the thermal protection curve for faults below the 70% level.

4.2.2 Faults that occur infrequently

Figure 2b, which is the solid portion of figure 2a, reflects primarily thermal damage considerations. It is not dependent upon the transformer short-circuit impedance and may be applied as a protection curve for faults that will occur only infrequently (typically not more than ten in the life of a transformer). This curve also may be used for backup protection where the transformer is exposed to frequent faults normally cleared by high-speed relaying.

4.3 Categories III and IV transformers

Short-circuit withstand capability of these transformers is based on the transformer short-circuit impedance, which is the sum of the transformer impedance and system short-circuit impedance, in accordance with IEEE Std C57.12.00-1993. The value of system impedance should be as specified in the user's transformer specification. If this value is not known or if the transformer was specified in accordance with the requirements of IEEE Std C57.12.00-1980 or later revision, the values from IEEE Std C57.12.00-1993 adopted in tables 4 and 5 should be used.

Table 4—Short-circuit apparent power of the system to be used unless otherwise specified

Maximum system voltage (kV)	System fault capacity	
	(kA rms)	(MVA)
Below 48.3	—	4 300
48.3	54	4 300
72.5	82	9 800
121.0	126	25 100
145.0	160	38 200
169.0	100	27 900
242.0	126	50 200
362.0	84	50 200
550.0	80	69 300
800.0	80	97 000

Neglecting the system impedance in fault calculations for the use of the curves of figures 3 and 4 may not change the results significantly. However, in cases where available fault levels are in a narrow margin (less than 5% of the curves' values), inclusion of the appropriate system impedance should be considered.

4.3.1 Category III transformers

The recommended duration limits depend upon fault frequency and are based upon the curves of figure 3a and 3b. Fault frequency refers to the number of faults with magnitudes greater than 50% of the maximum possible.

Table 5—Subtransient reactance of three-phase synchronous machines

Type of machine	Most common reactance per unit*	Reactance range per unit
Two-pole turbine generator	0.10	0.07–0.20
Four-pole turbine generator	0.14	0.12–0.21
Salient pole generators and motors with dampers	0.20	0.13–0.32
Salient pole generators without dampers	0.30	0.20–0.50
Condensers—air cooled	0.27	0.19–0.30
Condensers—hydrogen cooled	0.32	0.23–0.36

*Assumptions of rotating machine impedances should be defined by the transformer manufacturer.

4.3.1.1

Figure 3a, reflecting both thermal and mechanical damage considerations, should be applied as a protection curve for faults that will occur frequently (typically more than five in the life of a transformer). Part of the curve is dependent upon the transformer short-circuit impedance for fault currents above 50% of the maximum possible and is keyed to the I^2t of the worst-case mechanical duty (maximum fault current for 2s) as shown by the dashed curves for a few selected impedances. The remaining portion matches thermal protection curves for faults below the 50% level.

4.3.1.2

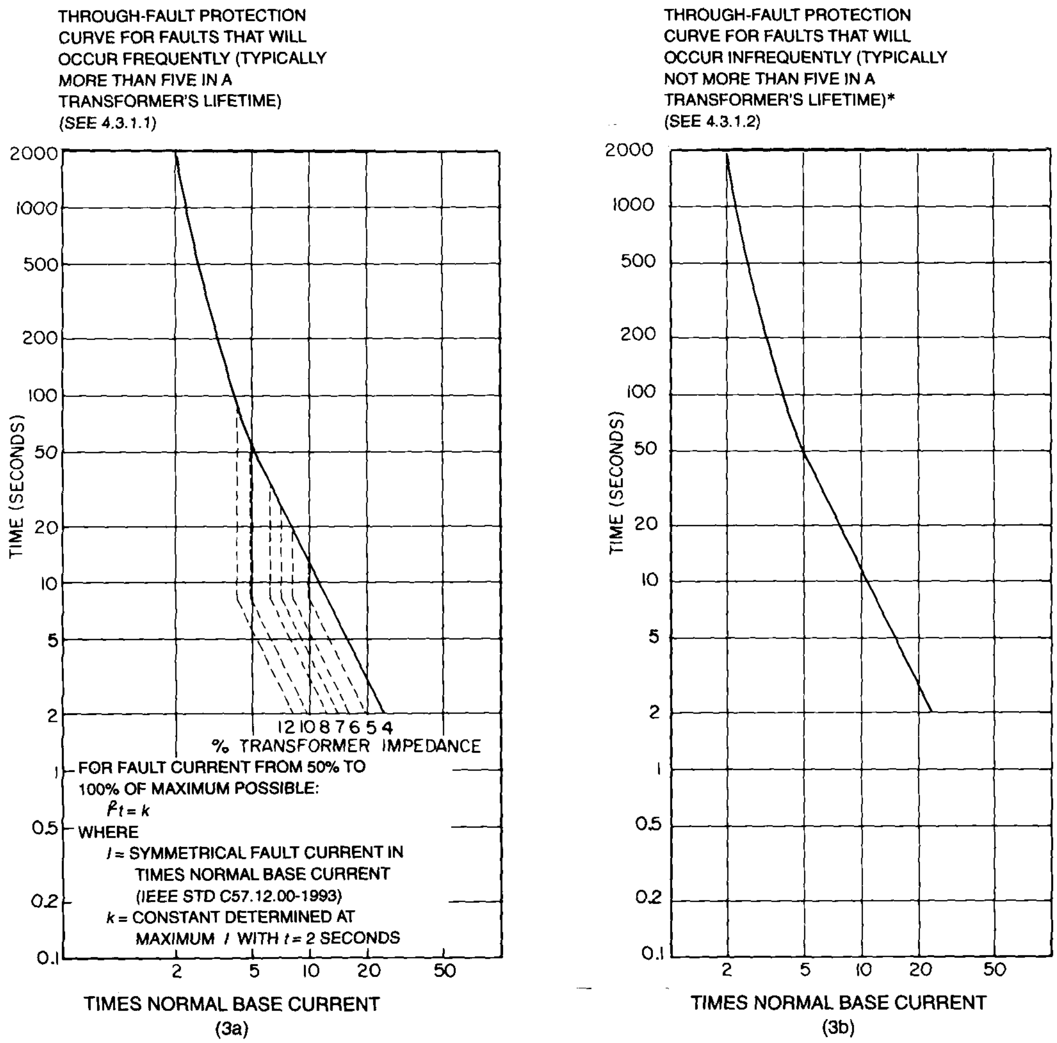
Figure 3b, which is the solid portion of figure 3a, reflects primarily thermal damage considerations. It is not dependent upon the transformer short-circuit impedance and may be applied as a protection curve for faults that will occur only infrequently (typically not more than five in the life of a transformer). This curve may also be used for backup protection where the transformer is exposed to frequent faults normally cleared by high-speed relaying.

