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# Examination Standard for Liquid-Insulated Transformers

**Class Number 3990**

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# Foreword

This standard is intended to verify that the products and services described will meet stated conditions of performance, safety and quality useful to the ends of property conservation. The purpose of this standard is to present the criteria for examination of various types of products and services.

Examination in accordance with this standard shall demonstrate compliance and verify that quality control in manufacturing shall ensure a consistent and reliable product.

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# 1 INTRODUCTION

## 1.1 Purpose

**1.1.1** This standard states testing and certification requirements for transformers insulated with certified liquids.

**1.1.2** Testing and certification criteria may include performance requirements, marking requirements, examination of manufacturing facility(ies), audit of quality assurance procedures, and a surveillance program.

## 1.2 Scope

**1.2.1** This standard sets performance requirements for liquid insulated distribution and power transformers, both naturally cooled and transformers utilizing forcibly circulated cooling medium. The standard limits certification for the naturally cooled (KNAN) transformers rated from 5 to 10,000 kVA and 35 kV class or lower. Certification of larger transformers will require the use of forcibly circulated cooling mediums (forced air or forced liquid (water or oil) cooling).

**1.2.2** This standard applies to any component intended for use as a protective device and that is normally provided as part of the transformer assembly. Use of components previously certified as individual protective devices shall not automatically result in a certification transformer assembly.

## 1.3 Basis for Requirements

**1.3.1** The requirements of this standard are based on experience, research and testing, and/or the standards of other organizations. The advice of manufacturers, users, trade associations, jurisdictions and/or loss control specialists was also considered.

**1.3.2** The requirements of this standard reflect tests and practices used to examine characteristics of transformers insulated with liquids for the purpose of obtaining certification. Transformers insulated with liquids having characteristics not anticipated by this standard may be certified if performance equal, or superior, to that required by this standard is demonstrated.

## 1.4 Basis for Certification

Certification is based upon satisfactory evaluation of the product and the manufacturer in the following major areas:

**1.4.1** Examination and tests on production samples shall be performed to evaluate:

- the suitability of the product;
- the performance of the product as specified by the manufacturer and required by the certification agency;
- the durability and reliability of the product.

**1.4.2** An examination of the manufacturing facilities and audit of quality control procedures is made to evaluate the manufacturer's ability to consistently produce the product which is examined and tested, and the marking procedures used to identify the product. Subsequent surveillance may be required by the certification agency in accordance with the certification scheme to ensure ongoing compliance.

### 1.5 Basis for Continued Certification

The basis for continual certification may include the following based upon the certification scheme and requirements of the certification agency:

- production or availability of the product as currently certified;
- the continued use of acceptable quality assurance procedures;
- satisfactory field experience;
- compliance with the terms stipulated by the certification;
- satisfactory re-examination of production samples for continued conformity to requirements; and
- satisfactory surveillance audits conducted as part of the certification agencies product surveillance program.

### 1.6 Effective Date

The effective date of this examination standard mandates that all products tested for certification after the effective date shall satisfy the requirements of this standard.

The effective date of this standard is eighteen (18) months after the publication date of the standard for compliance with all requirements.

### 1.7 System of Units

Units of measurement used in this standard are United States (U.S.) customary units. These are followed by their arithmetic equivalents in International System (SI) units, enclosed in parentheses. The first value stated shall be regarded as the requirement. The converted equivalent value may be approximate. Conversion of U.S. customary units is in accordance with ANSI/IEEE/ASTM SI 10.

### 1.8 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the cited edition applies.

ANSI/ASME Boiler and Pressure Vessel Code (BPV) Code, Section VIII, *Pressure Relief Devices*

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

ANSI/IEEE C57.12.90 - IEEE Standard *Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers*

ANSI/IEEE C57.12.80™ - IEEE Standard *Terminology for Power and Distribution Transformers*

ANSI/IEEE/ASTM SI 10 *American National Standard for Metric Practice*

IEC 60076-1 Power Transformers - Part 1: *General*

IEC 60076-2 Power Transformers - Part 2: *Temperature rise*

IEC 60076-3 Power Transformers - Part 3: *Insulation levels, dielectric test and external clearances*

IEC 60076-4 Power Transformers – Part 4: *Guide to lightning impulse testing of power transformers and reactors*

IEC 60076-8 Power Transformers - Part 8: *Application guide*

FM 6933 *Transformer Fluids*

### 1.9 Terms and Definitions

For purposes of this standard, transformer terminology available in ANSI/IEEE C57.12.80 shall apply. The IEEE Standards Dictionary Online should be consulted for terms not defined in this clause. Various types of tests (routine, design, conformance, and other) are also defined in ANSI/IEEE C57.12.80. Some definitions and short descriptions of tests are offered in the Appendix A to this standard.

