* Short-circuit tests
* General

This test code applies to liquid-immersed distribution and power transformers 5 kVA and above. Within this range, four categories shall be recognized as listed in Table 6.

|  |  |  |
| --- | --- | --- |
| * Transformer categories covered by this test code | | |
| Category | Single-phase  (kVA) | Three-phase  (kVA) |
| Ia | 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 |
| NOTE—All kilovoltampere ratings are minimum nameplate kilovoltampere for the principal windings. | | |
| aCategory I shall include distribution transformers manufactured in accordance with ANSI C57.12.20 up through 500 kVA, single-phase or three-phase. In addition, autotransformers of 500 kVA-equivalent two-winding kilovoltampere or less that are manufactured as distribution transformers in accordance with ANSI C57.12.20 shall be included in Category I even though their nameplate kilovoltampere may exceed 500 kVA. | | |

The code defines a procedure to demonstrate the mechanical capability of a transformer to withstand short-circuit stresses. The prescribed tests are not designed to verify thermal performance. Conformance to short-circuit thermal requirements shall be by calculation in accordance with Clause 7 of IEEE Std C57.12.00.

The short-circuit test procedure described in this standard is intended principally for application to new transformers to verify design. Tests may be conducted at manufacturer’s facilities, test laboratories, or in the field; but it shall be recognized that complete equipment is not usually available in the field for conducting tests and verifying results.

Note -- Some transformers may not be fully tested because of limitations of testing facility (test laboratory, manufacturer facility or field tests capability). Thermal ability to withstand short-circuit can be demonstrated by calculations per IEEE std C57.12.00 or IEC60076-5. The ability to withstand the dynamic effects of short-circuit shall preferably be demonstrated by test; if not possible it may be demonstrated by calculation and design considerations per IEC 60076-5.

* Test connections
* Two-winding transformers and autotransformers without tertiary windings
* Fault location

The short circuit may be applied on the transformer primary or secondary terminals as dictated by the available voltage source, but the secondary fault is preferred since it is the fault condition producing the highest fault current in each windings. The short circuit shall be applied by means of suitable low-resistance connectors.

In order of preference, the tests may be conducted by either of the following:

* Closing a breaker at the source terminal to apply energy to the previously short-circuited transformer, pres-set method, Figure 1



1. —One line diagram for the “pre-set” method

* Closing a breaker at the faulted terminal to apply short circuit to the previously energized transformer, post-set method, Figure 2



1. — One line diagram for the “post-set” method

Note 1 -- when using pre-set method, a), magnetizing inrushes may occur, particularly on autotransformers or axial split coils transformers.

Note 2 -- When using the pre-set method for a transformer with single concentric windings, the supply should preferably be connected to the winding farther from the core, the winding closer to the core being short-circuited. This will help to avoid saturation of the core which could lead to an excessive magnetizing current superimposed on the short-circuit current during the first few cycles.

Note 3 -- For type tests on distribution transformers or when there is no identified purchaser involved, the preferred location (secondary fault) and method (pre-set) should be used.

Add the following references:

* Leher G., **Investigation of Inrush Currents during a Short Circuit Test on a 440 MVA, 400 kV GSU-Transformer**, CIGRÉ paper 12-104, Session 2000.
* -Janssen A.L.J., te Paske L.H., **Short-Circuit Testing Experience with large Power Transformers**, CIGRÉ paper 12-105, Session 2000.
* Fault type

For single phase transformers a single phase supply shall be used. For three-phase transformers a three-phase supply is preferable, as long as the fault current requirements defined in C57.12.00 can be met. If this is not possible, an alternate single-phase source can be used:

a) For delta-connected windings, the single-phase supply is provided between two corners of the delta and the voltage during the test has to be the same as the voltage between phases during a three-phase test.

b) For star-connected windings, the single phase voltage is supplied between one line terminal and the other two line terminals connected together. The single-phase voltage during the test shall be equal to √3 /2 times the voltage between phases during the three-phase test.

c) Single phase source with short-circuit on one phase at a time.

