

Draft American National Standard

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guide for partial discharge measurement
in liquid-filled power transformers
and shunt reactors

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IEEE Trial-Use Guide for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors

1. Scope

This test procedure applies to the detection and measurement by the wide-band apparent charge method of partial discharges occurring in liquid-filled power transformers and shunt reactors during dielectric tests where applicable.

2. Object

Partial discharge measurements in transformers and shunt reactors may preferably be made on the basis of measurement of the apparent charge. Relevant measuring systems are classified as narrow-band or wide-band systems, and both systems are recognized and widely used. Without giving preference to one or the other it is the object of this document to describe the wide-band method. General principles of partial discharge measurements including the narrow-band method are covered in ANSI/IEEE Std 454-1973 [5], IEC 270-1981 [7],¹ and IEC 76-1980 [6].

3. Definitions

partial discharge. An electric discharge that only partially bridges the insulation between conductors.

apparent charge (terminal charge) q . That charge that, if it could be injected instantaneously between the terminals of the test object, would momentarily change the voltage between its terminals by the same amount as the partial discharge itself. The apparent charge should not be confused with the charge transferred across the discharging cavity in the dielectric medium. Apparent charge, within the terms of this document, is expressed in coulombs, abbreviated C. One pC is equal to 10^{-12} coulombs.

¹ The numbers in brackets correspond to those of the references listed in Section 4.

repetition rate n . The partial discharge pulse repetition rate n is the average number of partial discharge pulses per second measured over a selected period of time.

acceptable terminal partial discharge level. That specified maximum terminal partial discharge value for which measured terminal partial discharge values exceeding said value are considered unacceptable. The method of measurement and the test voltage for a given test object should be specified with the acceptable terminal partial discharge level.

voltage related to partial discharges. The phase to ground alternating voltage whose value is expressed by its peak divided by $\sqrt{2}$.

partial discharge-free test voltage. A specified voltage, applied in accordance with a specified test procedure, at which the test object should not exhibit partial discharges above the acceptable energized background noise level.

energized background noise level. Stated in pC, the residual response of the partial discharge measurement system to background noise of any nature after the test circuit has been calibrated and the test object is energized at 50% of its nominal operating voltage.

acceptable energized background noise level. Energized background noise level present during test that is considered acceptable.

bushing tap. Connection to a capacitor foil in a capacitively graded bushing designed for voltage or power factor measurement that also provides a convenient connecting point for partial discharge measurement. The tap-to-phase capacitance is generally designated as C_1 and the tap-to-ground capacitance is designated as C_2 . See: **bushing potential tap, bushing test tap, capacitance (of bushing)** in ANSI/IEEE Std 21-1976 [4].

4. References

The following publications shall be used in conjunction with this standard. When the standards referred to in this guide are superseded by a new revision approved by the relevant standards authority, the latest revision shall apply.

- [1] ANSI/IEEE C57.12.00-1980, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.²
- [2] ANSI/IEEE C57.12.90-1980, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and Guide for Short-Circuit Testing of Distribution and Power Transformers.
- [3] ANSI/IEEE Std 4-1978, IEEE Standard Techniques for High Voltage Testing.
- [4] ANSI/IEEE Std 21-1976, IEEE Standard General Requirements and Test Procedures for Outdoor Apparatus Bushings.
- [5] ANSI/IEEE Std 454-1973 (R 1979), IEEE Recommended Practice for the Detection and Measurement of Partial Discharges (Corona) During Dielectric Tests.
- [6] IEC 76-1980, International Electrotechnical Commission Publication for Power Transformers; Part 3: Insulation Levels and Dielectric Tests.³
- [7] IEC 270-1981, International Electrotechnical Commission Recommendation for Partial Discharge Measurements.

5. Measuring Instrument

The measuring instrument is composed of two main elements:

- (1) a measuring impedance unit (Z_m)
- (2) a partial discharge detector unit

5.1 Measuring Impedance Unit (Z_m). The measuring impedance unit (Z_m) is located physically close to the bushing tap or to a capacitive voltage divider and serves two main purposes:

²ANSI/IEEE publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or the Service Center, The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

³IEC publications are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, USA.

(1) It attenuates the test voltage present on the bushing tap to a safe value during the measurement of partial discharges.

(2) It matches the input impedance of the partial discharge detector unit to that of the bushing tap or capacitive voltage divider (on the low-frequency side of the detector bandwidth) to ensure measurement of partial discharges in terms of voltage pulses generated across tap-to-ground capacitance C_2 . This method insures a higher measurement sensitivity than integration of current flowing through tap-to-phase capacitance C_1 and eliminates the measurement errors introduced by the presence of C_2 as long as the product $R_m C_2$ satisfies (2) of 5.1.1.

