

5. Tests on On-load Tap-Changers

Operation Test

With the tap-changer fully assembled on the transformer the following sequence of operations shall be performed without failure:

- a) With the transformer un-energised, eight complete cycles of operations (a cycle of operation goes from one end of the tapping range to the other, and back again).
- b) With the transformer un-energised, and with the auxiliary voltage reduced to 85% of its rated value, one complete cycle of operation.
- c) With the transformer energized at rated voltage and frequency at no load, one complete cycle of operation
- d) With one winding short circuited and, as far as practicable, two rated current according to IEC 60076-1 in the winding, 10 tap-change operations across the range of two steps on each side from where a coarse or reversing changeover selector operates, or otherwise from the middle tapping(the tap changer will pass 20 times through the changeover position). Total tap change operations shall be 80.

6. Measurement of short-circuit impedance and load loss

The short-circuit impedance and load loss for a pair of windings shall be measured at rated current & frequency with voltage applied to the terminals of one winding, with the terminals of the other winding short-circuited, and with possible other windings open-circuited. The difference in temperature between the top and bottom liquid shall not exceed 5 K. To obtain this result more rapidly, the liquid may be circulated by a pump. Loss measurement for all combinations (HV-IV, HV-LV, IV-LV and at Normal and extreme taps).

If fibre optic sensors are installed, hotspot temperature of winding and oil may be recorded for reference.

Following parameters shall be recorded:

Current, voltage (RMS & Average), power factor, apparent power, active power, reactive power etc.

Current measured at all the phases shall be approximately same. If more variation is observed between current values of all phases measured, test circuit shall be reviewed and test shall be repeated.

Check points:

- Inputs like - constants, scaling factors, ratio errors, phase angle errors etc. to the loss measuring instrument shall be as per the latest calibration certificate.
- All wirings used for secondary measurements should be original as supplied by equipment manufacturer without any modification.
- Current can also be verified from one of the measuring type bushing CTs.

7. Dielectric Tests

Dielectric tests shall be carried in the following sequence as per IEC 60076-3:2013 clause 7.2.3:

- a) Lightning impulse tests (LIC, LIN)
- b) Switching impulse (SI)
- c) Applied voltage test (AV)
- d) Line terminal AC withstand test (LTAC)
- e) Measurement of transferred surge on LV or Tertiary as applicable due to HV lightning impulse and IV lightning impulse (as applicable). This test may be carried out followed by LI & SI test.
- f) Short time over voltage Test (830kVrms) for 765kV Reactor
- g) Induced voltage test with partial discharge measurement (IVPD)

Oil Sample shall be taken before starting and after completion of dielectric tests for DGA. In case any abnormality during testing, oil samples may also be taken for DGA.

7.1 Full wave lightning impulse test (LI) & chopped wave lightning impulse test (LIC)

Reference Standard:

IEC 60076-3:2013, IEC 60060-1 (General definitions of terms related to impulse tests and requirements for test circuits), IEC 60060-2 (measuring devices) & IEC 60076-4 & IEEE Std C57.98-1993

General

For liquid-immersed transformers, the test voltage is normally of negative polarity, because this reduces the risk of erratic external flashovers in the test circuit.

Tap positions

If the tapping range is $\pm 5\%$ or less and the rated power of the transformer is ≤ 2500 kVA then, the lightning impulse tests shall be made with the transformer connected on the **principal tapping**.

If the tapping range is larger than $\pm 5\%$ or the rated power of the transformer is > 2500 kVA then, the two extreme tappings and the principal tapping shall be used, one tapping for each of the three individual phases of a three-phase transformer or the three single-phase transformers designed to form a three-phase bank.

Records of tests

1. Applied Voltage; the records obtained shall clearly show the applied voltage impulse shape (front time, time-to-half value and amplitude).

The recorded curve and the extreme value of the recorded curve (as defined in IEC 60060-1) shall be presented in the test record.

The value of the test voltage (after the application of any filtering or correction for overshoot, U_t see IEC 60060-1) shall be reported in the test record.

2. At least one more measurement channel shall be used. In most cases an oscillogram of the current flowing to earth from the tested winding (neutral current). Further recommendations about failure detection, suitable time-base durations, etc. are given in IEC 60076-4.