4.3.2 Category IV transformers

The recommended duration limit is based upon the curve of figure 4. The curve reflects both thermal and mechanical damage considerations and should be applied as a protection curve for all faults, frequent and infrequent. The importance of protection for the increasing mechanical duty of large kilovoltampere transformers justifies the use of a single curve generally used for faults occurring frequently. It is dependent upon the transformer short-circuit impedance for fault current above 50% of the maximum possible, and is keyed to the I^2t of the worst-case mechanical duty (maximum fault current for 2s).

4.4 Recommended duration limits

Recommended duration limits designated for transformers given in IEEE Std C57.12.00-1993 as Categories I, II, III, and IV are given in figures 1 through 4.



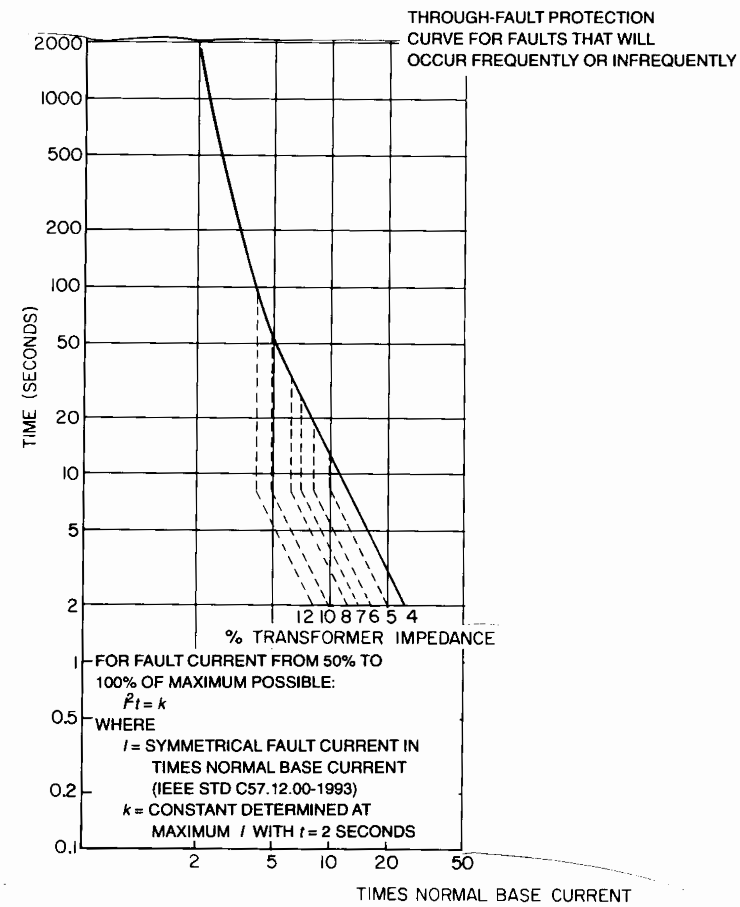
*This curve may also be used for backup protection where the transformer is exposed to frequent faults normally cleared by high-speed relaying.

NOTES

1—Sample $I^2t = k$ curves have been plotted for selected transformer short-circuit impedances as noted in 3a.

2—Low current values of 3.5 and less may result from overloads rather than faults. An appropriate loading guide should be referred to for specific allowable time durations.

Figure 3—Category III transformers
1668 to 10 000 kVA single-phase
5001 to 30 000 KVA three-phase



TIMES NORMAL BASE CURRENT

NOTES

1—Sample $I^2t = k$ curves have been plotted for selected transformer short-circuit impedances as noted.

2—Low current values of 3.5 and less may result from overloads rather than faults. An appropriate loading guide should be referred to for specific allowable time durations.

Figure 4—Category IV transformers above 10 000 kVA single-phase above 30 000 kVA three-phase