The measuring impedance unit should be configured in such a way as to permit test voltage level monitoring and to observe the phase relationship between the test voltage and the partial discharge pulses; this technique usually helps to identify the nature of the discharges.

5.1.1 Capacitive Voltage Divider Requirements. When a bushing tap is not available, a capacitive voltage divider may be used instead by means of a high-voltage high-resonant-frequency discharge-free capacitor as C_1 and a low-voltage high-resonant-frequency capacitor as C_2 . To ensure measurement of partial discharges as voltage pulses across C_2 , the values of C_1 and C_2 should be chosen as follows:

$$(1) C_1 \geq 100 \text{ pF}$$

$$(2) C_2 \geq \frac{1}{2\pi f_L R_m} \text{ (see Note below)}$$

where R_m is the parallel resistive part of the measuring impedance unit (Z_m). The value of R_m should be provided by the manufacturer of the particular partial discharge measuring instrument that is used.

NOTE: Example: For $f_L = 70 \text{ kHz}$, $R_m = 2.5 \text{ k}\Omega$ and $C_1 = 100 \text{ pF}$

$$C_2 = \frac{1}{6.28 \cdot 70\,000 \cdot 2500} = 909 \text{ pF}$$

a value of 1000 pF may be chosen for C_2 since $1000 \text{ pF} > 909 \text{ pF}$ and $\frac{1000}{100} = 10 < 15$.

$$(3) \frac{C_2}{C_1} \leq 15$$

5.2 Detector Unit Characteristics. The detector unit should be of the wide-band type. The charac-

teristics of the detector unit are defined by the following parameters.

5.2.1 Lower and Upper Cut-Off Frequencies f_L and f_H . The lower and upper cut-off frequencies f_L and f_H , respectively, are the frequencies at which the response to a constant sinusoidal input voltage has fallen by 6 dB from the maximum value occurring inside the recommended bandwidth that should be located in the frequency range of 70–300 kHz.

To minimize the effect of winding attenuation on partial discharge signals and at the same time to provide adequate rejection of silicon controlled rectifier generated noise present in manufacturing plants, f_L should be located in the range from 70–120 kHz. An upper limit on f_H of 300 kHz is usually necessary to prevent broadcast stations from interfering with the partial discharge measurement.

5.2.2 Filter Characteristics. The filter characteristics of the partial discharge detection circuit should be such as to provide attenuation of at least 40 dB at 25 kHz, at least 60 dB at 15 kHz and below, and at least 20 dB at 500 kHz and above, with respect to the response at the geometric mean frequency (f_C) of the system pass-bandwidth, which is given by

$$f_C = (f_L \cdot f_H)^{1/2}$$

5.2.3 Bandwidth Δf . The bandwidth Δf is defined as:

$$\Delta f = f_H - f_L$$

The bandwidth should not be less than 100 kHz. A wider bandwidth provides a response whose level is less sensitive to the location of a partial discharge pulse along a transformer winding and is therefore more uniform. A bandwidth wider than 100 kHz is preferable, but may lead to background noise problems.

5.2.4 Linearity. The instrument circuit, display unit, and discharge meter should be linear within $\pm 10\%$ of full scale in the range of 50–1000 pC.

5.2.5 Display Unit. The display unit should be a cathode ray oscilloscope with a linear, rectangular, or elliptical time-base. In all cases, the time-base should be synchronized to the test voltage and at least 98% of a full cycle should be displayed. The phase relationship of the partial discharges to the test voltage should be easy to determine. A suitable graticule should be provided.

5.2.6 Discharge Meter Characteristics. A discharge meter should be provided on the instrument or a suitable output for it should be made available. It should be established that the signal on this output tracks the signal appearing on the display within $\pm 5\%$ over the usable display range.

The discharge meter should be of the true peak type. Its charging time to 95% should be $1/(2 f_H)$ second⁴ or shorter. Its discharge time constant or the time taken for a reading to decay to 36.8% of its initial value should be between 100 ms and 750 ms.

5.2.7 Basic Sensitivity Requirement. The minimum partial discharge level that can be detected is determined by one of two factors: the partial discharge detector basic sensitivity, which depends on the amplifier noise level, or the test circuit background noise, which is either induced or conducted. The partial discharge detector basic sensitivity should be high enough that the measurement sensitivity during actual tests will be usually limited by the test circuit background noise alone and not by the amplifier noise of the detector.