Test connections

Test connections for lightning impulse on the Line Terminals

The impulse test sequence is applied to each of the line terminals of the tested winding in succession. The other line terminals of the transformer shall be earthed directly or, if needed to achieve the required wave shape, through an impedance. The impedance shall not exceed the surge impedance of the connected line (if a value is supplied by the purchaser) or $400\ \Omega$ whichever is lower. In all circumstances, the voltage appearing during the impulse test at the other line terminals shall not be more than 75% of their rated lightning impulse withstand voltage for star-connected

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windings, or 50 % for delta-connected windings. The lowest value of impedance at each terminal needed to achieve the required wave shape shall be used.

If the winding has a neutral terminal, the neutral shall be earthed directly or through low impedance such as a current measuring shunt. The tank shall be earthed. If the required wave shape cannot be obtained without the use of a resistor between neutral and earth, then an additional complete impulse test sequence shall be applied. In this case the first impulse test sequence tests the winding at the full voltage without the resistor but the required wave shape may not be achieved and the second sequence with the resistor achieves the wave shape. Chopped waves, if required, would not be repeated in the second sequence.

When a transformer is fitted with internal non-linear elements such as surge arresters which will limit the voltage on internal parts during the impulse test then the provisions of Clause 13.2.3 of IEC 60076-3 apply. Any such internal non-linear elements which are present in the service condition shall be present during the tests. External non-linear elements and other external voltage control elements such as capacitors shall be disconnected for test.

The impulse circuit and measuring connections shall remain unchanged during reference and full voltage tests

Test connections for lightning impulse on Line terminals

Lightning impulses are applied directly to the neutral with all other terminals earthed.

Full wave lightning impulse test (LI)

Wave shape, determination of test voltage value and tolerances

The test impulse shall be a full standard lightning impulse: $1.2 \pm 30 \% / 50 \mu s \pm 20 \%$.

The test voltage value shall be the test voltage value as defined specification If the maximum relative overshoot magnitude is 5 % or less, the test voltage value may be taken as the extreme value as defined in specification.

The tolerance on the test voltage value is $\pm 3 \%$.

If the standard impulse shape cannot reasonably be obtained because of low winding inductance or high capacitance to earth and the resulting impulse shape is oscillatory so that the relative overshoot magnitude exceeds 5 % then for windings that will receive a chopped wave lightning impulse test, the front time may be increased to reduce the overshoot. In all cases with $U_m \leq 800 \text{ kV}$ the front time shall not exceed $2.5 \mu s$. If the relative overshoot magnitude exceeds 5 % at the full wave voltage level, then a test voltage function shall be applied in accordance with IEC 60060-1 to determine the test voltage value. It is permissible to apply the requirements of IEC 60060-1 Annex B to the evaluation of the parameters of the lightning impulse irrespective of the overshoot value.

NOTE

Case of overshoot of more than 5 % the peak voltage of the impulse (maximum value of the recorded curve) shall be increased and the frequency of oscillation is higher than about 100 kHz by the application of the test voltage function in accordance with IEC 60060-1.

Tests on transformers without non-linear elements**Test sequence**

The test sequence shall consist of:

- a) one reference impulse of a voltage between 50 % and 70 % of the full test voltage
- b) Three subsequent impulses at full voltage.

If, during any of these applications, an external flashover in the circuit or across a bushing spark gap occurs, or if the recording fails on any of the specified measuring channels, that application shall be disregarded and a further application made.

NOTE

Additional impulses at amplitudes not higher than the reference impulse voltage level can be used, these do not need to be shown in the test report.

Test acceptance criteria

The test is successful if there are no significant differences between voltage and current transients recorded from the reference impulse and those recorded at the full test voltage.

NOTE

The detailed interpretation of the test records and the discrimination between marginal differences and differences indicating failure shall be clearly stated in the report. Further information is given in IEC 60076-4.

Additional observations during the test (abnormal sounds, etc.) may be used to confirm the interpretation of the records, but they do not constitute evidence in themselves.

