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IEEE Guide for Partial Discharge Measurement in Power Switchgear

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Abstract: This guide defines methods of measuring partial discharges that may occur in energized power switchgear apparatus in flaws, voids, and interfaces of non-self-restoring insulation that may then result in dielectric failure of the switchgear. Guidance on instrumentation and calibration technique is also given.
Keywords: calibration, corona, dielectric tests, partial discharge, switchgear

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Introduction

(This introduction is not a part of IEEE Std 1291-1993, IEEE Guide for Partial Discharge Measurement in Power Switchgear.)

A partial discharge is a localized dielectric breakdown of a section of dielectrically stressed insulation path that occurs generally in voids, cracks, or interfaces within that insulating system or from the sharp edges of energized apparatus parts. These discharges may or may not exhibit a glow discharge, based on location and the intensity of these discharges. The classic form of corona is usually denoted by a visual glow or dielectric breakdown of the insulating air or gas around overstressed conductors or the sharp edges of energized apparatus parts. Radio influence voltage (RIV) measurements are made to determine the extent of radio interference generated by this corona and the corrective measures that should be made. This corona, when associated with the self-restoring insulation of the apparatus, may not necessarily contribute to insulation damage.

In contrast, partial discharges, localized dielectric breakdowns of a section in an insulation path where the discharges occur in voids, cracks, or interfaces of solid and/or solid/gas dielectrics, are undesirable because of the possible deterioration of that insulation with the formation of ionized gas due to this breakdown that may accumulate at or in a critical stress region. This generally involves non-self-restoring insulation that may be subject to permanent damage.

Partial discharge measurements may be made on the basis of the resultant momentary change in the voltage at the terminals of the device. Such a change may be expressed as a voltage change [radio influence voltage (RIV) in microvolts] or by calibration as an apparent charge. When injected between the terminals of the device, this apparent charge, measured in picocoulombs, would cause the same voltage change as that resulting from the partial discharge.

The initial efforts at measuring partial discharge levels on apparatus to provide an acceptance criteria between user and manufacturer utilized NEMA 107-1987, Methods of Measurement of Radio Influence Voltage (RIV) of High-Voltage Apparatus. However, it has been determined that this narrow frequency band measuring system has limitations and that measuring partial discharges in terms of apparent charge has many advantages over that of the RIV approach. These advantages include:

a) The internal and stray capacitance of differing switchgear and/or components are accounted for by the calibration procedure. Thus, the measured value is related to the partial discharge level.
b) The partial discharge measurements are, in most cases, not affected by local radio broadcast signals. It should be noted that apparent charge measurements may be made on either a wide-band or narrow-band basis. Both methods are included in this document.

In developing this guide, the working group followed the basic instrumentation, calibration, techniques described in IEEE C57.113-1991, IEEE Guide for Partial Discharge Measurements in Liquid-Filled Power Transformers and Shunt Reactors, to the extent that they could be adapted to partial discharge testing in power switchgear. This commonality should provide for an efficient application of laboratory test equipment and a better understanding of partial discharge testing on various types of apparatus.

It is expected that by the application of this guide, both users and manufacturers of switchgear and components will utilize the apparent charge measurements on their devices such that an adequate base of experience can be developed for the evaluation of this equipment.

This guide was prepared by the Partial Discharge Working Group of the ADSCOM Subcommittee of the IEEE Switchgear Committee, which consisted of members from the High-Voltage Circuit Breaker; High-Voltage Switches, Reclosers, and Sectionalizers; High-Voltage Fuses; and Switchgear Assemblies Subcommittees.

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CLAUSE PAGE

IEEE Guide for Partial Discharge Measurement in Power Switchgear

1. Scope

This test procedure applies to the detection and measurement of partial discharges (corona) occurring in switchgear equipment and/or components during dielectric tests, where applicable. The following types of equipment are included: high-voltage fuses, high-voltage switches, high-voltage circuit breakers, reclosers and sectionalizers, and switchgear assemblies.

2. Purpose

Partial discharge measurement in switchgear equipment can 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. General principles of partial discharge measurement, including both broad and narrow-band methods, are covered in IEEE Std C57.113-1991 and IEC 270 (1981).[1]

The use of partial discharge testing as a tool to assess the integrity of insulation systems requires a great deal of judgment. It should not be used as a general, all inclusive test such as the 60 Hz and impulse dielectric tests. Although it may be appropriate to perform a partial discharge test on an entire device for some types of equipment, practice tends to indicate that it should be used to evaluate component parts of apparatus. If partial discharges on apparatus are associated with self-restoring insulation, such as air, and do not affect nearby non-self-restoring insulation materials, then relatively high levels of partial discharge may be acceptable if the resultant radio influence voltage (RIV) level and the audible discharge noise level is acceptable, see NEMA 107-1987. It may be necessary to temporarily isolate areas of high partial discharge so that other more critical areas involving non-self-restoring insulations may be more carefully evaluated. Immersing components in oil or SF_6 gas is an accepted means of isolating noncritical areas so that critical areas can be tested. Thus, partial discharge testing is used more effectively to evaluate isolated areas of high dielectric stress that are judged to have the probability of deterioration of their non-self-restoring insulation.

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[1] Information on references can be found in clause 3.