Annex xx gives some typical connection diagrams for testing a three-phase transformer using a single-phase source.

* Tap connection for test

When the transformer is provided with taps in any winding, at least one test satisfying the asymmetrical current requirement shall be made on the tap connection that calculations predict will produce the most severe mechanical stresses. Extremes of the tap range (all taps out or all taps in) normally produce the most severe stresses, and are recommended.

The tap connection that produces the most severe stress is determined by calculation and should be agreed upon between the manufacturer and the purchaser. Often the maximum forces occur with the lowest voltage tap connection. Tests on other taps, or connections in the case of dual voltage windings, may be required to ensure design adequacy.

* Multiwinding transformers, including autotransformers
* Fault location and type

Fault types and terminals to which they are to be applied shall be determined individually for each particular transformer. The maximum fault current for each winding shall be determined from calculations of fault types specified in Clause 7 of IEEE Std C57.12.00 using various fault types, fault locations, and applicable system data. During testing, each winding shall be subjected to its maximum calculated fault current on at least one test. In general, a given fault type and location will not produce the maximum fault current in more than one winding, so it will be necessary to make tests with several different connections to fully evaluate the capability of all windings. In order of preference, the tests may be conducted by either of the following methods:

* Closing a breaker at the source terminal to apply energy to the previously short-circuited transformer, pre-set method.
* Closing a breaker at the faulted terminal to apply short circuit to the previously energized transformer, post-set method.

Note 1 -- when using pre-set method, a), magnetizing inrushes may occur, particularly on autotransformers or axial split coils transformers.

Note 2 -- When the primary winding is connected to the supply, either one or both of the secondary windings, or either one or both of the common or tertiary windings for auto-transformers, may be short‑circuited for the test.

Note 3 -- For auto-transformers with tertiary windings, it may also be necessary to consider other fault conditions, such as single‑phase‑ or double‑phase‑to‑ground faults with either the common or series, or both, as the source(s) of supply.

Note 4 -- It is recommended that the tolerance on the agreed test current values and the duration of the tests are in line with those prescribed for two-winding transformers ant that the test sequence is selected according to the expected increase of electrodynamics forces.

Add the following references:

* Leher G., **Investigation of Inrush Currents during a Short Circuit Test on a 440 MVA, 400 kV GSU-Transformer**, CIGRÉ paper 12-104, Session 2000.
* -Janssen A.L.J., te Paske L.H., **Short-Circuit Testing Experience with large Power Transformers**, CIGRÉ paper 12-105, Session 2000.

12.2.3 Axial split transformers

Axial-split transformers comprise transformers having 3 or more windings with 2 or more windings physically assembledaxially on the same magnetic leg. Each of the axial-split windings can be connected to different sources and/or loads by different sets of bushings.

Some transformers use axial-split winding arrangement for which the windings are only connected internally to other windings. Such transformers are not considered as axial-split transformers and shall be short-circuit tested with the usual short-circuit test method.

**12.2.3.1 Fault location and type**

For axial-split transformers, the fault shall be applied to only one of the axial-split windings. The other axial-split winding(s) shall remain open circuited with possibly one of the terminals grounded for voltage reference. The short-circuit test sequence (6 tests see: 12.3) shall be repeated for each one axial split windings. Axial-split transformers shall preferably be tested

* by closing a breaker at the faulted terminal to apply short-circuit to the previously energized transformer, post-set method.

In case of power limitations from the Laboratory, by agreement between the manufacturer and the purchaser the test may be done using the following method

1. by closing a breaker at the source terminal to apply energy to the previously short-circuited transformer, pre-set method.

Note 1 -- Using the pre-set method, closing a breaker at the source terminal to apply energy to the previously short-circuited transformer, necessitate special precautions in order to control magnetizing inrushes and not cause undue high instantaneous current (high inrush superposed to the peak AC current) and related undue electromagnetic forces on the windings

Note 2 -- The preferred post-set method does not demonstrate that the transformer would be able to withstand energizing the transformer on a short-circuit, i.e. forgotten grounds. If such a performance is required per the client requirements the transformer should be tested using the pre-set method, with the pre-set short circuit applied on one of the axial split winding.