# 2 GENERAL INFORMATION

## 2.1 Product Information

This standard describes electrical and mechanical requirements of liquid-immersed distribution and power transformers, autotransformers and regulating transformers, single-phase and polyphase, with voltages of 601 V or higher in the highest voltage winding.

This standard applies to all liquid-immersed distribution, power, and regulating transformers that do not belong to the following types of apparatus:

a) Instrument transformers
b) Step voltage and induction voltage regulators
c) Arc furnace transformers
d) Rectifier transformers
e) Specialty transformers
f) Grounding transformers
g) Mobile transformers
h) Mine transformers

## 2.2 Certification Application Requirements

The manufacturer shall provide the following preliminary information with any request for certification consideration:

- A complete list of all models, types, sizes, and options for the products or services being submitted for certification consideration;
- General assembly drawings, complete set of manufacturing drawings, materials list, anticipated marking format, piping and electrical schematics, nameplate format, brochures, sales literature, spec. sheets, installation, operation and maintenance procedures, etc...; and
- The number and location of manufacturing facilities.
- All documents shall identify the manufacturer's name, document number or other form of reference, title, date of last revision, and revision level. All documents shall be provided with English translation.

## 2.3 Requirements for Samples for Examination

**2.3.1** Following authorization of a certification examination, the manufacturer shall submit samples for examination and testing based on the following:

- The manufacturer shall provide instructions and/or illustrations for proper installation, maintenance, and operation of the subject transformer.
- Upon request, the manufacturer shall furnish time/current curves of the fusing or protective relay schemes provided with the transformer. This applies whether the devices are of in-house manufacture or purchased.
- The manufacturer shall provide assembly drawings, component drawings, material lists, labeling format, brochures, sales literature, specification sheets, etc. for certification examination.

**2.3.2** Requirements for samples may vary depending on design features, results of prior or similar testing, and results of any foregoing tests.

**2.3.3** The manufacturer shall submit samples representative of production. Any decision to use data generated using prototypes is at the discretion of the certification agency.

**2.3.4** It is the manufacturer's responsibility to provide any necessary test fixtures, such as those which may be required to evaluate the transformer.

# 3 GENERAL REQUIREMENTS

## 3.1 Review of Documentation

**3.1.1** During the initial investigation and prior to physical testing, the manufacturer's specifications and details shall be reviewed to assess the ease and practicality of installation and use. The certification examination results may further define the limits of the final certification.

## 3.2 Physical or Structural Features

**3.2.1** Transformers shall be designed in accordance with the requirements of ANSI/IEEE C57.12.00 or IEC 60076 and the requirements of this examination standard. Where the certification agency's requirements exceed or are more specific than those of C57.12.00/IEC 60076 Series, the certification agency's requirements shall be used to determine certification.

**3.2.2** Rectangular and cylindrical transformer tanks shall be designed for a minimum withstand pressure of 7 psi (48 kPa) without permanent distortion. Rectangular tanks shall be designed for a minimum withstand pressure of 15 psi (105 kPa) without rupture; cylindrical for a minimum of 20 psi (140 kPa) without rupture.

**3.2.3** Transformers shall be provided with a pressure relief device of sufficient capacity to limit internal pressure, under low current arcing fault conditions, so that tank rupture does not occur. The nominal opening pressure of the relief device shall be 10 psi (69 kPa) and the minimum nominal flow rates shall be as follows:

**Table 1 – Minimum Nominal Flow Rates**

| kVA Rating<br>*3-Phase* *(1-Phase)* | *Flow Rate*<br>*SCFM @ 15 psi (103 kPa)* |
|---|---|
| 112.5 (37.5) | 35 |
| 150 (50) | 50 |
| 300 (100) | 100 |
| 1000 (333) | 350 |
| 2000 (667) | 700 |
| 10000 (3333) | 5000 |
| Over 10000 (3333) | 12600 |

**Note**: Table interpretation is, for example, kVA >150 and ≤ 300 requires flow rate of 100 SCFM.

**3.2.4** Transformers shall be insulated with a certified transformer fluid. Fluids shall have a fire point not less than 572°F (300°C) as determined by the ASTM D92—Open Cup Method.

**3.2.5** Electrical protection shall be provided to prevent tank rupture due to high current faults. This protection shall limit the electrical energy input to the transformer. The protection shall be in the form of current-limiting fuses or other technology of demonstrated equivalent or greater effectiveness.