5.3 Partial Discharge Detector Basic Sensitivity Test. To ensure that the partial discharge detector used has sufficient basic sensitivity, the test circuit shown in Fig 1 may be used. The circuit formed by C_T , C_1 , and C_2 represents a fairly bad case of bushing tap attenuation combined with an above average transformer equivalent capacitance. Any type of low-inductance, low-loss capacitors could be used, but mica capacitors are recommended. This test need only be performed when acquiring a new partial discharge detector and at fixed time intervals after that (for example, every six months or after the equipment is either repaired or modified).

A transformer equivalent internal capacitance is simulated by the 8000 pF capacitor (C_T). The bushing tap connection is simulated by capacitors of 100 pF (C_1) and 1500 pF (C_2). The measurement impedance is connected to the junction of C_1 and C_2 . The cable normally used for testing connects the measurement impedance to the detector. The sensitivity should be such that when 25 pC are injected into the 8000 pF capacitor, the peak amplitude of the signal appearing on the detector screen is at least twice the value of the amplifier noise level.

⁴ f_H is defined in 5.2.1.

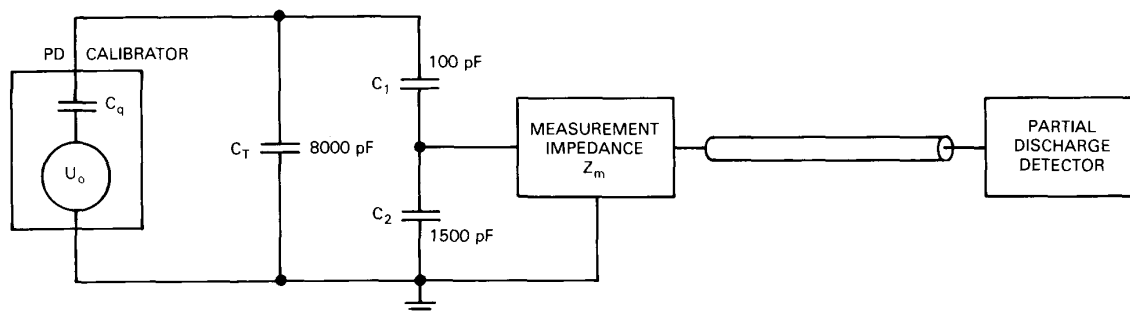


Fig 1
Partial Discharge Detector
Basic Sensitivity Test Circuit

6. Calibrator Characteristics

The calibrator comprises a pulse generator in series with a small capacitor (C_q) of known value. The generator and the capacitor may be placed in the same box or may be connected together via a properly terminated coaxial cable of sufficient length to permit calibration from the control room. The calibrator may be either line or battery powered.

Capacitor (C_q) should be placed as near as possible to the bushing. Additional information on calibration can be found in ANSI/IEEE Std 454-1973 [5].

6.1 Calibrating Capacitor Value (C_q). The capacitance of the calibrating capacitor should be no more than $0.1 C_t$, and should not exceed 150 pF or be less than 15 pF. Its value should be known with a precision of $\pm 3\%$. C_t is the equivalent capacitance at the test object terminal where the calibration pulse is injected. A method of measuring C_t is given in 8.3.

6.2 Pulse Generator Rise Time and Decay Time. The rise time of the pulse should be less than $0.1 \mu\text{s}$ from 10% to 90% of peak value. A decay time to 50% of peak value of not less than $100 \mu\text{s}$ will usually be suitable.

6.3 Pulse Generator Amplitude (U_o). The maximum amplitude (U_o) of the pulse generator output should be such that the product $U_o \cdot C_q$ can be made equal to at least 1000 pC.

6.4 Pulse Generator Output Impedance (Z_o). In the case that the pulse generator and the cali-

bration capacitor are connected together via a coaxial cable, then the output impedance of the generator should be the same as the characteristic impedance of the cable used.

6.5 Calibrator Output Level Adjustment. The amount of charge injected (q_o) will be determined using the formula $q_o = U_o \cdot C_q$. The pulse generator should either have a known calibrated output level or its output level should be monitored. A suitable output level adjustment in the form of a calibrated potentiometer or a calibrated step attenuator should be provided. The adjustment range should extend over at least two decades and a minimum of three adjusting steps per decade should be provided. A calibrated adjustment is not required if the generator output level is monitored. Adjusting its output level should not affect the pulse generator equivalent source impedance.

6.6 Pulse Generator Frequency. The pulse generator frequency should be the same as the power voltage frequency or the test voltage frequency $\pm 20\%$. Calibration pulse rate will be twice the pulse generator frequency and the pulse polarity will alternately be positive and negative. The approximate pulse generator frequency should be recorded if different from the power voltage frequency.

7. Test Circuits

7.1 Transformer Test Circuit. Figure 2 shows a typical test circuit for partial discharge measurement on a single-phase transformer. The transformer is energized through its low-voltage