Add the followint reference to the document:

Leher, G. **Investigation of Inrush Currents during a Short Circuit Test on a 440 MVA, 400 kV, GSU Transformer,** CIGRÉ paper 12-104, session 2000

Janssen, A. L. J., te Paske L. H., **Short-Circuit Testing Experience with Large Power Transformers,** CIGRÉ paper 12-104, session 2000

CIGRÉ WG A2.26 report, **Mechanical Condition assessment of Transformer Windings using Frequency Response Analysis (FRA)**, Electra No 228, October 2006.

* Test requirements
* Symmetrical current requirement, two-winding transformers

For two-winding transformers, the required value of symmetrical current for any test shall be determined from the equations in Clause 7 of IEEE Std C57.12.00.

NOTE—For Categories I and II, calculate *I*sc using transformer impedance only; except for Category I, the symmetrical current magnitude shall not exceed the values listed in 7.1.4.1 and Table 16 of IEEE Std C57.12.00. For Categories III and IV, calculate *I*sc using transformer plus system impedance.See Clause 7 of IEEE Std C57.12.00 for additional clarifying information on determining *Z*s.

* Symmetrical current requirement, multiwinding transformers and autotransformers

For multiwinding transformers and autotransformers, the required peak value of symmetrical current in each winding shall be determined by calculation based on applicable system conditions and fault types.

Note 1-- See Clause 7 of IEEE Std C57.12.00 for additional clarifying information on determining *Zs.*

Note 2 – The transformer category is determined based on the primary (common) winding ratings.

* Asymmetrical current requirement

The required first cycle peak for asymmetrical current tests shall be calculated in accordance with the equations in Clause 7 of IEEE Std C57.12.00.

* Number of tests

Each phase of the transformer shall be subjected to a total of six tests satisfying the symmetrical current requirement specified in Symmetrical current requirement, two-winding transformers (clause 12.3.1) or Symmetrical current requirement, multiwinding transformers and autotransformers (clause 12.3.2), as applicable. Two of these tests on each phase shall also satisfy the asymmetrical current requirements specified in Asymmetrical current requirement.

* Duration of tests

The duration of short-circuit tests shall be in accordance with Clause 7 of IEEE Std C57.12.00.

* Test procedure
* Fault application

To produce the fully asymmetrical current wave specified in 12.3.3 in the phase winding under test, the moment of switching on shall be adjusted by means of a synchronous switch or another controlled switching device. .

* Calibration tests

Calibration tests shall be carried out at less than 70 % of specified current to check the proper functioning of the test set-up with regard to the moment of switching on, the current setting, the damping and the duration. Tests which result in current of 95% or more of the specified current may be counted toward fulfillment of the required number of tests.

* Terminal voltage limits

When tests are to be made by applying a short circuit to energized transformers, the no-load source voltage shall not exceed 110% of the rated tap voltage unless otherwise approved by the manufacturer.

Throughout the course of any test, the voltage at the transformer source terminals shall be maintained within a range of 95% to 105% of that necessary to produce the required symmetrical short-circuit current as determined in 12.3.1 or 12.3.2, as applicable.

Note 1 -- When choosing the test voltage the possibility of over excitation and high inrush current shall be considered. All reasonable precautions shall be taken in order to reduce these inrushes.

Note 2 -- Autotransformers and split-coil transformers require special precautions and it may be required to use the post-set method instead of the preferred pre-set method.

* Temperature limits

For liquid-filled transformers, the top liquid temperature at the start of the test shall be between 0 C and 40 C.

Note -- For some small transformers, particularly those having a low *X/R*, special attentions should be take in order not to exceed the winding temperature limits. Additional delay between tests may be required in order to let the winding to cool.

