



IEEE Guide for Establishing Short-Circuit Withstand Capabilities of Liquid-Filled Power Transformers, Regulators, and Reactors

IEEE Power and Energy Society

Developed by the
Transformers Committee

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STANDARDS

IEEE Guide for Establishing Short-Circuit Withstand Capabilities of Liquid-Filled Power Transformers, Regulators, and Reactors

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Transformers Committee
of the
IEEE Power and Energy Society

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Abstract: Guidance on determining and establishing short-circuit withstand capabilities of power transformers, regulators, and reactors is provided in this standard.

Keywords: autotransformer, fault, IEEE C57.164™, reactor, short circuit, transformer

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Introduction

This introduction is not part of IEEE Std C57.164–2021, IEEE Guide for Establishing Short-Circuit Withstand Capabilities of Liquid-Filled Power Transformers, Regulators, and Reactors.

In this document, the term transformer refers to a power transformer, regulator, or reactor, unless noted specifically to apply to only one type of equipment.

Several references are made in this document to specific tables, equations, or clauses in IEEE standards such as IEEE Std C57.12.00^{TM6} that are frequently revised and are under revision at the time this guide was published. While this guide may refer to the current revision of such IEEE standards at the time that this guide is published, the user is encouraged to consult the latest revision of referenced standards with the knowledge that the referenced table, equation, or clause number may have changed during a subsequent revision and the newer table, equation, or clause number should apply.

A transformer must be constructed so that it is able to withstand the mechanical stresses caused by external system short-circuits, as specified in IEEE Std C57.12.00TM–2015, Clause 7, Short-circuit characteristics.

For a designer, the problem has two aspects, as follows:

- a) The calculation or measurement of the electromagnetic forces and mechanical stresses.
Dynamic analysis of electromagnetic forces and mechanical stresses, though desired, are very complex to perform (for now) on every new design. Over the years and to date, these have been analyzed assuming static conditions (i.e., forces based on the amplitude of the peak current), which will also be the basis for this guide (for radial stress, static analysis represents the worst case). 2D and or 3D magnetic field calculation methods should be the basis for calculating the static forces.
- b) The mechanical design of the transformer windings and its support structure to withstand these forces and the resulting stresses.

This requires a thorough knowledge of properties and the variations in the manufacturing processes of all the materials used in the construction, which are mainly copper/aluminum and various insulating materials. Mechanical winding stress due to radial and axial components of the electromagnetic force are different from each other, and these are analyzed as two separate components.

It is apparent that a thorough review of the design, understanding of the materials used, and a comprehensive review of individual manufacturing process for a specific plant needs to be performed. It is recognized that the manufacturing process and skill level of the manufacturing plant is extremely critical for the ability of a power transformer to withstand the stresses due to short circuits. While a manufacturer's force calculations in their validated short-circuit design programs can also be considered valid for other factories operated by the manufacturer, the factory-specific criteria, such as variations in worker training and experience, sub-supplier materials, manufacturing equipment and tooling, and manufacturing processes, should also be considered and evaluated. These factory-specific criteria can only be validated by a record of successful short-circuit testing. It should be recognized, however, that some factories have not yet performed any short-circuit tests or have made significant design changes since their last successful short-circuit test. If the manufacturer cannot provide validation of their design and/or factory-specific criteria with successful short-circuit test results, the purchaser should consider the calculated short-circuit design to be unproven and subject to additional scrutiny and/or margins or factors of safety.

The design review process should (at the very least but not just) analyze data such as calculations of short-circuit currents, electromagnetic forces with the resulting stresses in windings and its support structure, material specifications, and manufacturing practices.

For transformers of categories I and II, which are normally classified as units that are purchased in bulk, the evaluation procedure consisting of carrying out a short-circuit withstand test should be preferred.

⁶Information on references can be found in [Clause 2](#).

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IEEE Guide for Establishing Short-Circuit Withstand Capabilities of Liquid-Filled Power Transformers, Regulators, and Reactors

1. Overview

1.1 Scope

This guide describes theoretical and practical ways to evaluate liquid-immersed power transformers, regulators, and reactors capabilities to withstand short-circuit currents resulting from external short-circuit faults. The equipment capabilities will be assessed based on calculations, design characteristics, construction techniques and material properties. The methods described are not mandatory and will not set forth requirements on how the transformer must be designed.