When current limiting fusing is used, under-fluid expulsion fuses may be used in series in accordance with the manufacturer's recommended protection scheme.

If protection is designed to vent or emit gas during operation (such as is the case with expulsion fuses without current limiting fusing in series), this protection shall be located external to the transformer tank.

If lightning arrestors are provided with single phase pad, single phase pole, or three phase pole round tank transformers they shall be located external to the tank.

The maximum $I^2t$ let through for current limiting fuses and other types of protection shall not exceed the values shown in the table below.

**Table 2 – Maximum $I^2t$ Let Through**

| *kVA Rating* | | *Current Limiting Fusing* | *Other Protection* |
|---|---|---|---|
| *3-Phase* | *(1-Phase)* | | |
| 45 | (15) | 500000 | 700000 |
| 75 | (25) | 500000 | 800000 |
| 112.5 | (37.5) | 550000 | 900000 |
| 150 | (50) | 600000 | 1000000 |
| 225 | (75) | 650000 | 1200000 |
| 300 | (100) | 750000 | 1400000 |
| 500 | (167) | 900000 | 1900000 |
| 750 | (250) | 1100000 | 2200000 |
| 1000 | (333) | 1250000 | 3400000 |
| 1500 | (500) | 1500000 | 4500000 |
| 2000 | (667) | 1750000 | 6000000 |
| 2500 | (833) | 2000000 | 7500000 |
| 3000 | (1000) | 2250000 | 9000000 |
| 3750 | (1250) | 2500000 | 11000000 |
| 5000 | (1667) | 3000000 | 14000000 |
| 7500 | (2500) | 3000000 | 14000000 |
| 10000 and over | (3333) | 3000000 | 14000000 |

**Note**: Table interpretation is, for example, kVA ≥500 and <750 is limited to 900,000.

**3.2.6** Electrical protection shall also be provided to clear sustained low current faults. For units up to 2,500 kVA, fuse protection is acceptable as a minimum. For indoor installations, units above 500 kVA shall be equipped with alarm contacts on the pressure relief device. Units rated above 2,500 kVA, in all locations, shall be equipped with alarm contacts on the pressure relief device and sudden pressure relays or other technology having a demonstrated equivalent or greater effectiveness. Transformers with wye connected secondary windings of 150V or more, to ground, and rated at 1000 A or more, shall be provided with a ground fault sensing current transformer (CT) in the low voltage circuit unless prohibited by the authority having jurisdiction.

**3.2.7** All transformers, except pole mount and single phase pad mount, shall be equipped with a liquid level indicator. Transformers rated at 750 kVA or higher shall also be equipped with a liquid temperature indicator and a pressure-vacuum gage.

**3.2.8** Transformers shall be capable of tolerating, as a minimum, a 1.5° tilt from vertical without affecting their Basic Lightning Impulse Insulation Level (BIL).

### 3.3 Markings

**3.3.1** A certified transformer shall be labeled in accordance with the requirements of ANSI C57.12.00 pertaining to ratings and other essential operating data.

**3.3.2** A separate durable corrosion-resistant metal label(s) carrying the information noted below shall also be attached to the transformer.

a. Tank withstand pressure.
b. Pressure relief device(s) type/model/part number(s) and manufacturer.
c. Fuse type(s), rating, model/part number(s), and manufacturer.
d. Type of insulating liquid (Certified Class 6933 transformer fluid) and fluid volume.

The label shall also carry the following text:

Replacement fuses must be exact duplicates of those initially provided.

**3.3.3** Marking on the product or, if not possible due to size, on its packaging or label accompanying the product, shall include the following information:

- name and address of the manufacturer or marking traceable to the manufacturer;
- date of manufacture or code traceable to date of manufacture or lot identification;
- model number, size, rating, capacity, etc., as appropriate.

When hazard warnings are needed, the markings should be universally recognizable.

**3.3.4** When applicable (per Section 3.2.6), a tag shall be attached to the low voltage neutral bushing stating: "Secondary ground fault protection, or equivalent, must be installed unless specifically prohibited by the authority having jurisdiction."

**3.3.5** The model or type identification shall correspond with the manufacturer's catalog designation and shall uniquely identify the certification agency's mark of conformity.

**3.3.6** The certification agency's mark of conformity shall be displayed visibly and permanently on the product and/or packaging as appropriate and in accordance with the requirements of the certification agency. The manufacturer shall exercise control of this mark as specified by the certification agency and the certification scheme.

