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

Sponsor

**Transformers Committee
of the
IEEE Power Engineering Society**

Approved December 5, 1991

**IEEE Standards Board**

**Abstract:** 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 are covered. This standard covers the measuring instrument, calibrator characteristics, test circuits, calibration procedure, and partial discharge measurement during induced-voltage tests.

**Keywords:** Liquid-filled transformer, partial discharge, shunt reactor

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# Foreword

(This foreword is not a part of IEEE C57.113-1991, IEEE Guide for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors.)

As a long-term trend beginning in the 1950's, the combination of lower insulation levels and higher system voltages brought about increased interest in the detection and measurement of partial discharge activity within the insulation structure of a transformer. As the name implies, a partial discharge is the breakdown of a small section of the insulation path and is undesirable because of deterioration of the insulation and formation of gas that may accumulate at a critical stress area. In general, electrical measurements of partial discharge activity should be made on the basis of the resultant momentary change in the voltage at the terminals of the transformer. Such change may be expressed as a voltage change or, by suitable calibration, as an apparent charge. An apparent charge is that charge in coulombs that, if injected between terminals, would cause the same voltage change as that resulting from the partial discharge.

The initial efforts at measuring partial discharge levels, particularly in regard to acceptance criteria between the user and the manufacturer, utilized NEMA 107-1940, which provided radio influence voltage (RIV) readings in microvolts (μV) on a quasi-peak basis at or near 1.0 MHz. Later, this approach was modified by using the bushing tap instead of a separate coupling capacitor and eventually was included as the standard method of measuring partial discharges in transformers in IEEE C57.12.90-1980.

Meanwhile, however, the industry has recognized that measuring partial discharges in terms of apparent charge has many advantages over the RIV approach. Two advantages are (1) the differences in internal capacitance between transformers are compensated by the calibration procedure, thus the measured level is more closely related to the true level of the partial discharge, and (2) a generally lower specified measuring frequency provides for less attenuation of partial discharge located deep within the transformer insulation structure.

The problems that have delayed a change to apparent charge measurements as an industry standard have been that (1) the RIV approach has had the advantage of being based on a recognized and established circuit, and (2) the industry has gained a great deal of experience with the circuit including appropriate acceptance levels. To take advantage of the apparent charge approach required first that a standard circuit be developed. This was undertaken by the Task Force for the Measurement of Apparent Charge within the IEEE Transformers Committee. This document is the result of that effort. Apparent charge measurements may be made on a wide-band or narrow-band basis, as 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 IEC 270 (1981), IEC 76-3 (1980), and IEEE Std 454-1973. The Task Force that prepared this document hopes and expects that users and manufacturers of transformers will make apparent charge measurements on new transformers so that an adequate base of experience can be developed and so that the apparent charge method will eventually become the standard method of measuring partial discharge within transformers. This document was developed by the Task Force for the Measurement of Apparent Charge and the Working Group on Partial Discharge Tests in Transformers of the IEEE Transformers Committee.

At the time that this standard was completed, the Working Group on Partial Discharge Tests on Transformers had the following membership:

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CLAUSE PAGE

# IEEE 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. Purpose

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. 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 IEEE Std 454-1973 [7][1], IEC 270 (1981) [2], and IEC 76-3 (1980) [1].

## 3. References

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

[1] IEC 76-3 (1980), Power transformers; Part 3: Insulation levels and dielectric tests.[2]

[2] IEC 270 (1981), Partial discharge measurements.

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[1] The numbers in brackets correspond to those of the references in Section 3

[2] IEC publications are available from IEC Sales Department, Case Postale 131, 3 rue de Varembé, CH 1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[3] IEEE C57.12.00-1987, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers (ANSI).[3]

[4] IEEE C57.12.90-1987, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers; and Guide for Short-Circuit Testing of Distribution and Power Transformers (ANSI).

[5] IEEE Std 4-1978, IEEE Standard Techniques for High Voltage Testing (ANSI).