* Current measurements

Recording shall be made of the currents on the transformer terminals connected to the energy source. Oscillograms of currents shall be representative of stresses in the winding. When the transformer winding connected to the energy source is delta-connected, the first cycle peak asymmetrical current cannot be determined directly from terminal measurements at the source terminals. The following alternatives exist:

* When the faulted winding is wye-connected, record oscillograms of the currents on the faulted terminals. Convert to source winding current by inverse turns ratio.
* When all windings are delta-connected, connect current measuring devices inside the delta of the source winding and measure first cycle peak asymmetrical current from oscillograms obtained from these current measuring devices.

or

* When all windings are delta-connected, determine peak and symmetrical currents from oscillogram obtained by proper connection of current measuring devices or by digital calculations.

Whenever possible record the tank current by connecting the transformer tank to ground through a current measuring device.

Note 1 -- Any appropriate measuring devices may be used, as long that they give correct measurements with appropriate sensitivity, precision and uncertainty. Those measuring devices may be, for example, current transformers, shunts, Rogowski coils.

Note 2 -- The oscillograms shall show a scaled image of the current passing through the primary of the measuring device or a scaled image of the current passing in the corresponding winding. For example, the Rogowski coil voltage output shall be properly treated by digital or analogical mean in order to show an image of the real primary current instead of the primary current derivative.

* Tolerances on required current

After the measured impedance is taken into account, the measured current (symmetrical or asymmetrical) in the tested phase(s) shall not be less than 95% of the required current.

Note -- For transformers having a low *X/R* and for those having allowable impedance variation over 5% special attention shall be made to readjust as required the source settings (voltage and/or source impedance) in order to maintain the test current above 95% of the required current.

* Proof of satisfactory performance

The transformer under test shall be judged to have performed satisfactorily when the visual inspection (12.5.1) and the dielectric tests (12.5.2) criteria have been satisfactorily met. In 12.5.3 through 12.5.6, recommended measurements listed can be made during the course of the tests, but are not required unless specified. When the terminal measurements are made and the requirements of 12.5.3 through 12.5.6 have been met following all tests, it is probable that the transformer has sustained no mechanical damage during the test. A composite evaluation of the degree to which all criteria of 12.5.3 through 12.5.6 have been met may indicate the need for a greater or lesser degree of visual inspection to confirm satisfactory performance. A decision to waive all or part(s) on the extent of the visual inspection shall be based upon discussion and negotiation of all parties involved in specification and performance of short-circuit tests.

Note 1 -- Note that the proof of satisfactory performances is determined by visual inspection and the standard dielectric tests defined in C57.12.00. It may be advisable to proceed to a visual inspection before undertaking standard dielectric test.

Note 2 – If acetylene is detected by dissolved gas analysis, extensive visual inspection is required in order to identify and correct the defect before proceeding to other tests.

Note 3 -- Other recommended measurements listed are mainly to identify if something may go wrong, or something may evolve and cause failure of the transformer under test.

* Visual inspection

Visual inspection of the core and coils shall give no indication that any change in mechanical condition has occurred that will impair the function of the transformer. The extent of the visual inspection shall be established on the basis of combined evidence obtained from the measurements described in 12.5.3 through 12.5.6.

The extent of necessary visual inspection may range from an inspection through apertures on the tank (hand hole, manhole) to complete dismantling of the core and coils. The appropriate level of visual inspection shall be based upon discussion and negotiation of all parties involved. The measurements and observations made during the tests and the result of the standard dielectric test should then be considered during the negotiation.

* Dielectric tests

The transformer shall withstand standard dielectric tests of IEEE Std C57.12.00 at the full specification level following the short-circuit test series.

* Waveshape of terminal voltage and current

No abrupt changes shall occur in the terminal voltage or short-circuit current wave shapes during any test.

Note: When substantial changes occur in the terminal voltage or current it is then advisable to proceed to a dissolved gas analysis (DGA) before performing other tests. If dissolved gases generally associated with power arc are present it is advisable to investigate the situation in order not to have a catastrophic failure.