**3.3.7** All markings shall be legible and durable.

### 3.4 Manufacturer's Installation and Operation Instructions

**3.4.1** The manufacturer shall provide the user with:

- instructions for the installation, maintenance, and operation of the transformer and all auxiliary devices;
- facilities for repair of the product and supply replacement parts; and

- services to ensure proper installation, inspection, or maintenance for products of such nature that it would not be reasonable to expect the average user to be able to provide such installation, inspection, or maintenance;
- upon request, the manufacturer shall furnish time/current curves of the fusing or protective relay schemes provided with the transformer. This applies whether the devices are of in-house manufacture or purchased.

### 3.5 Calibration

**3.5.1** Each piece of equipment used to verify the test parameters shall be calibrated within an interval determined on the basis of stability, purpose, and usage. A copy of the calibration certificate for each piece of test equipment is required. The certificate shall indicate that the calibration was performed against working standards whose calibration is certified and traceable to the National Institute of Standards and Technology (NIST) or traceable to other acceptable reference standards and certified by an ISO/IEC 17025 accredited calibration laboratory. The test equipment shall be clearly identified by label or sticker showing the last date of the calibration and the next due date. A copy of the service provider's accreditation certificate as an ISO/IEC 17025 accredited calibration laboratory should be available.

**3.5.2** When the inspection equipment and/or environment is not suitable for labels or stickers, other methods such as etching of control numbers on the measuring device are allowed, provided documentation is maintained on the calibration status of thus equipment.

# 4 PERFORMANCE REQUIREMENTS

## 4.1 Examination

Sample transformers shall be examined to verify that they are constructed in accordance with the manufacturer's drawings and specifications, ANSI/IEEE C57.12.00/IEC 60076 Series requirements and the certification agency's requirements.

## 4.2 Pressure Capability

**4.2.1** Requirement

A. Transformer assemblies shall be capable of withstanding an internal pressure of 7 psi (48 kPa) without leakage, permanent distortion, or rupture.

B. Rectangular transformer tanks shall be capable of withstanding an internal pressure of 15 psi (105 kPa), cylindrical tanks 20 psi (140 kPa) or their design pressure, whichever is greater, without leakage or rupture.

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**EXCEPTION**

Cylindrical tanks with venting covers.

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**4.2.2** Test Verification

A. A complete transformer assembly, with all components that would normally penetrate the tank walls installed, shall be pressurized, to the level noted in 4.2.1.A above, for a period of one minute. There shall be no evidence of leakage, permanent distortion, or rupture.

B. transformer tank, with all openings plugged, shall be pressurized, to the level noted in 4.2.1.B above, for a period of one minute. There shall be no evidence of leakage or rupture of the tank itself or displacement of the components. Minor leakage at gasketed or other sealing surfaces is allowed.

**Note**:

1. For test A, venting through the pressure relief device shall be prevented by blocking the relief mechanism, plugging its outlet port, or removal of the device and plugging the tank port.
2. For test B, components may be left installed if it is more convenient and if they are capable of withstanding the test pressure.
3. Tests A and B may be conducted without windings installed unless their installation requires penetration of tank walls.

## 4.3 Electrical Capability

**4.3.1** Requirement

Completed transformer assemblies shall be subjected to applicable electrical tests specified in ANSI/IEEE C57.12.00, Table 16, entitled "Routine, Design, and Other Tests for Liquid-Immersed Transformers" or applicable electrical tests specified in IEC 60076-1, IEC 60076-2, IEC 60076-3, IEC

60076-4 and IEC 60076-8. All certification sample transformers shall be subjected to the routine tests. Design tests are required only for prototypes.

**4.3.2** Test/Verification

A. All tests shall be conducted in accordance with ANSI/IEEE C57.12.90 Test Code or IEC 60076 Series requirements for Liquid-Immersed Transformers.

B. Required Tests:

1. Verification of voltage ratio and vector group or phase displacement
2. Measurement of insulation resistance
3. Measurement of winding resistance
4. Lightning impulse test (full and reduced waves; chopped wave is not required) [LI or BIL]
5. Measuring the no-load loss and no-load current
6. Measuring short-circuit voltage / impedance and load loss
7. Separate source AC withstand voltage test or Applied-voltage test
8. Induced voltage tests
9. Temperature rise test – performed on a new transformer design only

## 4.4 Insulating Fluids

**4.4.1** Requirement

Transformer fluids shall be in conformance with FM Examination Standard 6933.