[6] IEEE Std 21-1976, IEEE Standard General Requirements and Test Procedures for Outdoor Apparatus Bushings (ANSI).

[7] IEEE Std 454-1973 (Withdrawn), IEEE Recommended Practice for the Detection and Measurement of Partial Discharges (Corona) During Dielectric Tests.[4]

## 4. Definitions

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

**apparent charge (terminal charge), *q*:** A 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 $10^{-12}$ C.

**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:** The 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,* and *capacitance (of bushing)* in IEEE Std 21-1976 [6].

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[3] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

[4] This standard has been withdrawn. A photocopy is available from the IEEE Service Center.

# 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:

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 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 ensures 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 such as $C_1$, and a low-voltage high-resonant-frequency capacitor such 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) $C_1 \geq 100$ pF

2) $C_2 \geq \dfrac{1}{2\pi f_L R_m}$ (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 $f_L = 70$ kHz, $R_m = 2.5$ kΩ and $C_1 = 100$ pF

   $$C_2 = \frac{1}{6.28 \cdot 70\,000 \cdot 2500} = 900 \text{ pF}$$

   A value of 1000 pF may be chosen for $C_2$ since 1000 pF ≥ 909 pF and 1000/100 = 10 <15.

3) $\dfrac{C_2}{C_1} \leq 15$

## 5.2 Detector Unit Characteristics

The detector unit should be of the wide-band type. The characteristics 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 amplitude sinusoidal input voltage has fallen by 6 dB from the maximum output value occurring inside the recommended bandwidth.

The frequency, $f_L$, should be located at 70 kHz or below. A value of $f_L$ that is as low as possible is desirable in order to help minimize the effect of winding attenuation on partial discharge signals but could lead to background noise problems. However, a value of 70 kHz for $f_L$ is still acceptable from the point of view of signal attenuation and is usually necessary to provide sufficient rejection of SCR generated noise present in manufacturing plants and/or harmonics from the test voltage source. An upper limit on $f_H$ of not higher than 300 kHz usually helps to prevent broadcast stations from interfering with the partial discharge measurement.

### 5.2.2 Filter Characteristics

To help prevent background noise problems, 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, $\Delta f$

The bandwidth, $\Delta f$, 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 that is 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 ±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 ±5% over the usable display range.

The discharge meter should be of the true peak type. Its charging time to 95% should be $1/2f_H$ s or shorter[5]. 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).

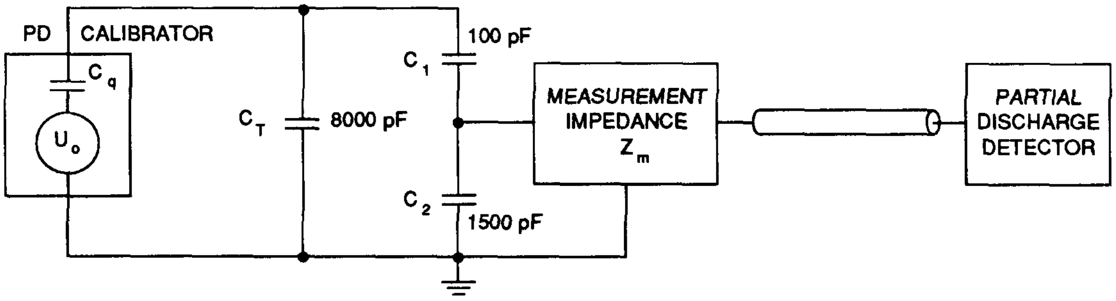

**Figure 1—Partial Discharge Detector Basic Sensitivity Test Circuit**

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.

