7.2 **Switching impulse test**

Standards:

IEC 60076-3, 60076-4, IEC 60060-1 (for Reactor IEC 60076-6) & IEEE Std C57.98-1993

General

During switching impulse tests, the voltages developed across different windings are approximately proportional to the ratio of numbers of turns. The switching impulse test voltage shall be as specified for the winding with the highest *U*m value. If the ratio between the windings is variable by tappings, the tappings shall be used to bring the test voltage for the winding with lower *U*m as close as possible to the corresponding test value given in Table 2 of IEC-60076-3.

The windings with lower *U*m values may not receive their full test voltage; this shall be accepted. In a three-phase transformer, the voltage developed between line terminals during the test shall be approximately 1.5 times the voltage between line and neutral terminals.

Test Connection

The impulses are applied either directly from the impulse voltage source to a line terminal of the highest voltage winding, or to a lower voltage winding so that the test voltage is inductively transferred to the highest voltage winding. The specified test voltage shall appear between the line terminal of the highest voltage winding and earth. The voltage shall be measured at the line terminal of the highest voltage winding. A three-phase transformer shall be tested phase by phase.

Star connected windings with the neutral brought out shall be earthed at the neutral terminal either directly or through a low impedance such as a current measuring shunt. A voltage of opposite polarity and about half amplitude appears on the two remaining line terminals which may be connected together but not connected to earth. To limit the voltage of opposite polarity to approximately 50 % of the applied level, it is permissible to connect high resistance damping resistors (5 kΩ to 20 kΩ) to earth at the non-tested phase terminals.

For delta connected windings the terminal corresponding to the end of the phase under test shall be earthed either directly or through a small measuring impedance, the other terminals shall be open circuit. Tests on a three-phase transformer shall be arranged so that a different terminal of the delta is earthed for each phase test. Delta connected windings with more than three terminals brought out shall have the delta closed for the test.

For a single phase transformer with one or more windings which will have both ends connected to a line in service and with a switching impulse test specified, then the switching impulse test shall be applied to both ends of the winding.

Bushing spark gaps may be removed or their spacing increased to prevent spark over during the test.

Reactor shall also be tested by the method mentioned above. However, additionally for reactor, clause 8.3 of IEC 60076-4 may also be referred. Since there is only one winding per phase, the application point for the test voltage is the line terminal of the phase winding which is to be tested. The other terminal of this phase winding should be earthed.

For three-phase reactors, the normal impulse test procedures as used for lightning impulse tests are required.

Wave shape

The test voltage is normally of negative polarity to reduce the risk of erratic external flashover in the test circuit.
The voltage impulse shall have a time to peak (*T*p as defined in IEC 60060-1) of at least 100 μs, a time above 90 % (*T*d as defined in IEC 60060-1) of the specified amplitude of at least 200 μs, and a time to zero (*T*z as defined in IEC 60060-1) of a minimum of 1000 μs.

Normally the transformer characteristic of Td ≥ 200 μs is not a problem for small reactors (<100 Mvar for three-phase reactors with relatively high impedances). For large reactors, Td and Tz as specified for transformers would require excessive impulse generator extension. For such cases, a minimum value for Td and Tz should be 120 μs and 500 μs respectively to assure adequate volt-time stress.

Test Sequence

The test sequence shall consist of one reference impulse of a voltage between 50 % and 70 % of the full test voltage and three impulses at full voltage. Sufficient reverse polarity applications shall be made before each full impulse to ensure the magnetization of the core is similar before each full wave impulse in order to make the time to first zero as uniform as possible.

Oscillographic records shall be made of the impulse wave-shape on the line terminal under test and the current between the tested winding and earth. 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.

Acceptance Criteria

The test is successful if there is no sudden collapse of voltage or discontinuity in the voltage or current indicated on the oscillographic records.

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

7.3 Applied voltage test (AV)

The test shall be carried out on each separate winding of the transformer in turn.

The full test voltage shall be applied for 60 s between all accessible terminals of the winding under test connected together and all accessible terminals of the remaining windings, core, frame and tank or casing of the transformer, connected to earth.

The test shall be made with an approximately sinusoidal single-phase alternating voltage at rated frequency. The peak value of voltage shall be measured. The peak value divided by √2 shall be equal to the test value.

NOTE
Approximately sinusoidal can be taken to mean that the peak value divided by √2 does not differ from the r.m.s value of the waveform by more than about 5 % (see IEC 60060-1), but wider deviations may be accepted.

The test shall commence at a voltage not greater than one-third of the specified test value, and the voltage shall be increased to the test value as rapidly as is consistent with measurement. At the end of the test, the voltage shall be reduced rapidly to less than one-third of the test value before switching off.