3. References

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

IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing.[2]

IEEE Std C57.19.00-1991, IEEE Standard General Requirements and Test Procedures for Outdoor Apparatus Bushings (ANSI).

IEEE Std C57.113-1991, IEEE Guide for Partial Discharge Measurements in Liquid-Filled Power Transformers and Shunt Reactors.

IEC 270 (1981), Partial discharge measurements.[3]

NEMA 107-1987, Methods of Measurement of Radio Influence Voltage (RIV) of High-Voltage Apparatus.[4]

4. Definitions

4.1 partial discharge (PD), *q*: A localized electric discharge resulting from ionization in an insulation system when the voltage stress exceeds the critical value. This discharge partially bridges the insulation between electrodes.

4.2 apparent charge (terminal charge): A charge that, if 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 over-stressed insulation in the dielectric medium. Apparent charge within the terms of this document is expressed in picocoulombs, which is abbreviated as pC (10^{-12} Coulombs).

4.3 repetition rate, *n*: The average number of partial discharge pulses per second measured over a selected period of time.

4.4 acceptable terminal partial discharge level: The specified maximum terminal partial discharge level for which measured terminal partial discharge values exceeding this value are considered unacceptable. This level may be defined by the appropriate apparatus test standard or may be a level agreed to by the user and manufacturer. The method of measurement and the test voltage for a given test object must be specified with respect to the acceptable terminal partial discharge level.

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

4.6 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.

4.7 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 energized at 100% of the test voltage without the test object connected.

4.8 partial discharge inception voltage: The voltage that should be recorded on the device or system under test when raised to a point where the PD signal rises above the energized background noise level.

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[2] 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.

[3] 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.

[4] NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Washington, DC 20037, USA.

4.9 partial discharge extinction voltage: The voltage at which partial discharge (corona) is no longer detectable on instrumentation adjusted to a specified sensitivity, following application of a specified higher voltage.

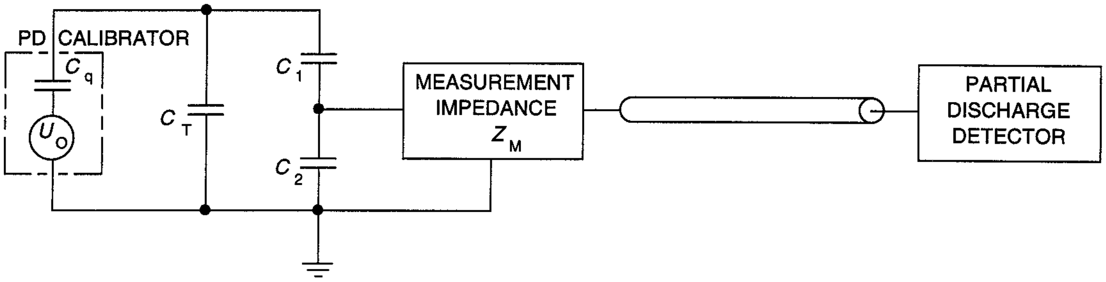
4.10 acceptable energized background noise level: Energized background noise level present during test that does not exceed 50% of the acceptable partial discharge level of the test specimen. Spurious noise, however, can exceed this level if identified as not emanating from the specimen. This may require extending the period of voltage application.

4.11 bushing tap: A 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 C57.19.00-1991.

5. Test circuits

5.1 Partial discharge detector basic sensitivity test

Figure 1 is a schematic of the basic PD test circuit that, for simplicity, omits the high-voltage source. C_1 is a high-voltage capacitor that provides for coupling the partial discharges generated by the specimen (C_T) to the measurement circuit. C_1 and C_2 function as a voltage divider that separates the high-voltage circuit from the low-voltage measuring circuit. By calibrating the test circuit with the test specimen in place, the effect of the specimen capacitance, C_T, is taken into account and the sensitivity of the system is determined.



C_T is the capacitance of the switchgear or components under test
C_1 is the high-voltage coupling capacitor
C_2 is the signal pick-up capacitance

Figure 1— Partial discharge detector basic sensitivity test

The measurement impedance, Z_m, is normally a resistance, R_m, that parallels C_2 when broad-band PD measurements are made (see 6.1). However, in the case in which the switchgear under test has a large capacitance, it is desirable to use an inductance, L_m, instead of C_2 such that a resonant PD coupling circuit is formed with maximum circuit sensitivity at resonance. This narrow-band measuring system is applicable to the test circuit shown in figures 2, 3, and 4. Either broad-band or narrow-band PD measurements are acceptable.

5.2 Partial discharge test circuit with signal coupling from the step-up transformer bushing tap

Figure 2 shows a PD test circuit with the signal coupling to the PD detector from a capacitively graded bushing of the transformer used to energize the test circuit. As shown, the capacitance, C_1, is the capacitance of the bushing lead to a foil in the bushing body that is brought out at the bushing tap. This foil also has a capacitance, C_2, to the outermost bushing shield and mounting flange. The capacitances, C_1 and C_2, constitute a voltage divider that is used to couple PD signals to the measuring instrument.

As shown in figure 2, a circuit breaker is in place for system calibration, followed by a test with the calibration leads removed. Tests are made with the circuit breaker in the various contact open/closed positions with grounded and ungrounded adjacent terminals as prescribed by the product standard.