**4.4.2** Tests/Verification

Any fluid, submitted as a component of a transformer assembly, which is not certified shall be evaluated for conformance to the requirements of FM Examination Standard 6933 as a prerequisite to its use.

## 4.5 Level, Pressure, and Temperature Protective Device

**4.5.1** Physical Features

**4.5.1.1** Requirement

Protective devices shall be practicably useable, shall not present unreasonable hazards in their normal use, shall not be capable of being assembled or installed improperly, and shall not be easily defeated or bypassed. They shall be protected from environmental conditions that could impair their operation.

**4.5.1.2** Test/Verification

Protective devices shall be assembled, installed, removed, operated, and/or serviced in accordance with the manufacturer's instructions and responsible trade practices. There shall be no evidence of failure to comply with the above noted requirements.

**4.5.2** Pressure Relief Devices

**4.5.2.1** Requirement

Pressure relief devices shall meet the requirements of the ANSI/ASME BPV Code, Section VIII, Division 2 as it pertains to release pressure. They shall have a rated working pressure equal to or greater than the tank rated pressure. A means of annunciating overpressure alarms shall be provided for transformers rated above 2,500 kVA.

**4.5.2.2** Test/Verification

A. These devices shall be subjected to ten operational cycles. Relieving pressure shall remain within the manufacturer's stated tolerance or ±2 psi (14 kPa) whichever is less.

B. The devices shall be held closed and subjected to a pressure equal to 1.5 times their rated pressure for one minute. There shall be no evidence of leakage or damage.

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**EXCEPTION**

This test is not required if the device cannot be held closed by ordinary means such as plugging of the vent port or wedging of the relief mechanism.

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C. The manufacturer shall provide data pertaining to the flow capacity of the device.

**4.5.3** Level Indicators

**4.5.3.1** Requirement

A level indicator shall have, as a minimum, the same pressure capability as the tank as described in Section 4.2.1.A above.

**4.5.3.2** Test/Verification

The indicator shall be subjected to the same test as described Section in 4.2.2.A above.

**4.5.4** Pressure/Temperature Indicators and/or Switches

**4.5.4.1** Requirement

A. Accuracy of indication shall conform to the manufacturer's specification.

B. Switching (trip) point shall repeat within the manufacturer's specification. Reset, automatic or manual, shall not occur until the input is below the trip point.

**Note**: When applicable, the devices shall comply with the above requirements over a range of 85 to 110 percent of nominal supply voltage.

C. Devices that have adjustable trip points shall be configured so as prevent adjustment by means readily accessible to an operator. Typically, a special tool, removal of an access cover, or a password for electronic devices shall be required.

D. These devices shall be capable of conforming to the requirements noted in A and B over a temperature range of 32–120°F (0–49°C) or their specified operating (ambient) temperature range, whichever is greater.

**4.5.4.2** Test/Verification

A. Input signals, equal to 0, 25, 50, 75, and 100 percent of the operating range, shall be applied to the device. Indication shall comply with the manufacturer's accuracy specification.

B. An input signal shall be applied slowly, until the switch actuates, for ten successive operations. The device shall conform to the requirements noted in 3.5.4.1.B above.

C. When applicable, the above tests shall be repeated at 85 and 110 percent of nominal operating voltage.

D. The set point adjustment instructions and the device shall be examined in order to verify compliance with the requirement noted in 4.5.4.1C above.

E. The devices shall be conditioned at the operational temperature extremes noted in 4.5.4.1D above for a period of at least 24 hours at each temperature. Accuracy and repeatability shall be tested as noted in A and B above and results shall comply with stated requirements.

## 4.6 Transformer Tilt

### **4.6.1** Requirement

A transformer shall be capable of being tilted, as a minimum, 1.5° from vertical without affecting its Basic Lightning Impulse Insulation Level (BIL) or Lightning Impulse (LI) as determined in Section 4.3.2 B.4 above.

### **4.6.2** Test/Verification

**Note**: For this test, fluid in the transformer, shall be set at a level equivalent to the minimum contracted fluid volume at a temperature of -4°F (-20°C).

The tilt will be simulated by reducing the fluid level to the equivalent depth caused by physically tilting the transformer. The BIL/LI shall not be less than that determined in Section 4.3.2 B.4 above and there shall be no evidence of internal flashover.

# 5 OPERATIONS REQUIREMENTS

## 5.1 Demonstrated Quality Control Program

**5.1.1** A quality assurance program is required to assure that subsequent products produced by the manufacturer shall present the same quality and reliability as the specific products examined. Design quality, conformance to design, and performance are the areas of primary concern.

