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Interpretation of IS/IEC and IEEE Standards for Dielectric Type Testing of Instrument Transformers

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Abstract

The requirements of Instrument Transformers are given in standards IS16227-1, IEC 61869-1 and IEEE Std. C57.13.5. Indian Standard IS 16227-1 is in line with IEC 61869-1. Most of the utilities in India are the following IS: 16227-1/IEC 61869- 1. Many failures of the high voltage instrument transformers are being reported by the utilities. In this connection, a review of the requirements/test procedure and acceptance criteria specified by IEC 61869-1 and IEEE Std C57-13.5 for dielectric-type tests are reviewed in this paper which may help decision-making for adopting a particular standard for dielectric-type tests on instrument transformers considering Indian climatic conditions.

Keywords: Dielectric Type, Instrument Transformer, Partial Discharge Test, Radio Influence Voltage, Wet switching-Impulse Voltage

1. Introduction

Instrument transformers play a vital role in the transmission and distribution of electrical power. They are used for metering, protection and control of power flow in a power system. In a high-voltage power system, they reduce the high voltages and high currents to measurable safe values for metering and control purposes and generate signals in the event of a fault in the system to protect the system. Therefore, the Instrument transformers are very important in the reliable and economic operation of a High Voltage Power System network. The Instrument Transformers are to be suitably designed insulation design in particular, to withstand all the stresses that they are exposed to, when in operation. The requirements of Instrument Transformers are specified in standard IS: 16227, IEC 61869[1–4], IEEE Std. C57.13[5-6]. Indian Standard IS 16227 is a dual standard in line with IEC 61869. The requirements and the test procedure for dielectric tests of Instrument transformers specified in IS/IEC and IEEE standards are reviewed and compared in this paper. It is observed that the IEEE standard is more stringent for dielectric tests when compared to Indian and IEC standards.

IEEE Std. C57.13 gives the requirements for Class 1, Current and Inductively coupled Voltage Transformers. IEEE Std. C57.13.5 gives the requirements of Instrument Transformers of Class 2 and above with a nominal system voltage of 115 kV and above. IS: 16227 Part-1 and IEC 61869-1 give General Requirements of Instrument Transformers, Part-2 of these standards give specific requirements of Current Transformers while Part-3 of these standards give specific requirements of inductively coupled Voltage Transformers.

2. Tests on Instrument Transformers

As per IEEE Std. C57.13.5, the tests shall be carried out at ambient temperature range from +10 °C through +40 °C with +20 °C as the reference temperature while as per IS:16227-1/IEC 61869-1, all type tests shall be carried out at ambient temperatures between +10 °C and +30 °C. India being a tropical country, carrying out tests at ambient temperatures between +10 °C and +30 °C is difficult at all times. As per IS: 16227-1/IEC 61869-1, the Instrument transformer shall be subjected to routine tests after completion of dielectric-type tests. No sequence is specified for dielectric-type tests on current and inductively coupled transformers. The test sequence is specified only for capacitive voltage transformers. As per IEEE Std. C57.13.5, type tests are to be carried out in a sequence. Additionally, capacitance and dielectric dissipation factor

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measurements and partial discharge measurements have to be carried out before and after dielectric-type tests. For Instrument Transformers of rating greater than 345 kV, dissolved gas and water content analysis are to be carried out after type tests.

The tests on Instrument Transformers specified in IEC 61869-1 and IEEE Std C57.13.5 are as tabulated in Table 1 (type tests), Table 2 (routine tests) and Table 3 (special tests)

Table 1. List of type tests for Instrument transformers as per IEC 61869-1 & IEEE Std C57.13.5 standards