For this and other test circuits, the 60 Hz power feeder circuit conducted noise level may exceed the acceptable energized background noise level as defined in 3.10. In that case, a low-pass filter (not shown) should be installed on the low-voltage side of the step-up transformer to block this interference.

5.3 Partial discharge test circuit with signal coupling from a bushing tap of the circuit breaker

Figure 3 shows a PD test circuit in which the circuit breaker under test has capacitively graded bushings. In this case, the capacitances of the breaker bushing, C_1 and C_2, may be used to couple the PD signal to the measuring instrument. Tests should be made with the circuit breaker in the contact open and closed positions with adjacent terminals grounded and ungrounded as required by the product standard.

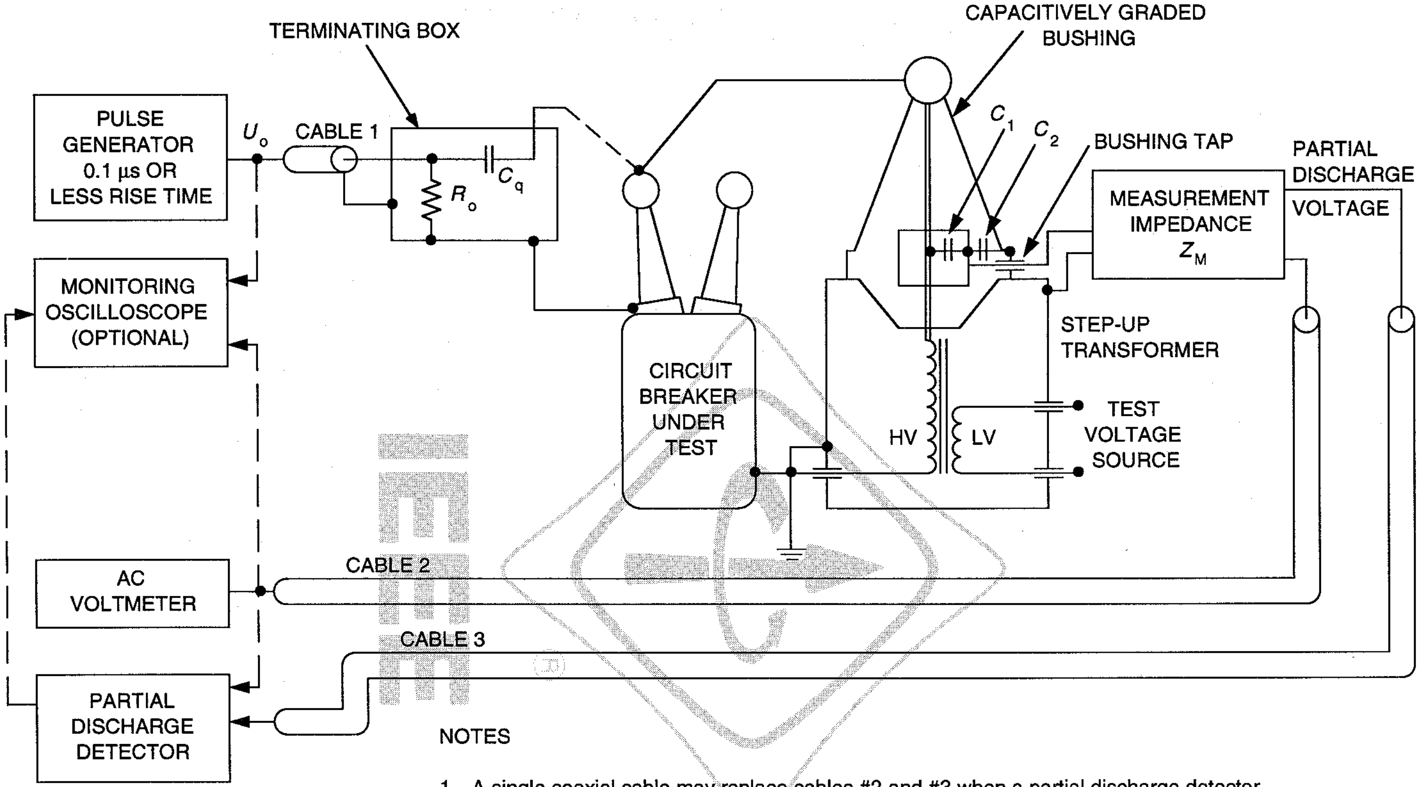
For this test circuit, a low-pass filter (not shown) may be used in the power feeder to the step-up transformer to block conducted interference noise on that system. Also, a low-pass filter, Z (optional), shown at the high-voltage terminal of the step-up transformer, may also be used to block interference noise from both the power feeder and the transformer.

5.4 Partial discharge test circuit with signal coupling from a capacitance voltage divider

Figure 4 shows a PD test circuit with signal coupling from a voltage divider. In this case, the coupling divider is independent of both the test specimen and the step-up transformer. The voltage divider, C_1 and C_2, is a pure capacitance voltage divider and is a common coupling circuit for PD measurements.

The low-pass filter, Z (optional), may be used to block interference signals from the power feeder and test transformer, and a low-pass filter (not shown) may be used at the input to the step-up transformer.

As shown, a three-phase circuit breaker is calibrated and then tested one phase at a time. All switchgear contact positions must be tested, including the effects of adjacent grounded and ungrounded bushings as required by the product test standard.