- Design quality is determined during the examination and tests and may be documented in the certification report.
- Continued conformance to this standard is verified by the certifier's surveillance program.
- Quality of performance is determined by field performance and by periodic re-examination and testing.

**5.1.2** The manufacturer shall demonstrate a quality assurance program which specifies controls for at least the following areas:

- existence of corporate quality assurance guidelines;
- incoming quality assurance, including testing;
- in-process quality assurance, including testing;
- final inspection and tests;
- equipment calibration;
- drawing and change control;
- packaging and shipping; and
- handling and disposition of non-conforming materials.

**5.1.3** Documentation/Manual

There should be an authoritative collection of procedures/policies. It should provide an accurate description of the quality management system while serving as a permanent reference for implementation and maintenance of that system. The system should require that sufficient records are maintained to demonstrate achievement of the required quality and verify operation of the quality system.

**5.1.4** Records

To assure adequate traceability of materials and products, the manufacturer shall maintain a record of all quality assurance tests performed, for a minimum period of two years from the date of manufacture.

**5.1.5** Drawing and Change Control

- The manufacturer shall establish a system of product configuration control that shall allow no unauthorized changes to the product. Changes to critical documents, identified in the certification report, may be required to be reported to, and authorized by the certification agency prior to implementation for production.
- Records of all revisions to all certified products shall be maintained.

## 5.2 Surveillance Audit

**5.2.1** An audit of the manufacturing facility may be part of the certification agency's surveillance requirements to verify implementation of the quality assurance program. Its purpose is to determine

that the manufacturer's equipment, procedures, and quality program are maintained to ensure a uniform product consistent with that which was tested and certified.

**5.2.2** Certified products or services shall be produced or provided at, or provided from, location(s) disclosed as part of the certification examination. Manufacture of products bearing a certification mark is not permitted at any other location prior to disclosure to the certification agency.

### 5.3 Installation Inspections

**5.3.1** Field inspections may be conducted to review an installation. The inspections are conducted to assess ease of application, and conformance to written specifications. When more than one application technique is used, one or all may be inspected at the discretion of the certification agency.

### 5.4 Manufacturer's Responsibilities

**5.4.1** The manufacturer shall notify the certification agency of changes in product construction, components, raw materials, physical characteristics, coatings, component formulation or quality assurance procedures prior to implementation.

### 5.5 Manufacturing and Production Tests

**5.5.1** As minimum, manufacturer shall perform the following routine tests described in ANSI/IEEE C57.12.00 and ANSI/IEEE C57.12.90 or IEC 60076 Series on all production samples:

1) Verification of voltage ratio and vector group or phase displacement;
2) Measurement of insulation resistance;
3) Measurement of winding resistance;
4) Measuring the no-load loss and no-load current;
5) Measuring short-circuit voltage / impedance and load loss;
6) Separate source AC withstand voltage test or Applied-voltage test;
7) Induced voltage tests;
8) Test on on-load tap-changers and other auxiliary equipment;
9) Induced Voltage Tests - only if so mandated as a routine test by an applicable IEEE of IEC Standard.

# 6 BIBLIOGRAPHY

ISO/IEC 17025: 2017 General Requirements for the Competence of Testing and Calibration Laboratories

ABB Business Area Power Transformers: 2003 Testing of Power Transformers; Routine tests, Type tests and Special tests

The J&P Transformer Book – 13th edition: 2007

FM Global Property Loss Prevention Data Sheets, DS 5.4 Transformers

# APPENDIX A: TRANSFORMER SPECIFIC DEFINITIONS AND TESTS

**(Explanations and references)**

**Verification of voltage ratio and vector group or phase displacement**
IEC 60076-1 "Connection and voltage displacement symbols for three-phase transformers", and “Measurement of voltage ratio and check of phase displacement”
ANSI/IEEE C57.12.90 “Polarity and phase relation test” and “Ratio tests"

The turn ratio of a transformer is the ratio of the number of turns in the high-voltage winding to that in the low-voltage winding. The voltage ratio of a transformer is the ratio of the rms terminal voltage of a higher voltage winding to the rms terminal voltage of a lower voltage winding under specified conditions of load. For practical purposes, when the transformer is on open circuit, its voltage and turns ratio may be considered equal.

Measurement of dissipation factor (Tan δ) of the insulation system capacitances*
IEC 60076-1 “Power transformers Part 1: General, -Measurement of the dissipation factor (Tan δ) of the insulation resistance capacitances”
ANSI/IEEE 57.12.90 “Insulation power factor tests"

The insulation power-factor test is similar to the insulation resistance test and allowing to test condition of the transformer insulation. Power-factor is helpful in assessing the condition of the insulation.