IEC 61869-1	**IEEE Std C57.13.5**
Type tests	**Type tests to be carried out in sequence**
Temperature-rise test	Dissolved gas and water content analysis
Impulse voltage test on primary terminals	Mechanical test
Wet test for outdoor transformers -Wet power-frequency voltage withstand test for Transformers of rating Um ≤ 245 kV Wet switching impulse test for	Ground shield check Verification of terminal marking and polarity Insulation resistance test on windings Resistance measurement of windings Capacitance and dielectric dissipation factor test before dielectric test
Transformers of rating Um ≥ 245 kV	
Electromagnetic compatibility tests	Applied voltage test on secondary windings Applied voltage test on neutral terminal (For VT's)
Test for accuracy	Lightning impulse voltage test on primary winding
Verification of degree of protection by enclosures	Wet power-frequency voltage withstand test for Transformers of rating Ur ≤ 345 kV - Wet switching impulse test for Transformers of rating Um ≥ 345 kV
Enclosure tightness test at ambient temperature	External RIV test Power frequency voltage withstand test Partial discharge test Capacitance and dielectric dissipation factor test after dielectric test
Pressure test for the enclosure	Temperature rise test Short time mechanical and thermal rating test Sealing test

Table 2. List of routine tests for Instrument transformers as per IEC 61869-1 & IEEE Std C57.13.5 standards

Routine tests as per IEC 61869-1	**Routine tests to be carried out in sequence as per IEEE Std. C57.13.5**
Power-frequency voltage tests on primary terminals	Ground shield check
Partial discharge measurement	Verification of terminal marking and polarity
Power-frequency voltage tests on secondary terminals and between sections	Insulation resistance test on windings
Test for accuracy	Capacitance and dielectric dissipation factor test before dielectric test
Verification of markings	Applied voltage test on secondary windings
Enclosure tightness test at ambient temperature	Inter- turn over voltage (For CT's) Applied voltage test on neutral terminal (For VT's)
Pressure test for the enclosure	- Sample lightning impulse voltage test on primary winding (For IT's of rating of Ur ≤ 230 kV) - Lightning impulse voltage test on primary winding (For IT's of rating of Ur > 230 kV)
	Power frequency voltage withstand test Partial discharge test
	Capacitance and dielectric dissipation factor test after dielectric test
	Accuracy performance test Dissolved gas and water content analysis

Table 3. List of special tests for Instrument transformers as per IEC 61869-1 & IEEE Std C57.13.5 standards

Special tests as per IEC 61869-1	Special tests as per IEEE Std. C57.13.5
Chopped impulse voltage withstand test on primary terminals	Endurance chopped wave test
Multiple Chopped impulse test on primary terminals	Internal arc test
Measurement of capacitance and dielectric dissipation factor	Seismic test
Transmitted overvoltage test	
Mechanical tests	
Internal arc fault test	
Enclosure tightness test at low and high temperatures	
Gas dew point test, Corrosion test and Fire hazard test	

3. Dielectric Type Tests

3.1 Impulse Voltage Test on Primary Terminals

As per IEC 61869-1, the Impulse test is carried with standard impulse voltage wave shape as specified in reference standard IEC 60060-1[7] for inductively coupled transformers viz. Current and Voltage Transformers. The impulse voltage is applied between the primary terminal and grounded terminal of the instrument transformer with all secondary terminals and base frame grounded. For capacitor voltage transformers, a non-standard impulse wave shape with a front time of up to 8 μs is allowed due to the high capacitance values of the test object. Generally, an impulse test is conducted by applying a reference impulse voltage between 50 to 75 % of the rating impulse withstand voltage and then applying rated withstand voltage depending upon the rating of the instrument transformer. The peak magnitude of the impulse voltage applied with wave shapes of the applied voltage and current flowing to the ground is recorded. Variations in the wave shapes recorded at reference and rated withstand levels indicate insulation failure.

For Instrument transformers of Um ≤ 245 kV, the test involves the application of 15 positive and 15 negative impulse voltage with a magnitude as applicable to the basic impulse insulation level. The test voltage shall not be corrected for prevailing ambient conditions. The transformer is deemed to have passed the test if the number of disruptive discharges does not exceed two in each polarity and no variation is observed in the wave shapes of the recorded quantities.

For Instrument transformers of Um ≥ 245 kV, the test involves the application of 3 numbers of positive and three numbers of negative impulse voltage with a magnitude as applicable to the basic impulse insulation level. The test voltage shall not be corrected for prevailing ambient conditions. The transformer is deemed to have passed the test if no disruptive discharges occur and no variation is observed in the wave shapes of the recorded quantities.