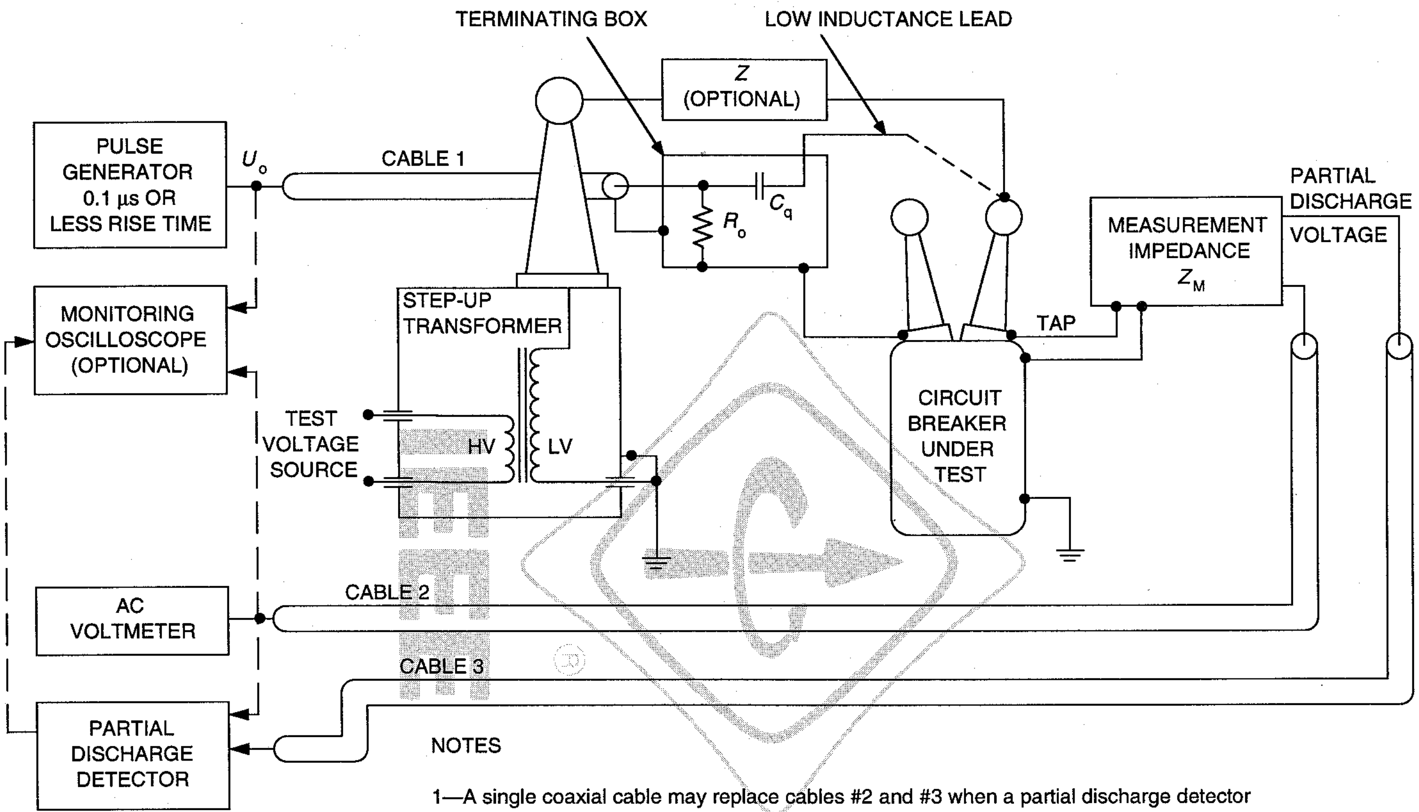


NOTES

1—A single coaxial cable may replace cables #2 and #3 when a partial discharge detector that is 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— Partial discharge test circuit with signal coupling from the step-up transformer bushing tap



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1—A single coaxial cable may replace cables #2 and #3 when a partial discharge detector that is designed to use a single cable is used.