1.2 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{7,8}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is

⁷The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁸The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 60076-5, Power transformers—Part 5: Ability to withstand short-circuit.⁹

IEEE Std C57.12.00™, IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.^{10,11}

IEEE Std C57.12.80™, IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.12.90™, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.15™, IEEE Standard Requirements, Terminology, and Test Code for Step-Voltage Regulators.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹² All other definitions, except as specifically covered in this guide, shall be in accordance with IEEE Std C57.12.80.

asymmetry factor K: The asymmetry factor K, as defined in IEEE Std C57.12.00, is the ratio of the peak value of the short-circuit current (I_p) to the symmetrical short-circuit current (I_F). $I_p = K \times I_F$ or $K = I_p/I_F$.

bending stress: Axial or radial stress a conductor between two fixed supports, either between sticks for radial bending or between spacers for axial bending in a core form transformer.

blocks and clamping: Blocks are a component in core form transformers used to maintain pressure or provide structural support between two points. Blocks are generally made of wood, laminated high density pressboard, or other composite type materials. Clamping is - used in core form transformers to maintain the designed axial pressure on the windings and/or structural parts. It can involve screw-type devices, tie rods, blocks and/or shims that keep the winding in compression by maintaining the axial force. Core clamping is the structural support of the core through the core frame, flitch plates, tie plates or tie rods, core bands and other supports that maintains the integrity of the core when exposed to mechanical stresses.

buckling stress: inward radial compressive stress on windings in core form transformers

coil head: Part of the pancake coils outside the magnetic circuit in shell form transformers.

compressive stress: Inward stresses on windings, spacers, conductor paper, insulation and pressure rings (or pressure plates) due to radial forces resulting in tangential compressive stress. Also applied to interphase wedges in shell form transformers.

conductor: The current-carrying cable, wire, or sheet in the winding.

continuously transposed cable (CTC): A type of conductor that consists of multiple enameled strands (unbonded or thermo-set epoxy bonded) that are transposed at regular intervals.

⁹IEC publications are available from the International Electrotechnical Commission (<https://www.iec.ch/>). IEC publications are also available in the United States from the American National Standards Institute (<http://www.ansi.org>).

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¹¹IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<https://standards.ieee.org/>).

¹²*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

core tightening system: Device placed at the joints of the magnetic circuit exerting a pressure normal to the plane of the core laminations in shell form transformers. This could consist of a spring or a jack or other similar mechanisms.

core wedge: Steel or insulating material inserted between the top of the core and the phases providing radial tightening in shell form transformers.

de-energized tap changer (DETC): Also referred to as a tap changer for de-energized operation: A selector switch device used to change transformer taps with the transformer de-energized.

deflection: The movement of a structural support when an external force is applied. Parameter used to evaluate the allowable elastic stresses and structural capability to withstand axial forces in pressure rings/pressure plates.

disk type winding: A winding where the turns are wound radially in the form of multiple disks. Each disk has more than one turn. The turns are wound alternately from inner diameter to outer diameter and vice versa. Each of the disks are stacked axially to form the complete winding and share a common inner diameter and outer diameter. A space is created between turns and/or disks to allow for cooling and insulation by use of axial and/or radial spacers.

electromagnetic force: The force resulting from the vector product of a magnetic field and a current, multiplied by the length of the conductor.

end insulation collapse: Failure of the end winding support or common press plate to continue support or clamp the winding. This phenomenon can be due to the fact that the winding is not rotational symmetric.

end wedge: An insulating structure placed between top and bottom coil heads and tank supporting the phases and transmitting the axial forces to the tank in shell form transformers.

end winding support (also pressure ring, pressure plate or top and bottom ring): A mechanical structure used in core form transformers placed on the top and bottom of a winding set supporting the axial clamping, lifting and short-circuit forces of the winding. These are generally made of laminated wood or laminated high density pressboard.

factor of safety (FoS): The additional mechanical strength of a component or material above the calculated mechanical forces or stress on the component or material, and calculated as $[(\text{Strength}/(\text{force or stress}))]$. For example, for a material with a rated strength of 120 N/mm², and a stress of 100 N/mm², the calculated FoS would be 1.2, indicating that the strength of the material is 1.2 times the stress that it will be exposed to.

flitch plates (or lock strips or tie plates): Structural plates used in core form transformers in tension placed vertically along the core legs and used to apply a clamping force on the windings transferred through the upper and lower sections of the core frame and on the windings.

helical type winding: A winding similar to a layer type winding except the turns are separated from each other by spacers.

insulating supports for coils: Insulating material used in core form transformers inserted between a horizontal surface and top or bottom ring to provide clearance and provide mechanical support

inter-phase wedge: An insulating structure placed between top and bottom coil heads of the middle phase and extreme phases of a three-phase shell form transformer and transmitting the axial forces.