The test is successful if no collapse of the test voltage occurs.

For windings with non-uniform insulation, the test is carried out with the test voltage specified for the neutral terminal. In transformers where windings having different U_m values are connected together within the transformer (usually auto-transformers), the test voltages shall be determined by the insulation of the common neutral and it's assigned U_m.

7.4 Line terminal AC withstand test (LTAC)

The test shall be arranged so that the test voltage appears between the tested terminal and earth. Each phase terminal of the tested winding shall be tested in turn. The test time, frequency and voltage application shall be same as Induced voltage withstand test (IVW).

$$\text{Test time in Seconds} = 120 \times \frac{\text{rated frequency}}{\text{test frequency}}, \text{ but not less than 15 s}$$

For transformers with taps and a non-uniformly insulated lower voltage winding, the tap position for test shall be selected so that when the required test voltage appears on the highest voltage winding terminals, the voltage appearing on the lower voltage winding terminals shall be as close as possible to the required test value. For transformers with a uniformly insulated lower voltage winding subject to an applied voltage test, the tap position may be chosen by the manufacturer.

The test is successful if no collapse of the test voltage occurs.

NOTE
This test is intended only as a withstand test for each line terminal of a non-uniformly insulated transformer to earth, it is not intended to test the phase to phase or turn to turn insulation so the test arrangement can be made in any convenient way, for example with voltage at the neutral to reduce the turn to turn voltage and the test will normally be carried out as three single phase tests. Partial discharge measurements can be made during this test.

7.5 Induced voltage withstand test (IVW)

The test time at full test voltage shall be 60 s for any test frequency up to and including twice the rated frequency, unless otherwise specified. When the test frequency exceeds twice the rated frequency, the test time in seconds of the test shall be:

$$120 \times \frac{\text{rated frequency}}{\text{test frequency}}, \text{ but not less than 15 s}$$

The test shall commence at a voltage not greater than one-third of the specified test value, and the voltage shall be increased to the test value as rapidly as is consistent with measurement. At the end of the test, the voltage shall be reduced rapidly to less than one-third of the test value before switching off.

The test is successful if no collapse of the test voltage occurs.

7.6 Measurement of transferred surge on LV or Tertiary due to HV & IV Lightning impulse

The voltage shall be applied on the phase for which transferred surge shall be measured in the same phase of tertiary (i.e. if voltage is applied on 1W, the transferred surge shall be measured at 3W terminal). The above process shall be repeated for the remaining HV & IV terminals.
Similar tests to be conducted for switching surge transformer at Max, Nor. and Min. Voltage Tap. However, applied voltage shall be selected such a way that induced voltage at other winding should not go more than the SI limit of that winding.
Following tests shall be carried out with applying 50% to 80% of rated Impulse & Switching impulse (upto 60% for IV to limit the max. limit of HV SI level) voltage. Finally, measured value shall be extrapolated for 100% rated voltage.
For each tap position, atleast 2 nos. shots (one at approx. 50% and other at approx. 80%) shall be applied and measured values shall be extrapolated to 100%. Measured and extrapolated values shall be recorded.
During Transfer surge for 765 kV ICT, if Lightning Arrestor are to be connected in service same shall be used during Test at factory for HV and IV lightning & switching impulse Test.
Table for Transfer surge (Impulse) at Max, Nor. and Min. Voltage Tap

1-Phase Transformer

Sr. No.	Impulse Type	Voltage applied	Earthed Points	Open / not earthed point	Measurement Point
1	FW	1.1	2.1, N & 3.2	-	3.1
2	FW	1.1	2.1, N & 3.1	-	3.2
3	FW	2.1	1.1, N & 3.2	-	3.1
4	FW	2.1	1.1, N & 3.1	-	3.2

Where,

1.1 : HV Terminal
2.1 : IV Terminal
3.1 & 3.2 : LV or Tertiary Terminal

3-Phase Transformer

Sr. No.	Impulse Type	Voltage applied	Earthed Points	Open / not earthed point	Measurement Point
5	FW	1U	1V, 1W, 2U, 2V, 2W, N, 3V & 3W	-	3U
6	FW	1V	1U, 1W, 2U, 2V, 2W, N, 3U & 3W	-	3V
7	FW	1W	1U, 1V, 2U, 2V, 2W, N, 3V & 3U	-	3W
8	FW	2U	1U, 1V, 1W, 2V, 2W, N, 3V	-	3U

			& 3W		
8	FW	2V	1U, 1V, 1W, 2U, 2W, N, 3U & 3W	-	3V
9	FW	2W	1U, 1V, 1W, 2U, 2V, N, 3V & 3U	-	3W

Transformer with non-linear element in the winding

Voltage shall be applied progressively to check at which point the surge arrestor is actuated. This measured voltage shall be the value of transfer surge for that particular connection and tap position.