* Leakage impedance

Leakage impedance measured on a per-phase basis after the test series shall not differ from that measured before the test series by more than the following values:

* *Category I and Distribution:* The allowable variation shall be a function of the transformer impedance *Z*T as follows in Table 7:

|  |  |
| --- | --- |
| * Leakage impedance variation for category I and Distribution transformers | |
| *Z*T (per unit) | Percentage variation |
| 0.0299 or less | 22.5–500 *Z*T |
| 0.0300 or more | 7.5 |

* *Categories II and III:* 7.5% allowable for noncircular concentric coils; 2% allowable variation for circular coils.
* *Category IV:* 1% allowable variation.

The measuring equipment shall have the demonstrated capability of giving reproducible readings within an accuracy of ± 0.2%.

Note: 4 wire measuring method is generally required to attain these reproducible readings.

Note: It may be worthwhile to measure impedance after each short-circuit. These measurements will allow to identify progressive variations, or early substantial impedance change.

* Dissolved gas analysis (DGA)

Dissolved gas analysis made after tests shall not show signs that a power arc have occurred in the transformer. (add references: ASTM D3612, Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography. ASTM D3613, Standard Practice for Sampling Insulating Liquids for Gas Analysis and Determination of Water Content, IEEE C57.104 IEEE Guide for the Interpretation of Gases Generated in Oil – ImmersedTransformers).

* Excitation current

Excitation current measured after the test series shall not increase above that measured before the test series by more than 5% for stacked-type cores. For transformers with wound core construction, the increase shall not exceed 25%.

* Other diagnostic measurements

Other diagnostic measurements may be made during the course of the tests to evaluate whether any sudden or progressive changes have occurred in the mechanical condition of the transformer. Such results may be useful to understand the response to short-circuit forces, but they shall not form part of the proof criteria.

Frequency response analysis (FRA) and/or frequency response of stray losses (FRSL) are measurements that may serve to qualify the mechanical condition of winding or part of it (i.e. tap winding).

Add the following references to the document:**b:** L. BOLDUC, P. PICHER, G. PARÉ, R.J. DEMERS, J. BÉLANGER, **DETECTION OF TRANSFORMER WINDING DISPLACEMENT BY THE FREQUENCY RESPONSE OF STRAY LOSSES (FRSL),** © CIGRÉ Session 2000 paper no 12/33-02

Transient oil pressure measurement (TOP) may also help to detect some movements or the loss of clamping pressure of the coils or the coil assembly.

Add the following reference to the document:Kraetge, A., Kalkner, W., Plath, R., Plath, K.-D., Jaekelmann, R., Eisemann, D., Hoffmann, U., *The transient oil pressure measurement as a diagnostic method to assess the short-circuit duty of power transformer,* CIGRÉ A2 Transformer Colloquim 2007, Bruges, Belgium.

# Annex xx (informative) Connections diagrams for testing three-phase transformer using alternate single-phase source

For three-phase transformers three-phase supply is preferable. When the test capability do not allow three-phase tests at the fault current requirement defined in C57.12.00-2006 alternate single phase source can be used The following Figure 1 to Figure 8 show connection diagrams of the alternate single phase source. Figure 1 to Figure 5 show connections for phase to phase tests and Figure 6 and Figure 8 show connections for phase to ground testé



1. —Single phase test, phase to phase Star – star connected windings



1. — Single phase test, phase to phase Star - delta connected windings



1. — Single phase test, phase to phase Delta – star connected windings



1. — Single phase test, phase to phase Delta – delta connected windings



1. — Single phase test, phase to phase Star – Star autotransformer

Single phase source with short-circuit on one phase at a time (C57.12.90, clause 12.2.1.2 c)) applies for star –star connected transformers or auto-transformers and star – delta transformers. Source is then applied between a phase terminal and the ground terminal. The ground terminal shall be capable of carrying the fault current for the specified test duration. In order to control the voltage on the 2 other phases, it is recommend connecting their terminals together see Figure 6 to Figure 8.



1. — Single phase test, phase to ground star – star connected windings



1. — Single phase test, phase to ground star – star autotransformer



1. — Single phase test, phase to ground star – delta transformer.

In the above figures:

* *S1*: for pre-set method: synchronous switch;

for post-set method: source circuit breaker

* *S2*: for pre-set method: rigid connection bar;

for post-set method: synchronous switch.