Measurement of insulation resistance
IEC 60076-1 “Power transformers”-Part 1 - "General";
ANSI/IEEE 57.12.90 "Insulation resistance tests".

Insulation resistance tests - Megger tests - are performed to determine the insulation resistance from individual windings to earth or between individual windings. Knowledge of the insulation resistance is of value when evaluating the condition of the transformer insulation. Nowadays different sophisticated methods are in use to assess the quality of the insulation system, such as low frequency dielectric spectroscopy measurements (FDS), time domain polarization /depolarization current measurements (PDC) and return voltage polarization spectra (RVM).

Measurement of winding resistance
IIEC 60076-1 "Measurement of winding resistance”;
ANSI/IEEE C57.12.90 “Resistance Measurements".

Winding resistance serves a number of important functions:
Providing a base value to establish load loss
Providing a basis for an indirect method to establish winding temperature and temperature rise within a winding
Inclusion as part of an in-house quality assurance program, like verifying electric continuity within a winding.

Lightning impulse test
IEC 60076-4 "Guide to lightning impulse and switching impulse testing of power transformers and reactors";
ANSI/IEEE C57.12.90 "Dielectric tests”.

The purpose of the test is to verify the insulation integrity for transient voltages, caused either by atmospheric phenomena lightning, network disturbances or switching operations.

IEC specifies the ratings Lightning Impulse Withstand level, (abbreviated LI) for impulse withstand. IEEE specifies the rating Basic lightning Impulse insulation level (abbreviated BIL). IEC allows free selection of standardized values for LI, while a given BIL value specifies the lightning impulse as well as the switching impulse insulation requirements.

IEC specifies:

- One reduced level full impulse (calibration impulse)

- One full level full impulse (LI)
- One or more reduced level chopped impulse(s) (only if specially requested) – not required by this Standard
- Two full level chopped impulses (UC). Only if specifically requested – not required by this Standard
- Two full level full impulses (LI)

If not otherwise requested, IEC test requirements specify that the chopped wave should have an amplitude of 110% of the LI value.

IEEE specifies:

- One reduced full wave impulse (calibration impulse)
- Two front-of-wave impulses at specified amplitude (only if specifically requested)
- Two chopped wave impulses at specified amplitude – not required by this Standard
- One full wave impulse at rated amplitude (BIL)

The chopped wave should be at 110% of the BIL value and the front-of-wave should have an amplitude according to table 5 of ANSI/IEEE C57.12.00 (only for Class I transformers). The integrity of the transformer is confirmed when there is a close similarity between the voltage traces for the applied calibration impulse voltage and all of the applied full test voltages.

Measuring the no-load loss and no-load current
IEC 60076-1 “General requirement for routine, type and special tests" and “Measurement of no-load loss and current";
IEC 60076-8 “Guide to the measurement of losses in power transformers";
ANSI/IEEE C57.12.90 “No-load losses and excitation current".

The no-Load loss is developed by the excitation of the transformer and it represents a considerable amount of energy during the life-time of the transformer. In general the actual loss figure has to be guaranteed by the manufacturer and a correct value on the measured no load loss is therefore important.

Measuring short-circuit voltage / impedance and load loss
IEC 60076-1 "General requirement for routine, type and special tests” and “Measurement of short-circuit impedance and load”;
IEC 60076-8 “Guide to the measurement of losses in power transformers";
ANSI/IEEE C57.12.90 "Load losses and impedance voltage”.

Transformer short-circuit voltage and load loss are guaranteed by the manufacturer and are verified for the customer during the acceptance test. Exact knowledge of the load loss is important not only for capitalization of losses but is also important for the safe operation of large power transformers. A comparison of the calculated and measured values gives an indication about the eddy losses caused by leakage flux in the mechanical parts and the tank wall. Furthermore, it is essential to know the short-circuit voltage and load loss to carry out the temperature rise test, see section 11. For transformers with tapped windings the short-circuit voltage has to be measured in the two extreme tap positions in addition to the principal tap position. Knowledge about short-circuit voltage in extreme tap position is important for parallel operation.

Temperature rise test
IEC 60076-2 "Test of temperature rise"
ANSI/IEEE C57.12.00 "Temperature rise and loading conditions"
ANSI/IEEE C57.12.90 "Temperature rise".