Acceptance criteria

Transfer surge at Tertiary should not exceed the rated impulse level of that winding. The extrapolated values measured at 50% and 80% as stated above shall be approximately matched.

When non-linear element is connected in the winding, the non-linear element should limit the transferred voltage below the rated impulse level of that winding.

7.7 Induced voltage test with partial discharge measurement (IVPD)

Standards

IEC 60076-3, IEC 60270 & POWERGRID Technical Specification for Transformers & Reactors.

General

This test is intended to verify that the transformer will be free of harmful partial discharges under normal operating conditions. The test voltage is applied in the same way as the voltage that the transformer will experience in service. During the test, symmetrical voltages appear at all the line terminals and between turns, **with no voltage at the neutral**. The test is performed with a three phase voltage on three phase transformers

Each PD measurement channel including the associated bushing or coupling capacitor shall be calibrated in terms of apparent charge (pC) according to the method given in IEC 60270.

Voltage calibration to be done to check the test voltages to be applied as per test sequence given below before start of PD Test as there is no option of keeping the voltage divider connected to the transformer for voltage measurement continuously during PD test.

The PD measurement shall be given in pC and shall refer to the highest steady-state repetitive impulses indicated by the measuring instrument**. Occasional bursts of high partial discharge level may be disregarded.**

If high partial discharge is coming repeatedly, and may be due to external reason, manufacturer should improve the system and bring the value to ambient level before starting the PD cycle.

For each required PD measurement step in the test sequence, PD measurements shall be made and recorded on all the line terminals equipped with bushings with a Um ≥ 72.5 kV, during the test, however if there are more than six such terminals then only six measurements need to be made (one on each of the highest voltage terminals) unless otherwise specified.

Test sequence

The test sequence shall be as follows:

a) The voltage shall be switched on at a voltage not higher than $(0.4 \times Ur)/\sqrt{3}$.
b) The voltage shall be raised to $(0.4 \times Ur)/\sqrt{3}$ and a background PD measurement shall be made and recorded.
c) The voltage shall be raised to $(1.2 \times Ur)/\sqrt{3}$ and held there for a minimum duration of 1 min and only long enough to make a stable PD measurement.
d) The PD level shall be measured and recorded.
e) The voltage shall be raised to the one hour PD measurement voltage and held there for a minimum duration of 5 min and only long enough to make a stable PD measurement.
f) The PD level shall be measured and recorded.
g) The voltage shall be raised to the enhancement voltage and held there for the test time mentioned below.

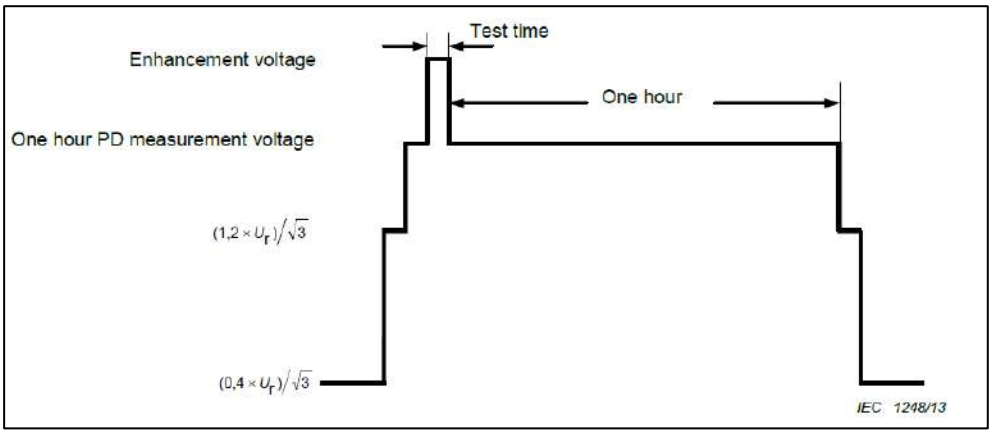
h) Immediately after the test time, the voltage shall be reduced without interruption to the one hour PD measurement voltage.
i) The PD level shall be measured and recorded.
j) The voltage shall be held at the one-hour PD measurement voltage for a duration of at least one hour following the PD measurement.
k) The PD level shall be measured and recorded every 5 min during the one hour period.
l) After the last PD measurement in the one hour period the voltage shall be reduced to (1.2 × Ur) /√3 and held there for a minimum duration of 1 min and only long enough to make a stable PD measurement.
m)The PD level shall be measured and recorded.
n) The voltage shall be reduced to (0.4 × Ur) /√3 and the background PD level shall be measured and recorded.
o) The voltage shall be reduced to a value below (0.4 × Ur) /√3.
p) The voltage shall be switched off.