## 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.

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[5] $f_H$ is defined in 5.2.1

Capacitor $C_q$ should be placed as near as possible to the bushing. Additional information on calibration can be found in 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 ±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 µs from 10% to 90% of peak value. A decay time to 50% of peak value of not less than 100 µs 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 in which the pulse generator and the calibration capacitor are connected together via a coaxial cable, 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 ±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

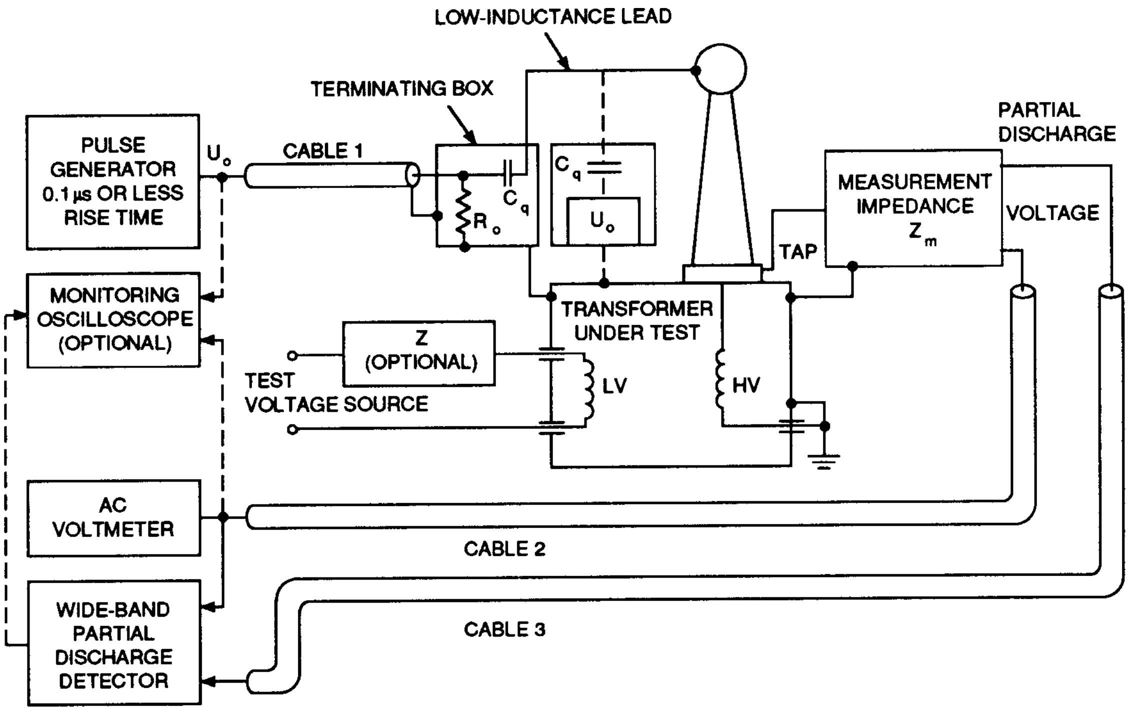
Fig 2 shows a typical test circuit for partial discharge measurement on a single-phase transformer. The transformer is energized through its low-voltage winding. With some test voltage sources, the filter, $Z$, may be required to reduce the interference coming from the source. A measurement impedance, $Z_m$, is connected to the bushing tap using low-inductance leads as short as possible. A shield of suitable size is mounted on the bushing end to eliminate air corona that would interfere with the measurement of internal discharges. The measurement impedance, $Z_m$, is connected to a wide-band partial discharge detector and to a suitable ac voltmeter.

Some partial discharge detectors may not have a built-in display. In such cases, an oscilloscope may be used for this purpose. The same oscilloscope may also be used during calibration.

Partial discharge measurement should be performed on all high-voltage winding terminals of 115 kV class and above. Low-voltage winding terminals of less than 115 kV class and neutral terminals are not usually measured and may not be equipped with capacitance tap bushings. The low-frequency test circuit used during partial discharge tests should be in accordance with IEEE C57.12.90-1987 [4], which requires simulations of the actual operating configuration.