Tests on transformers with non-linear elements**Test sequence**

If non-linear elements or surge arresters are built into the transformer for the limitation of transferred overvoltage transients, they may operate during the test procedure and this may cause differences between impulse records made at different voltages. There will be a threshold voltage at which the differences caused by the non-linear elements start to appear and the test sequence shall include at least one record below this threshold. The test sequence shall consist of:

- a) one reference impulse at between 50 % and 60 % of the full test voltage;
- b) one reference impulse at between 60 % and 75 % of the full test voltage;
- c) one reference impulse at between 75 % and 90 % of the full test voltage;
- d) three consecutive 100 % full wave impulses;
- e) a comparison impulse at as nearly as possible the same voltage as c) above;

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- f) a comparison impulse at as nearly as possible the same voltage as b) above;
- g) A comparison impulse at as nearly as possible the same voltage as a) above.

The reference impulse voltages shall be at least 10 % (of the 100 % level) different from each other. If none of the 100 % full wave records differ from the lowest voltage record of the reference impulse records, then impulses e), f) and g) above may be omitted.

The time interval between the application of the last chopped wave and the first full wave after the chop waves shall be as short as practicable.

NOTE

Additional impulses at amplitudes not higher than the reference impulse voltage level can be used, these do not need to be shown in the test report. If, during any of these applications, an external flashover in the circuit or across a bushing spark gap should occur, or if the recording should fail on any of the specified measuring channels, that application shall be disregarded and a further application made.

The same types of measuring channels and oscillographic records are specified as for the full wave impulse test.

As far as possible the same time to chop shall be used for all chopped impulses in the sequence.

Test criteria

The test is successful if there are no significant differences between voltage and current transients recorded from the lowest voltage reference impulse and those recorded at the full test voltage. If this is not the case then the records of current and voltage from the following impulses shall be compared:

- a) and g)
- b) and f)
- c) and e)
- all the 100 % level impulse records.

The test is successful if there is no significant difference between the compared records (beyond that which can reasonably be explained by small differences in the test voltage) and any changes between successive records are progressive and smooth, consistent with the proper operation of the non-linear element.

NOTE

Additional observations during the test (abnormal sounds, etc.) may be used to confirm the interpretation of the records, but they do not constitute evidence in themselves.

Chopped wave lightning impulse test (LIC)

Wave shape

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The chopped wave lightning impulse shall have a time to chopping between 3 μ s and 6 μ s. The time to first voltage zero after the instant of chopping shall be as short as possible. The test shall be made without the deliberate addition of impedance in the chopping circuit, but if the overswing observed during a reduced voltage application is more than 30 % then the minimum impedance required to bring the overswing below 30 % may be added to the chopping circuit.

NOTE

Transformers are normally designed to withstand an overswing to the opposite polarity of 30 % of the amplitude of the chopped wave lightning impulse. Usually, the same settings of the impulse generator and measuring equipment are used, and only the chopping gap equipment is added.

Different time bases may be used to record the chopped wave lightning impulses. It is recommended to use a triggered-type chopping gap with adjustable timing, although a plain rod-rod gap is allowed. The peak value of the chopped wave lightning impulse shall be 110 % of rated impulse voltage.

Tests on transformers without non-linear elements

Test sequence

The test is combined with the full impulse test in a single sequence. The order of the different impulse applications shall be:

- a) one full wave reference impulse at between 50 % and 70 % of the full wave lightning
- b) impulse test voltage;
- c) one full wave impulse at the full wave lightning impulse test voltage;
- d) two chopped impulses at the chopped wave lightning impulse test voltage;
- e) Two full wave impulses at the full wave lightning impulse test voltage.

The same types of measuring channels and oscillographic records are specified as for the full wave impulse test.

NOTE

Additional impulses (full or chopped) at amplitudes not higher than the reference impulse voltage level can be used, these do not need to be shown in the test report. If, during any of these applications, an external flashover in the circuit or across a bushing spark gap should occur, or if the recording should fail on any of the specified measuring channels, that application shall be disregarded and a further application made. As far as possible the same time to chop shall be used for all chopped wave lightning impulses in the sequence.

Test criteria

The test is successful if there are no significant differences between voltage and current transients recorded from the reference reduced level full impulse and those recorded at the full test voltage including the chopped impulses up to the time of chop. In the case of the chopped impulses differences after the chopping time may be due to minor variations in the performance and timing of the chopping gap.