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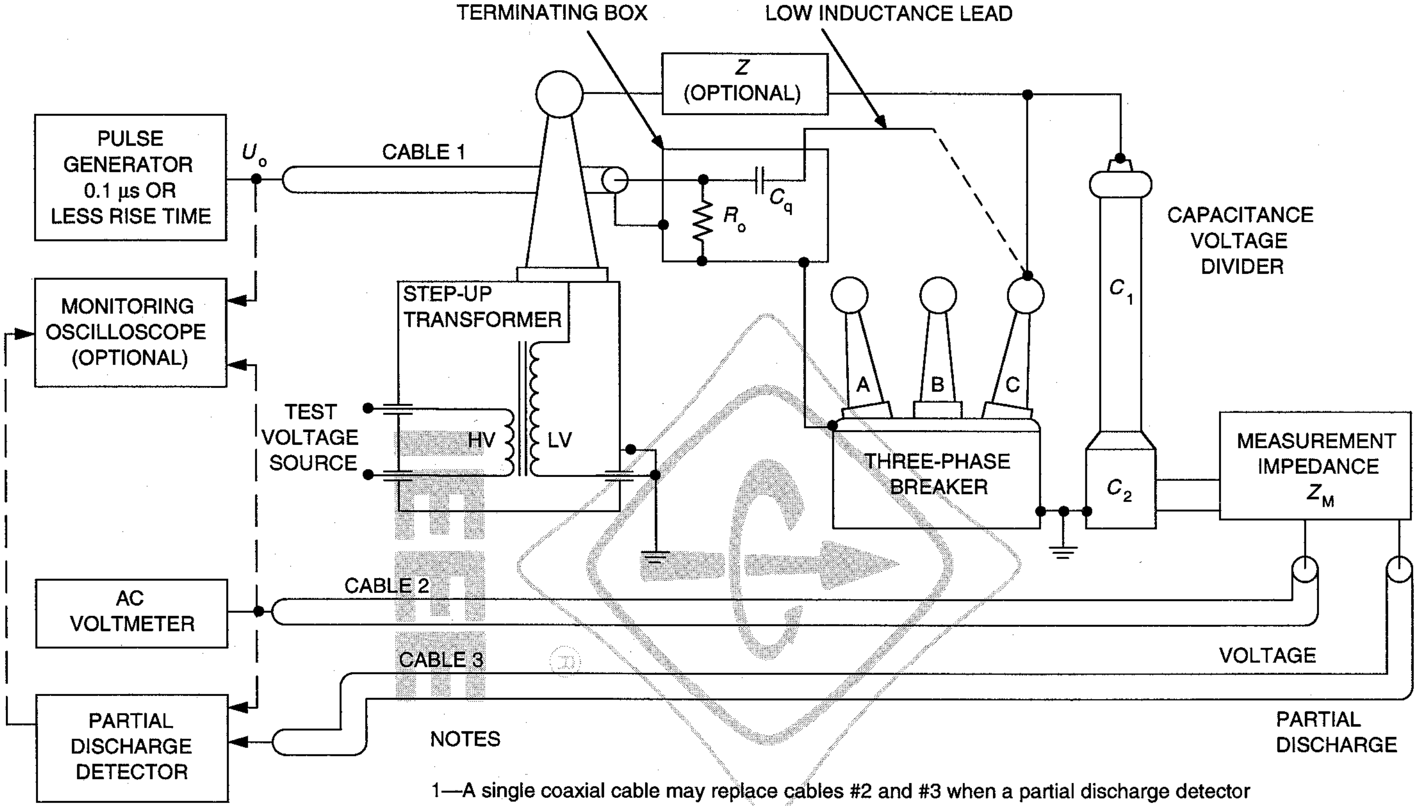
Figure 3— Partial discharge test circuit with signal coupling from the bushing tap of the circuit breaker



NOTES

1—A single coaxial cable may replace cables #2 and #3 when a partial discharge detector that is designed to use a single cable is used.

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

Figure 4— Partial discharge test circuit with signal coupling from a capacitance voltage divider

6. Measuring instrument

The measuring instrument is composed of two main elements:

a) A measuring impedance unit (Z_m)
b) A partial discharge detector unit

6.1 Measuring impedance unit (Z_m)

The measuring impedance unit (Z_m), see figures 1, 2, 3, and 4, is physically located as close as possible to a high-voltage bushing tap or to C_2, which is the low-side element of a special high-voltage divider.

The purpose of Z_m is to

a) Attenuate the normal frequency test voltage at the capacitance bushing tap or, in the case of the high-voltage divider, attenuate the voltage at C_2 to a safe value for measurement of partial discharge signals.
b) Match the input impedance of the partial discharge detector to that of the bushing tap or the voltage divider element, C_2, so that there are no input circuit oscillations that would interfere with the PD measurements.

The measuring impedance, Z_m, should be configured to allow observation of the phase relationship between the test voltage and the partial discharges. Z_m normally will be a resistor, R_m, specified by the PD instrument manufacturer, that parallels C_2.

6.1.1 Voltage divider requirements

When a bushing tap is not available on the equipment to be tested, a voltage divider consisting of a high-voltage (high resonant frequency) blocking capacitor, C_1, and a low-voltage arm, designated as C_2, should be provided. (See figure 4.)

As a result of the rated voltage range (1.0 to 800 kV) of equipment under test and the wide spread of capacitance values for the switchgear and components to be tested under this guide, it is not possible to specify limiting values of C_1 and C_2. The capacitors, C_1 and C_2, are chosen on the basis of providing the required voltage divider ratio and are sized so that they provide a sensitive coupling network to the apparatus under test.

In the case of test specimens with large capacitances, an inductor, L_M, should be substituted for C_2 and sized with capacitor C_1 to provide a sensitive narrow band resonant frequency coupling divider. Likewise, the reactor, L_m, should be paralleled by a resistor, R_m (contained in Z_m), so that the impedance can match the input impedance to the partial discharge detector. Again, it is not possible to specify the sizes of C_1 and L_M because the choice is influenced by the capacitance of the test specimen and the test voltage level required.

By direct measurement of the capacitance of the test specimen, an estimation of the selected metering circuitry can be made. The actual validity of the voltage divider/PD meter sensitivity for a specific test application must be demonstrated as indicated in 6.3.

6.2 Detector unit characteristics

The detector unit should be of the wide-band type. A narrow-band detector may be used for PD measurements on equipment with high capacitance that require a resonant frequency coupling divider for detection sensitivity. The characteristics of the wide-band detector unit are defined in 6.2.1 through 6.2.7.