## 7.2 Shunt Reactor Test Circuit

Fig 3 shows a typical test circuit for partial discharge measurement on a shunt reactor. The circuit is the same as the one for a power transformer except that the test voltage is usually applied from a step-up transformer. A filter, *Z*, may be required on the high-voltage (HV) side of the step-up transformer to reduce the level of the interference coming from the test voltage source. This filter may also be positioned on the low-voltage side of the step-up transformer, but it is better to place it on the high-voltage side because it keeps the internal capacitance of the step-up transformer from appearing in parallel with the reactor. This shunting capacitance reduces the partial discharge measurement sensitivity.



**NOTES: (1) A single coaxial cable may replace Cables 2 and 3 when a partial discharge detector designed to use a single cable is used.**

**(2) The injected charge is taken to be the product $U_o \cdot C_q$.**

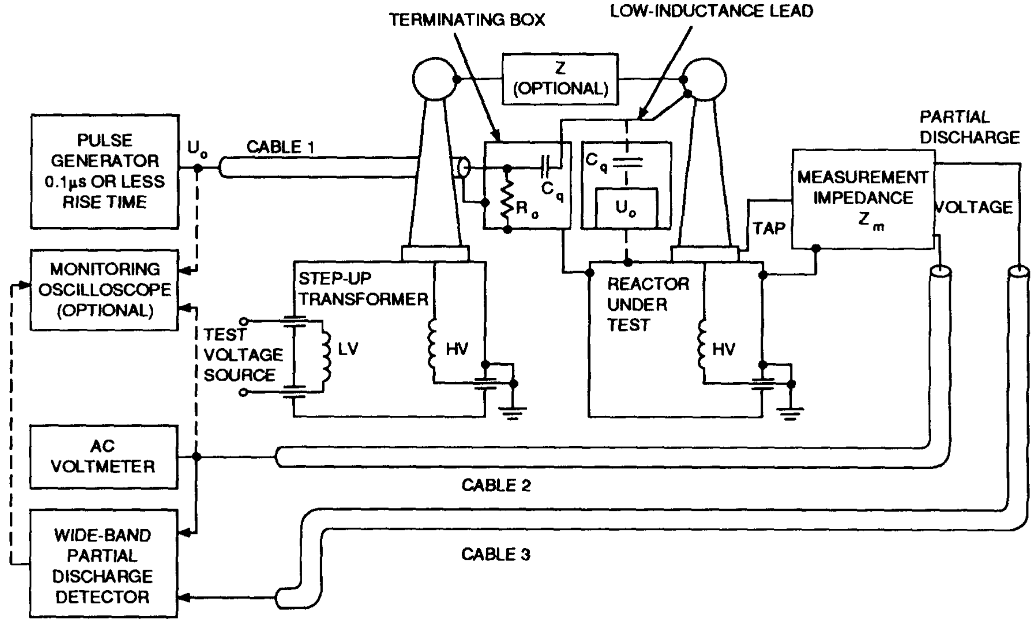
**Figure 2—Test Circuit for the Measurement of Partial Discharges in Power Transformers**

## 8. Calibration Procedure

Before calibration is started, all equipment must be set up exactly as it will be during the induced voltage test. This includes the partial discharge (PD) detector and its measuring impedance unit. If the device to be tested is a three-phase transformer, PD calibration must be performed at each terminal to be measured, in turn, while making sure that the PD detector is always connected to the corresponding measuring impedance unit. Once the test circuit has been set up and calibrated, no further changes to the test circuit or instrumentation settings are permitted.

### 8.1 Considerations Regarding Test Voltage

Wide-band partial discharge detectors need a sample of the test voltage to synchronize their display. The most convenient place to obtain this signal is from the measurement impedance box or power separation filter that is connected to the bushing tap (see Fig 2). To make sure that the bushing tap potential will not exceed a value that is safe for both the measuring impedance unit and the partial discharge detector, the bushing tap potential attenuation factor, with the partial discharge detector connected, should be measured or calculated when the total capacitance of the partial discharge measuring system and that of $C_1$ are known. Once this factor is obtained, the highest bushing tap potential that will be attained during the actual test can be calculated. The maximum value reached will be equal to the maximum test voltage expected to be reached during test multiplied by the value of the bushing tap potential attenuation factor. This factor must be small enough to prevent the tap voltage from exceeding a safe value for the PD measuring system during testing.