The purpose of the temperature rise test is to verify guaranteed temperature rises for oil and windings. It may also be used to establish possible hot-spots (inside and outside the windings), especially for transformers with high stray fields (for instance, power transformers> 300 ... 500 MVA or auto-transformers). Knowledge of the measured average- and top oil temperature rise and of the winding-oil gradient is even more important today than in the past, in view of future upgrade and overload considerations.

Separate source AC withstand voltage test or Applied-voltage test
IEC 60076-3 "Separate source AC withstand voltage test"
ANSI/IEEE C57.12.90 "Applied-voltage tests"
ANSI/IEEE C57.12.00 "Insulation levels"

The purpose of the separate source AC withstand test or applied-voltage test (according to ANSI/IEEE) is to verify the integrity of the main insulation. This main insulation does not only mean the insulation system between the two windings (major insulation), but also more generally the insulation between the winding and earth (end insulation) and all connections to earth and to each other.

Induced voltage tests
IEC 60076-3 "Dielectric tests", "Induced AC voltage tests"
ANSI/IEEE C57.12.00 "Insulation levels"
ANSI/IEEE C57.12.90 "Induced voltage tests"

The induced voltage test is intended to verify the AC withstand strength of each line terminal and its connected winding(s) to earth and other windings; it also verifies the withstand strength between phases and along the winding(s) under test (tum-to-turn insulation).

Measurement of zero-sequence impedance(s) on three-phase transformers*
IEC 60076-1 "Measurement of the zero-sequence impedance(s) on three-phase transformers"
ANSI/IEEE CS7.12.90 "Zero-phase-sequence impedance"

The zero-sequence impedance is the impedance measured between phase terminal and neutral when the three-phase terminals are connected together. The zero-sequence impedance can only develop in star connected or zig-zag connected windings in three-phase transformers. The zero-sequence impedance to be attributed to each individual phase is three times the measured value.

Test on on-load tap-changers and other auxiliary equipment*
IEC 60076-1 "Test on on-load tap-changers"
IEC 60076-3 "Insulation of auxiliary wiring"
IEEE Std. C57.12.00, table 19: "Dielectric test for low voltage control wiring, associated control equipment and current transformer secondary circuits, on Class 11 power transformers"

*these tests are not required by the Standard

Cooling Attributes of a Liquid Insulated Transformer

Liquid insulated transformers offer several options for cooling. ANSI/IEEE Standard C57.12.00 defines a 4 digit code to describe the cooling attributes of the transformer.

| The first letter designates the internal cooling medium in contact with the windings. | |
|---|---|
| **Letter** | **Meaning** |
| O | mineral oil or synthetic insulation fluid with a fire point ≤ 300°C |
| K | insulating fluid with a fire point > 300°C |
| L | insulating liquid with no measurable fire point. |

| The second letter designates the circulation mechanism for internal cooling medium | |
|---|---|
| **Letter** | **Meaning** |
| N | Natural convection flow through cooling equipment and in windings |
| F | Forced circulation through cooling equipment and natural convention flow in the windings (also called "directed flow") |
| D | Forced circulation through cooling equipment, directed from the cooling equipment into at least the main windings |

| The third letter designates external cooling medium | |
|---|---|
| **Letter** | **Meaning** |
| A | Air |
| W | Water |

| The fourth letter designates the circulation mechanism for the external cooling medium | |
|---|---|
| **Letter** | **Meaning** |
| N | Natural convection |
| F | Forced circulation (Fans (air cooling) , pumps (water cooling)) |

For example: ONAN designates an oil filled unit that has natural convection flow in the tank and utilizes natural air convection cooling externally.

If this transformer has fans added for forced air externally, the designation would be ONAF.

A transformer that has natural convection cooling as a base rating and an elevated rating when fans were added later, would be designated as ONAN/ONAF.

High fire point fluids use the designation of "K" for fluid type. Thus a naturally cooled high fire point fluid would be KNAN and the same unit with fans would be KNAF.

Types of tests

The IEC 60076 and ANSI/IEEE C57.12.00 Standards distinguish between the following types of tests:

- Routine tests
- Type*- or design** tests
- Special* - or other** tests

* This is the IEC terminology
** This is the IEEE terminology

Routine tests are tests required for each individual transformer. Typical examples: Resistance measurements, voltage ratio, loss measurements, etc.

Type or design' tests are conducted on a transformer which is representative of other transformers, to demonstrate that these transformers comply with specified requirements not covered by routine tests. Typical example: Temperature rise test.

Special- or other tests are tests other than type- or routine tests agreed to by the manufacturer and the purchaser. Typical example: Measurement of zero-sequence impedance, sound level measurement, etc.