6.2.1 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 within the recommended frequency range of 70 kHz to 300 kHz.

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

6.2.2 Filter characteristics

The filter characteristics of the partial discharge detector should 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

$$f_C = \sqrt{f_L \cdot f_H}$$

6.2.3 Bandwidth, Δf

The bandwidth, Δf, is defined as:

$$\Delta f = f_H - f_L$$

For PD measurements using a high-voltage divider or capacitance bushing with a tap to provide the elements C_1 and C_2, a nominal bandwidth of 100 kHz is preferred. (See figures 2, 3, and 4.) However, narrow bandwidths that are obtained using voltage divider elements of C_1 and L_M are acceptable when required as a result of the large range of switchgear specimen capacitances and voltage ratings. (See figure 4 and 6.1.1).

6.2.4 Linearity

The instrument circuit, display unit, and discharge meter should be linear within ±15% over the working range of the test.

6.2.5 PD instrument

A partial discharge instrument that includes a cathode ray oscilloscope with an appropriate time base is recommended. The time base should be synchronized to the test voltage frequency with a complete normal frequency cycle displayed. The phase relationship of the partial discharges to the test voltage should be easy to determine. A partial discharge meter can be included as an attachment to this instrument.

A partial discharge meter or pulse analyzer without an oscilloscope display unit can be used instead of the above. However, the instruments must have the requisite frequency response and sensitivity throughout the operating range.

In all cases, the instrument cables must be properly terminated to match the surge impedance to that of the instrument.

6.2.6 Discharge meter characteristics

The partial discharge meter should track the peak voltage of the cathode ray oscilloscope display unit within ±5% over the usable range. Instrument charge time to 95% of signal maximum should be $1/2f_H$ seconds[5] (one half the period of

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[5] f_H is defined in 6.2.1.

f_H) or shorter. The discharge time constant, or the time taken for a reading to decay to 36.8% of its initial value, should be between 100 and 750 ms.

6.2.7 Basic sensitivity

The minimum partial discharge level that can be detected is determined by the partial discharge detector basic sensitivity, the test specimen capacitance, and the efficiency of the PD coupling network to the discharge detector. The partial discharge detector basic sensitivity should be high enough that the measurement sensitivity during actual tests will be limited by the test circuit background noise alone and not by the amplifier noise of the detector. The signal to noise ratio should be at least 2:1 at the specified apparatus or component test voltage.

6.3 Partial discharge detector/circuit sensitivity

To ensure that the combination of the test circuit and partial discharge detector has the required sensitivity for the apparatus or component to be tested, the following procedure should be followed. With the switchgear equipment in the test circuit, the calibration procedure should be performed as required with appropriate voltage injections. The sensitivity of the total system should then be such that, with the required injection signal magnitude, the peak signal recorded by the detector is at least two times the value of the total circuit and instrument background noise.

7. Calibrator characteristics

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

Capacitor C_q should be placed as near as possible to the apparatus under test.

7.1 Calibrating capacitor value (C_q)

The capacitance of the calibrating capacitor, C_q, must be chosen based on the capacitance of the test specimen and the high-voltage coupling network. If a high-voltage capacitor bushing with a tap or capacitance voltage divider consisting of C_1 and C_2 is used, the value of C_q should be no more than 10% of the capacitance of the test specimen. This will allow measurements with broad-band bandwidths up to 100 kHz. For other cases in which a voltage divider consisting of C_1 and L_m (narrow-band measurements) is used (see 6.1.1), the value of C_q relative to the capacitance of the test specimen may be considerably larger.

7.2 Pulse generator rise time and decay time

The rise time of the pulse generator 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 usually will be suitable.

7.3 Pulse generator voltage amplitude (U_o)

The maximum voltage amplitude (U_o) of the pulse generator output should be such that the product $U_o \cdot C_q$ can be varied up to two times the required PD level.

7.4 Pulse generator output impedance (Z_o)

In the case in which the pulse generator and the calibration capacitor, C_q, are connected together via a coaxial cable, the output impedance of the generator should be the same as the characteristic impedance of the coaxial cable.

7.5 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 either should have a known calibrated output level, or its output level should be monitored. A suitable means of adjusting the output level, such as a calibrated potentiometer or a calibrated step attenuator, should be provided. The adjustment range should extend over at least two decades with a minimum of three adjusting steps per decade. 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.

7.6 Pulse generator repetition rate

The pulse generator output should be synchronized with the power system normal frequency. The calibration pulse rate output will be twice the normal frequency with alternate positive and negative discharges.

8. Calibration procedure

Before calibration is started, all equipment should be set up exactly as it will be during the partial discharge test and should include the partial discharge detector and its measuring impedance unit.[6] If the device to be tested is three-phase switchgear equipment, PD calibration should be performed at each terminal to be measured 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 except where the test sample characteristics are significantly different at different terminals or in different test configurations, where recalibration is necessary to ensure proper sensitivity.

8.1 Considerations regarding test voltage

Wide-band partial discharge detectors need a sample of the test voltage to synchronize their display. When a bushing with a capacitor tap is part of the apparatus or high-voltage test supply, 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 figures 2 and 3). To make sure that the bushing tap voltage will not exceed a value that is safe for both the measuring impedance unit and the partial discharge detector, the bushing tap voltage attenuation factor should be measured or calculated with the partial discharge detector connected.