**NOTES: (1) A single coaxial cable may replace Cables 2 and 3 when a partial discharge detector designed to use a single cable is used.**

**(2) The injected charge is taken to be the product $U_o \cdot C_q$.**

**Figure 3—Test Circuit for the Measurement of Partial Discharges in Reactors**

### 8.1.1 Direct Method of Bushing Tap Circuit Ratio Measurement

The dividing ratio of the bushing tap is the reciprocal of the potential attenuation factor and may be measured directly at the test voltage frequency by means of a suitable ratio bridge. The value expected will usually be in the range of 1000–50 000, depending on the partial discharge detector model used and the value of bushing capacitance, $C_1$.

### 8.1.2 Indirect Method of Bushing Tap Circuit Ratio Measurement

To measure the bushing tap ratio with this method, a voltmeter with an impedance higher than 10 kΩ must first be connected in parallel with the voltage input of the partial discharge detector or to some other terminal on it provided for this purpose. Then, one of the devices specified in IEEE Std 4-1978 [5] for alternating voltage measurement is connected to the HV bushing and to an appropriate voltage reading device. The transformer is then energized at some convenient low value of voltage at the test frequency. The voltage measured by the IEEE Std 4-1978 [5] method is then compared with the reading of the voltmeter connected to the PD measurement system, and the bushing tap ratio may then be calculated by dividing the two values thus obtained.

### 8.1.3 Test Voltage Measurement

It is convenient to use the voltmeter connected to the partial discharge measurement system for test voltage measurement. The test voltage value is then given by the voltmeter reading multiplied by the tap ratio. When this method is used, calibration shall be in accordance with requirements of IEEE Std 4-1978 [5]. Only HV terminals actually required for the determination of the test voltage need be calibrated.

## 8.2 Partial Discharge Calibration

The equipment must be set up exactly as it will be during the induced voltage test. Partial discharge calibration is performed by injecting a known charge between the top of the high-voltage bushing and the tank. Either a portable battery powered calibrator or a pulse generator along with a terminating box may be used (see Fig 2). The advantage of the pulse generator is that the calibration level can be adjusted from the control room and no battery is required. The portable calibrator or the terminating box should be placed as close as possible to the HV terminal in order to keep the connecting lead as short as possible. At least three separate charge levels should be injected to ensure that the PD measuring circuit is linear over the range of interest. For example, for an acceptance level of $N$ pC, the three levels injected would be $N$ pC, $2N$ pC, and $N/2$ pC. The signal amplitude read on the discharge meter should not deviate by more than 10% from a straight line for allvalues injected. In order for a partial discharge detector to read directly in pC, it is necessary to establish a relationship between the amount of charge injected at calibration and the indication of the discharge meter This is most easily done by injecting a known calibration level into the bushing and then adjusting the sensitivity control on the detector to get an exact ratio between the value injected and the resulting reading of the discharge meter. Calibration should be made on each bushing on which PD are to be measured during the test.

## 8.3 Measurement of the Equivalent Terminal Capacitance, $C_t$

$C_t$ can be measured in the following manner:

1) With all the equipment configured exactly as it will be during the test, inject approximately 500 pC into the terminal for which the value of $C_t$ is to be found.
2) Note the reading produced on the PD detector connected to this terminal and call this reading $M_1$.
3) Put an external high-resonant-frequency capacitor, $C_m$, of a value of 100 pF in parallel with the same terminal using low-inductance leads, note the new reading of the PD detector, and call it $M_2$. If $M_2$ is within 5% of $M_1$, this indicates that the terminal capacitance is fairly high. A 1000 pF capacitor should then be used instead for $C_m$ to obtain a better measurement accuracy.
4) The value of $C_t$ may then be calculated by applying the following formula:

$$C_t = C_m \cdot \frac{M_2}{M_1 - M_2} - C_q$$

where

$C_t$ = equivalent terminal capacitance in pF

$C_m$ = 100 pF or 1000 pF, ±3%

$C_q$ = calibrating capacitor value in pF

$C_t$ should be equal to at least ten times $C_q$ as stated in 6.1.