The chopped impulse voltage withstand test on primary terminals is a special test as per IEC 61869-1 and is carried out with negative impulse voltage of peak magnitude 115% of basic impulse insulation level and chopped between 2 to 5 μs. This test can be clubbed with an impulse voltage test. The standard recommends limiting the swing to the opposite polarity within 30 % of the peak value. For transformers of rating Um ≤ 245 kV, the sequence of impulse application is One full impulse, two full chopped impulses followed by fourteen full impulse voltage. For transformers of rating Um ≥245 kV, the sequence of impulse application is One full impulse, two full chopped impulses followed by two full impulse voltages. Variation in the wave shape of full wave applications before and after the chopped impulses indicates internal insulation failure.

IEEE Std. C57.13.5 specifies the Impulse test on Instrument transformers which involves the application of full wave and chopped impulse voltages. The test is conducted with impulse voltage wave shape as specified in IEEE Std. 4[8]. The test is to be conducted first with negative polarity followed by positive polarity impulse voltage application. The negative impulse voltage sequence involves one or two reduced full wave impulse voltage applications with peak magnitude between 50% to 70% of basic impulse insulation level, one full wave with basic impulse insulation level as peak magnitude, two chopped waves, fourteen full waves and one reduced wave. The chopped wave voltage application is done with 115% of the basic impulse insulation level and the minimum time to chop shall be 3 μs. Also, the standard does not permit the connection of series resistance in the chopping circuit even if the overshoot is greater than 30%. The positive impulse sequence consists of one or two reduced full wave impulse voltage, fourteen full waves and one reduced full wave application. The standard does not

permit conditioning of the insulation system by applying more than two reduced waves after the negative impulse sequence. The transformer is deemed to have passed the test if the number of external disruptive discharges does not exceed two for the sequence of each polarity and no variation is observed in the wave shapes of reduced and full wave records or between two full wave records or between two chopped records.

The test voltages specified in both IEC and IEEE standards are at standard atmospheric conditions of temperature 20 ^{0}C, atmospheric pressure of 760 mm of Hg and absolute humidity of 11 g/m^3. Normally tests conducted at laboratory conditions have to apply a correction for ambient conditions to test voltages as per IEC 60060-1 or IEEE Std. 4. However, both the standards for Instrument transformers have not specified any correction for atmospheric conditions to impulse test voltages. The IEC standard for switchgear and bushings have specified that the test voltage be corrected for the polarity of the test voltage which affects the external insulation. Instrument transformers have both internal insulation and external insulation. The housing either porcelain or composite housing of the transformer along with surrounding air forms the external insulation. The insulation strength of the external insulation is affected by the prevailing atmospheric conditions. Hence, without applying a correction to the test voltage for atmospheric conditions, there may be a possibility of different test results of lightning impulse tests conducted under different conditions.

3.2 Wet Power-Frequency Voltage Withstand Test on Primary Terminals

IEC 61869-1 specifies a wet power-frequency voltage withstand test for instrument transformers of rating Um ≤ 245 kV with a magnitude of test voltage depending upon the rating of the transformer to be tested. The duration of the test for current transformers is 60 s and for voltage transformers, the test duration depends on the frequency of the test voltage, as a high-frequency test voltage of 120 Hz and above is used to avoid the saturation of the core. The test voltage application and the wetting procedure are as per IEC 60060-1 and the test voltage shall be corrected for atmospheric conditions as specified in IEC 60060-1. The instrument transformer is deemed to have passed the test if no disruptive discharge is observed.

Similar to IEC, IEEE Std. C57.13.5, also specified this test for instrument transformers of rating Ur ≤ 245 kV with a magnitude of test voltage depending upon the rating of the transformer to be tested. The test duration and the test voltage magnitude, application of correction factor and acceptance criteria are the same as specified in IEC: 61869-1. Also, the precipitation rate of water is specified as standard procedure specified in IEEE Std. 4, which is the same as that specified in IEC: 60060-1.