NOTE

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The detailed interpretation of the test records and the discrimination between marginal differences and differences indicating failure requires a great deal of skill and experience. Further information is given in IEC 60076-4.

Additional observations during the test (abnormal sounds, etc.) may be used to confirm the interpretation of the records, but they do not constitute evidence in themselves.

Tests on transformers with non-linear elements

Test sequence

The test is combined with the full impulse test in a single sequence.

If non-linear elements or surge diverters are built into the transformer for the limitation of transferred overvoltage transients, they may operate during the test procedure and this may cause differences between impulse records made at different voltages. There will be a threshold voltage at which the differences caused by the non-linear elements start to appear and the test sequence shall include at least one record below this threshold.

The test sequence shall consist of:

- a) one full wave reference impulse at between 50 % and 60 % of the full wave lightning impulse test voltage;
- b) one full wave reference impulse at between 60 % and 75 % of the full wave lightning impulse test voltage;
- c) one full wave reference impulse at between 75 % and 90 % of the full wave lightning impulse test voltage;
- d) one full wave impulse at the full wave lightning impulse test voltage;
- e) two chopped impulses at the chopped wave lightning impulse test voltage;
- f) two full wave impulses at the full wave lightning impulse test voltage;
- g) a comparison impulse at as nearly as possible the same voltage as c) above;
- h) a comparison impulse at as nearly as possible the same voltage as b) above;
- i) a comparison impulse at as nearly as possible the same voltage as a) above.

The reference impulse voltages shall be at least 10 % (of the 100 % level) different from each other. If none of the 100 % full wave records differ from the lowest voltage of the reference impulse record then impulses g), h) and i) above may be omitted.

The time interval between the application of the last chopped wave and the first full wave after the chop waves shall be as short as practicable.

NOTE

Additional impulses (full or chopped) at amplitudes not higher than 75 % of the full level can be used, these do not need to be shown in the test report. If, during any of these applications, an external flashover in the circuit or across a bushing spark gap should occur, or if the recording should fail on any of the specified measuring channels, that application shall be disregarded and a further application made. The same types of measuring channels and oscillographic records are specified as for the full wave impulse test. As far as possible the same time to chop shall be used for all chopped impulses in the sequence.

Test criteria

The test is successful if there are no significant differences between voltage and current transients recorded from the lowest voltage reference impulse and those recorded at the full test voltage including the chopped wave impulses up to the time of chop. In the case of the chopped impulses differences after the chopping time may be due to minor variations in the performance and timing of the chopping gap. If this is not the case then the records of current and voltage from the following impulses shall be compared:

- a) and i);
- b) and h);
- c) and g);
- all the 100 % level impulse records;
- both the chopped wave records up to the time of chop.

The test is successful if there is no significant difference between the compared records (beyond that which can reasonably be explained by small differences in the test voltage) and any changes between successive records should be progressive and smooth, consistent with the proper operation of the non-linear element.

NOTE

Further information is given in IEC 60076-4.

Additional observations during the test (abnormal sounds, etc.) may be used to confirm the interpretation of the records, but they do not constitute evidence in themselves.

NOTE

The information given in IEC 60076-4 with reference to waveshape evaluation is based on the visual observation of oscillographic records. Under certain circumstances it might be appropriate to evaluate the waveshape parameters of non-standard waveshapes and perform the interpretation of deviations manually rather than relying completely on software tools.

Lightning impulse test on a neutral terminal (LIN)**General**

Full wave lightning impulses at the impulse voltage level specified for the neutral are applied directly to the neutral with all other terminals earthed.

Waveshape

The wave shape of the full wave impulses shall be as given in 13.2.1 of IEC-60076-3 except that the duration of the front may be up to a maximum of 13 μ s.

Test sequence

The test sequence shall be as given in clause 13.2.2.1 of IEC-60076-3 for transformers without a non-linear element and clause 13.2.3.1 of IEC-60076-3 for transformers with a non-linear element.

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Test criteria

The test criteria shall be as given in clause 13.2.2.2 of IEC-60076-3 for transformers without a non-linear element and clause 13.2.3.2 of IEC-60076-3 for transformers with a non-linear element.