In the absence of a bushing with a capacitor tap, a capacitive voltage divider should be used as shown in figure 4.

8.1.1 Direct method of bushing tap circuit ratio measurement

The dividing ratio of the capacitance bushing tap or the voltage divider is the reciprocal of the voltage attenuation factor and may be measured directly at the test voltage frequency by means of a suitable ratio bridge. The value will usually be in the range of 100 to 50 000, depending on the partial discharge detector model used and the value of capacitances C_1 and C_2.

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[6] If equipment is relocated following calibration, the calibration sensitivity may be changed, thereby resulting in an invalid test.

8.1.2 Indirect method of bushing tap circuit ratio measurement

To measure the bushing tap or capacitive voltage divider ratio with this method, a voltmeter with an impedance higher than 10 MΩ should be connected in parallel with the voltage input to the partial discharge detector or to some other terminal provided for this purpose. One of the measuring systems that is specified in IEEE Std 4-1978 for alternating voltage measurement is connected to the high-voltage bushing or voltage divider and to an appropriate voltage-reading device. The test source transformer should be energized at some convenient low value of voltage at the test frequency, and the voltage measured by the IEEE Std 4-1978 method should be compared with the reading of the voltmeter connected to the PD measurement system. The voltage divider ratio can be calculated by dividing these two values.

8.1.3 Test voltage measurement

A voltmeter connected to the partial discharge measurement system can be used for test voltage measurements. The test voltage value is obtained by multiplying the voltmeter reading by the divider ratio. When this method is used, calibration shall be in accordance with the requirements of IEEE Std 4-1978.

8.2 Partial discharge calibration

Partial discharge calibration is performed by injecting a known charge between the high-voltage bushing and the grounded portion of the apparatus. Either a portable, battery-powered calibrator or a pulse generator and a terminating box can be used (see figures 1, 2, 3, and 4). The portable calibrator or the terminating box must be placed as close as possible to the HV terminal so that the connecting lead is 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. As an example, for an acceptance level of 100 pC, the three levels injected would be 50 pC, 100 pC, and 200 pC. The required degree of linearity of the reading depends on the application of the apparatus.

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 on the discharge meter. This can be done easily by injecting a known calibration level into the test specimen and adjusting the sensitivity control on the detector to get a ratio between the value injected and the resulting reading on the discharge meter. Calibration must be made on a representative test specimen on which partial discharges are to be measured.

The test circuit/system PD calibration will vary depending on the contact positions of the switchgear under test. With switch contacts closed and a higher total specimen capacitance, calibration sensitivities will be reduced. Ideally, the test apparatus should be calibrated for every circuit condition. Generally, calibration of the apparatus with the contact position with the largest capacitance will be sufficient.

9. Partial discharge measurement

PD measurements are an ideal method for evaluating switchgear apparatus with non-self-restoring insulation. During a temporary overvoltage, during a high-voltage test, or under transient voltage conditions during operation, PDs may occur on insulation of this type, which includes gas, liquid, and solid materials. If these PDs are sustained due to poor materials, design, and/or foreign inclusions in the insulation, degradation and possible failure of the insulation structure may occur.

Due to the variability of performance of dielectric materials and system designs, it is recommended that partial discharge tests be made as design tests in conjunction with the other dielectric tests on new switchgear equipment designs. The partial discharge test should be performed both before and after the impulse and normal frequency dielectric tests. Once performance is established, partial discharge tests on the switchgear equipment design need only be performed following the normal frequency withstand tests. Due to the possible influence that the impulse and normal frequency dielectric tests may have on the outcome of the partial discharge test, the partial discharge test may be performed a substantial time after these dielectric tests. In some cases, the partial discharge test can be made as a part of the normal frequency withstand test.

The following procedure is recommended for PD tests on switchgear equipment. The normal frequency voltage is applied and raised to the dry normal frequency withstand voltage level, as specified by standards, for no less than 10 s. Partial discharges may occur at this test voltage depending on the PD voltage inception level of the equipment under test. The voltage is then decreased to the partial discharge test voltage level as specified by the equipment standard and held at that voltage for one minute. If the measured PD level exceeds the level allowed by the equipment standard at the end of this time limit, the equipment is considered to have failed this test. A PD level lower than that allowed by the equipment standard signifies that the apparatus has passed.

Partial discharge acceptance levels and related normal frequency test voltages are not listed in this guide because the various switchgear equipment standards list the specific test levels established for that equipment. Until the individual PD acceptance levels and test voltages are established by standards, the responsibility rests with the manufacturer for meeting the technical requirements for the specific equipment, in agreement with the user.

Annex A will help the user of this document to recognize typical PD signals that emanate from various types of insulation/switchgear systems during partial discharge tests, as well as extraneous interference signals that may be present on the system.

Annex A—PD recognition

(Informative)

(These annexes are not a part of IEEE Std 1291-1993, IEEE Guide for Partial Discharge Measurement in Power Switchgear, but are included for information only.)