## 9. Partial Discharge Measurement During Induced Voltage Tests

Partial discharge measurements are normally performed during the induced voltage tests. The duration of the test, the time sequence for the application of test voltage, connection and grounding of windings, and the test voltage values should be as specified in IEEE C57.12.90-1987 [4] and IEEE C57.12.00-1987 [3]. Further information on partial discharge measurement may be found in IEEE Std 454-1973 [7].

### 9.1 Test Procedure

The voltage should first be raised to 50% of the rated voltage value of the test object, and the energized background noise should then be measured and recorded on each measured terminal. The acceptable energized background noise level should not exceed 50% of the acceptable terminal partial discharge level and, in any case, should be below 100 pC.

The voltage is then raised to the one-hour test level and held there long enough to verify that there are no partial discharge problems. The voltage is then raised to the enhancement level and held for 7200 cycles. The voltage is next reduced directly back to the one-hour test level and held for 60 min or more.

During the 60 min period, partial discharge measurements should be made at 5 min intervals on each terminal of 115 kV class and above.

In terms of interpretation of partial discharge measurements, the results should be considered acceptable and no further partial discharge tests required if

1) The magnitude of the PD level does not exceed the acceptable terminal partial discharge level.
2) The increase in PD levels during the 60 min period does not exceed 39% of the acceptable terminal partial discharge level.
3) The PD levels during the 60 min period do not exhibit any steadily rising trend and there is no sudden, sustained increase in levels during the last 20 min of the tests.

If the PD level rises above the specified limit for a significant time and then returns below this level again, the test may continue without interruption until acceptable readings have been obtained for 60 min. Occasional high readings should be disregarded. As long as no breakdown occurs, and unless very high levels of partial discharge are sustained for a long period of time, the test is regarded as nondestructive. A failure to meet the partial discharge acceptance criteria should not therefore warrant immediate rejection, but should lead to consultation between purchaser and manufacturer about further investigations.

# Annex

# (Informative)

(This appendix is not part of IEEE C57.113-1991, IEEE Guide for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors, but is included for information only.)

## A1 Partial Discharge Recognition

One of the greatest advantages of the wide-band method is the ease with which the results can be displayed on a cathode ray oscilloscope, which means that the PD signal can be observed in terms of the phase of the applied test voltage. This is of great help in determining whether or not the discharges originate inside the test object. The pulse polarity can also be identified, and pulses may be counted and sorted according to their amplitude or polarity, or both. Digital processing of PD signals by computer is also possible.

Examples of the most common oscillographic patterns encountered during partial discharge tests on large transformers appear in Fig A1 (see also [B95] [6] and [B62] ). Fig A1(a) represents the case of air corona on the high-voltage electrode. Fig A1(b) is for air corona on a point on the ground side. Such corona can usually be eliminated by selecting a high-voltage electrode of larger diameter for case (a) and by covering protrusions on and around the transformer with rounded metallic shields or semiconductive material, such as rubber, for case (b). These corona discharges are usually very large, but it should be pointed out that they appear only during one half-cycle of the applied voltage. Small discharges are present on the other half-cycle but are so low in amplitude that they usually cannot be observed.

The case shown in Fig A1(c) occurs when ungrounded metallic objects are present on or near the transformer under test. The obvious solution in this case is to remove as many of the loose objects from the test area as possible and ground the rest, especially metallic fences.

The case shown in Fig A1(d) is the result of a bad ohmic contact, usually inside the transformer, although it could also be from the connections outside. Note that, in this case, the discharges occur on both sides of and at the zero-crossings of the test voltage.