3.3 Wet Switching-Impulse Voltage Withstand Test on Primary Windings

Wet switching impulse test is specified in both IEC: 61869-1 and IEEE Std C57-13.5 for instrument transformers with Um > 230 kV. The test specified is to be conducted under wet conditions with standard positive polarity switching impulse wave shape as specified in IEC: 60060-1/IEEE Std. 4. Wetting procedure is the same in both standards. The test involves the application of one or two waves between 50 to 70 % of the rated level followed by 15 switching impulses of full waves with correction applied to test voltage for ambient conditions as specified in IEC: 60060-1 and IEEE Std. C57.13.5. Only the difference between the two standards is that IEEE Std. C57.13.5 does not permit conditioning of the insulation system by applying more than two reduced waves. Both standards have specified the same acceptance criteria. The transformer is deemed to have passed the test if the number of disruptive discharges does not exceed two and no variation is observed in the wave shapes between reduced and full waves and between full waves.

3.4 External Radio Influence Voltage (RIV) Test

IEC: 61869-1 has specified the RIV test on instrument transformers of rating Um ≥ 123 kV. RIV measuring circuit and calibration shall be as specified in CISPR 18-2[9]. The test voltage is applied between one of the terminals of the primary winding and the earth of the instrument transformer. Background RIV level shall be at least 6 dB below (preferably 10 dB) the specified RIV level. The test involves the application of a prestress voltage of 1.5 Um/Ö3 for a duration of 30 s and then decreased to 1.1 Um/Ö3 within 10 s and held at this value for 30 s before recording the RIV. The instrument transformer is deemed to have passed the test if the RIV level measured at 1.1 Um/Ö3 is less than 2500 μV.

IEEE Std. C57.13.5 has specified RIV test for Instrument transformers of nominal system voltage of 115 kV and above. RIV measuring circuit and calibration shall be as specified in NEMA 107[10]. The background noise level shall not be more than half the maximum Radio Influence Voltage (RIV). The

standard has not specified any pre-stress voltage. The test voltage has to be increased to RIV extinction voltage, which is the same as RIV measuring voltage specified in IEC, and the RIV level to be measured. The instrument transformer is said to have met the requirements of the standard if the RIV level measured at RIV extinction voltage is specified in Table 4.

Table 4. RIV test voltage and acceptable limits with respect to the highest system voltage levels

Nominal system voltage (line to line), kV_{rms}	RIV test voltage (line to ground), kV_{rms}	Maximum RIV, µV
230	156	250
345	230	250
500	349	350
765	508	500

3.5 Partial Discharge Test

IEC: 61869-1 and IEEE Std. C57.13.5 applicable for instrument transformers are reviewed in respect of dielectric type tests. As per IEEE Std. C57.13.5, the type tests and routine tests on Instruments transformers are to be carried out in a sequence while IEC: 61869-1 does not specify any sequence except for the capacitor voltage transformer. Type and routine test requirements of IEC 61869-1 and IEEE Std C57.13.5 for Instrument Transformers are different while the IEC 61869-1 standard recommended performing this test as a part of the routine test to assess the failures that occurred during the dielectric type test. The preconditioning test procedure for the partial discharge measurement is similar for both standards however, the IEC standard recommended measuring the partial discharge level at $1.2Um/\sqrt{3}$ in addition to the highest system voltage of the equipment. The measured partial discharges shall be less than 5 pC at $1.2Um/\sqrt{3}$ whereas IEEE Std. C57.13.5 is not recommended to measure the partial discharges at this voltage level. The test circuit for the measurement of partial discharges is the same for both standards and the circuit shall be in line with IEC 60270 standard[11]. IEEE Std. C57.13.5 is also specified to measure the partial discharges after the completion of 60 sec duration of application of voltage. This test is categorized under type and routine tests as per IEEE Std. C57.13.5. The partial discharges measured at the prescribed extinction voltage shall be less than 10 pc and there shall not be any internal insulation failure during the measurement. The internal failure shall be confirmed with the measurement of capacitance and dielectric dissipation factor. IEEE Std. C57.13.5 relaxed to perform the partial discharge test within 30 min duration of the after completion of power frequency voltage withstand test at either the same laboratory or in a different laboratory.

4. Conclusion

The dielectric-type test procedure and acceptance criteria are more stringent in IEEE Std C57.13.5 compared to IEC 61869-1. The choice of standards for instrument transformers has to be made by utilities considering the cost factor and the importance of reliable operation of instrument transformers.

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