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

Examples of the most common oscillographic patterns encountered during partial-discharge tests on power apparatus are shown in figures A.1 to A.6. The Lissajous patterns displayed in these figures all have the positive half cycle of the normal frequency voltage at the top and the negative half cycle at the bottom. Time is displayed in a clock-wise direction. These oscillograms are reproduced with permission from [B24] .

Figure A.1 represents the case of air corona on the high-voltage electrode. Such corona usually can be eliminated by selecting a high-voltage electrode of larger diameter or by covering protrusions on and around the equipment with rounded metallic shields or semiconductive material, such as rubber. These corona discharges are usually very large; however, 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 low in amplitude and usually cannot be observed. A calibration pulse is shown on this half-cycle.

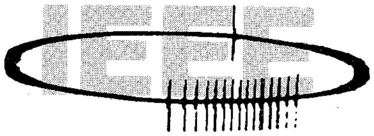

Figure A.1—Classic “corona” in air or gas from a sharp point

Figures A.2, A.3, A.4, and A.5 represent PDs occurring within the insulation structure of a test specimen. 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 the zero-crossings. There is usually a fair amount of hysteresis present, but excessive hysteresis and rapidly decreasing inception voltage are indicative of PDs in voids. Figure A.2 is typical of discharges in voids in solid-sheet or cast insulating material. Figure A.3 shows discharges in a large number of cavities of different shapes and sizes, or discharges on an external dielectric surface, or discharges between a touching conductor on a dielectric surface that creates a high tangential stress. Figure A.4 illustrates partial discharges in cast-resin insulation. Figure A.5 represents PDs in oil-paper insulation systems or in gas bubbles related to those systems.

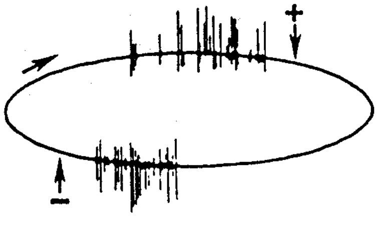

Figure A.2—Internal discharges in a solid dielectric cavity

Figure A.3—Internal discharges of cavities of different shapes and sizes

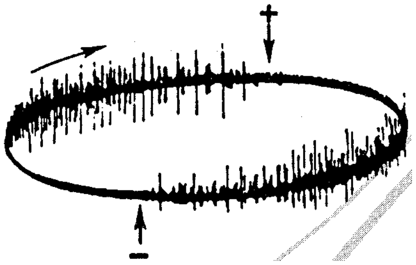

Figure A.4—Discharges in voids in cast-resin insulation

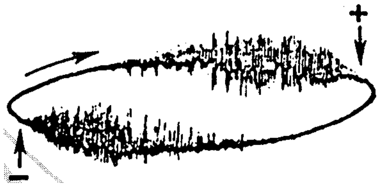

Figure A.5—Partial discharge in gas bubbles in an insulating liquid

Figure A.6 shows the result of a bad ohmic contact that is usually inside the equipment; although it could also be from the connections outside. In this case, the discharges occur on both sides of the zero-crossings of the test voltage.

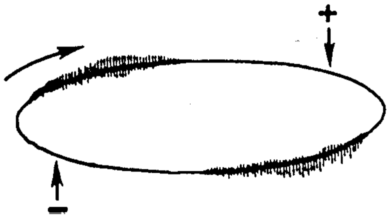

Figure A.6—Contact noise due to imperfect metal-to-metal contact

Figures A.7 to A.10 represent typical cases of external interference. Figure A.7 is typical of thyristor interference, the pulses being equally spaced and of roughly the same amplitude. 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.

Figure A.8 is the very common fluorescent light interference pattern. Figures A.9 and A.10 show typical radio frequency and industrial high-frequency processing equipment interferences. Other than the fact that they are not usually synchronized to the test voltage, interference signals are not usually dependent on the test-voltage level and do not normally disappear when the test voltage is lowered, as do PD signals. In normal situations, these characteristics suffice to identify the signals as interference.

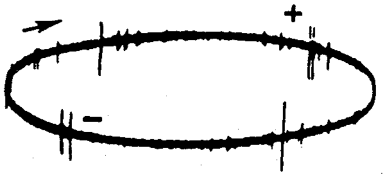

Figure A.7—Mercury-arc or thyristor rectifier interference

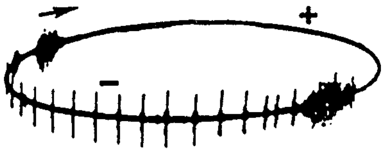

Figure A.8—Fluorescent lamp interference

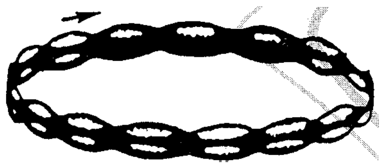

Figure A.9—Radiation from high-frequency power amplifiers and oscillators

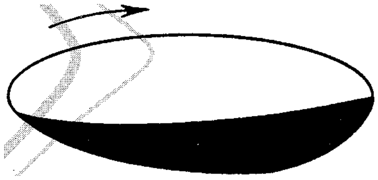

Figure A.10—Interference from industrial high-frequency equipment

For more detailed information, see [B24]. Figures A.1 to A.10 in this Annex are figures 40, 5, 9, 11, 15, 38, 44, 45, 47, and 49 respectively from [B24].

Annex B—Bibliography

(Informative)

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