An enhancement (phase to earth) voltage level of (1.8 × Ur) /√3 and a one hour PD measurement voltage of (1.58 × Ur) /√3. Alternative higher voltage levels may be used if specified by the purchaser. In particular an enhancement voltage of Um and a one hour PD measurement voltage of (1.5 × Um) /√3 may be used if higher.

The partial discharge level shall be continuously observed on at least one measuring channel for the entire duration of the test.

During the test sequence the inception and extinction voltages of any significant PD activity should be noted to aid the evaluation of the test result if the test criteria are not met.

Test sequences are illustrated in below figure.



Test Duration & Frequency

The test time at the enhancement voltage shall be 60 s in case *U*m ≤ 800 kV and 300 s in case U_m > 800 kV for any test frequency up to and including twice the rated frequency, unless otherwise specified. When the test frequency exceeds twice the rated frequency, the test time in seconds of the test shall be:

120 × rated frequency / test frequency, but not less than 15 s for *U*m ≤ 800 kV

The duration of the test, except for the enhancement level, shall be independent of the test Frequency.

Test acceptance criteria

The test can only be considered valid if the measured background PD level does not exceed 50 pC at both the beginning and the end of the test. For tests on shunt reactors a background PD level higher than 50pC may be accepted.

The test is successful if all the following criteria are fulfilled:

a) No collapse of the test voltage occurs;
b) None of the PD levels recorded during the one hour period exceed 100 pC;
c) The PD levels measured during the one hour period do not exhibit any rising trend and no sudden sustained increase in the levels occur during the last 20 min of the test;
d) The measured PD levels during the one hour period do not increase by more than 50 pC;
e) The PD level measured at a voltage level of $(1.2 \times U\text{r})/\sqrt{3}$ after the one hour period does not exceed 100 pC.
f) If the criteria c) or d) are not met, the one hour period may be extended and these criteria will be considered to have been met if they are fulfilled for a continuous period of one hour.

Check points:

1. For 3-Ph Transformer/Reactor, IVPD test shall be carried out by 3-Phase supply

2. Before start of the test, all parameters / data used for PD testing and mentioned in the computer software to be checked with calibrated result of the instrument.

3. In case of doubt, change of PD measuring channel, creating PD temporarily, and check the healthiness of the measuring channel.

4. Before and after the PD test, calibration of the channel and measuring circuit to be repeated.

5. Continuous PD recording (if facility available) to be carried out for reference.

8. Temperature Rise Test on Transformer

Reference Standard:

IEC 60076-1 Edition 3.0 2011-04 Clause 11.4 Measurement of short-circuit impedance and load loss & IEC 60076-2 Edition 3.0 2011

For each cooling combination with cooler bank, tests shall be done for a minimum of 12 hours for ONAN/ONAF and 24 hours for ODAF or OFAF or ONAF2 with saturated temperature for at least 4 hours while the appropriate power and current for core and load losses are supplied.

The total testing time, including ONAN heating up period, steady period and winding resistance measurements is expected to be about 48 hours.

Gas chromatographic analysis on oil shall also be conducted before, during and after this test and the values shall be recorded in the test report. The sampling shall be in accordance with IEC 60567.

Oil sample shall be drawn before and after heat run test and shall be tested for dissolved gas analysis. Oil sampling to be done 2 hours prior to commencement of temperature rise test. Keep the pumps running for 2 hours before and after the heat run test. Take oil samples during this period. For ONAN/ONAF cooled transformers, sample shall not be taken earlier than 2 hours after shut down. The acceptance norms with reference to various gas generation rates shall be as per IEC 61181. The DGA results shall generally conform to IEC/IEEE/CIGRE guidelines.

Temperature of the cooling media

Ambient temperature

For the temperature rise test, the cooling air temperature should be in the range between 10 °C and the maximum ambient temperature 50 °C for which the transformer is designed.

At least four sensors shall be provided and the average of their readings shall be used to determine the ambient temperature for the evaluation of the test results.

Around an ONAN transformer, the ambient sensors shall be placed at a level about half-way up the cooling surfaces. The sensors shall be distributed around the tank, about 2 m away from the perimeter of tank and cooling surfaces, and protected from direct heat radiation.

For a forced-air-cooled (ONAF, OFAF, ODAF) transformer the sensors shall be placed in the air at about 0.5 m from the intake of the coolers.

Readings should be taken at regular intervals (30 minutes). Automatic continuous recording may be used.

In the case of separate cooling equipment placed at a distance of at least 3 m from the transformer tank, the ambient temperature shall be measured around the cooling equipment applying the same