Figs A1(e) and A1(f) represent PDs occurring within the insulation structure of a transformer. They are usually present on the increasing voltage slope of both half-cycles and do not normally cross the voltage peaks; although they may extend down to zero-crossings. There is usually a fair amount of hysteresis present, but excessive hysteresis and rapidly decreasing inception voltage are indicative of PDs in gas bubbles. Fig A1(e) represents PDs in oil-paper insulation or in gas bubbles. Fig A1(f) represents creeping discharges, which are usually higher in amplitude but less numerous than those in case (e).

Figs A1(g) and A1(h) represent two cases of external interference. The first is typical of thyristor interference, the pulses being equally spaced and of roughly the same amplitude. Since the test voltage frequency for transformers is usually different from the power frequency, the pulses are not synchronized. The number of pulses appearing during one cycle of the test voltage depends on the ratio of its frequency to that of the power system and on the particular design of the equipment producing the interference. Usually a range from two to six pulses is seen, even though fewer than two pulses may be present at every cycle. This is due to the fact that the eye tends to see many superposed cycles at the same time.

Fig A1(h) is typical of a periodic signal with a frequency falling inside the bandwidth of the PD detector. One such source of interference in North America is the navigational system, LORAN C, operating at 100 kHz. Other than the fact that they are not usually synchronized to the test voltage, interference signals are not usually dependent on the test-

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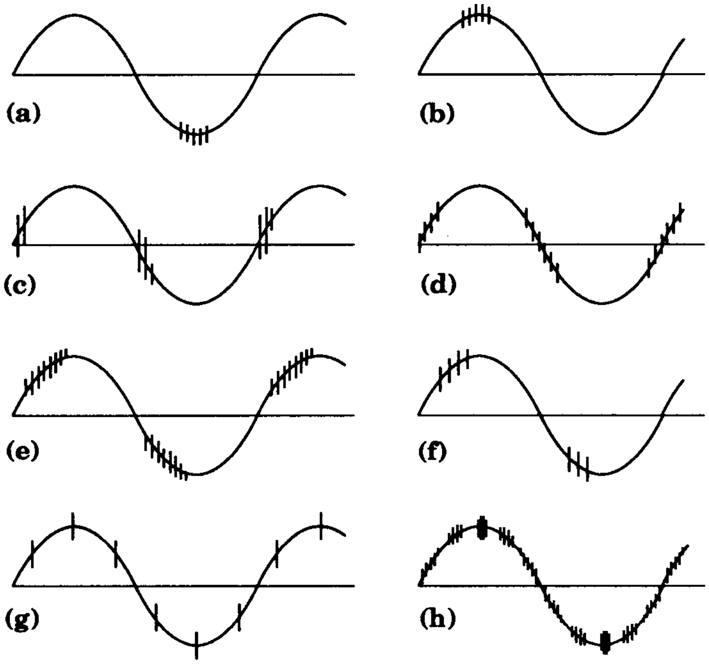
[6] The numbers in brackets, when preceded by the letter “B,” correspond to those of the bibliographic entries in Section A2.

voltage level and do not normally disappear when the test voltage is lowered as PD signals do. In normal situations, these characteristics suffice to identify the signals as interference.



**Diagrams from (a) to (f) are after Kraaij et al. [B62]:**

**(a) Corona discharges on a high-voltage electrode**
**(b) Corona discharges on a grounded point**
**(c) Unearthed conductive object near or inside the test object**
**(d) Noise due to a bad contact***
**(e) PDs in oil-paper insulation or gas bubbles**
**(f) Surface (creeping) discharges in oil**
**(g) Interference due to thyristor pulses**
**(f) Interference due to a modulated periodic signal**

***This pattern may also occur in some type of internal discharges.**

**Figure A1 —Examples of the Most Common Discharge and Interference Patterns Encountered During Partial Discharge Tests on Power Transformers**

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