Designation: D1868 – 13

# Standard Test Method for Detection and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems[1]

This standard is issued under the fixed designation D1868; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

## 1. Scope*

1.1 This test method covers the detection and measurement of partial discharge (corona) pulses at the terminals of an insulation system under an applied test voltage, including the determination of partial discharge (corona) inception and extinction voltages as the test voltage is raised and lowered. The test method is also useful in determining quantities such as apparent charge and pulse repetition rate together with such integrated quantities as average current, quadratic rate and power. The test method is useful for test voltages ranging in frequency from zero (direct voltage) to approximately 2000 Hz.

1.2 The test method is directly applicable to a simple insulation system that can be represented as a two-terminal capacitor **(1), (2)** .

1.3 The test method is also applicable to (distributed parameter) insulation systems such as high-voltage cable. Consideration must be given to attenuation and reflection phenomena in this type of system. Further information on distributed parameter systems of cables, transformers, and rotating machines will be found in Refs. (**1**), (**2**), (**3**), (**4**), (**5**), (**6**), (**7**), (**8**), and (**9**).[2] (See AEIC CS5-87, IEEE C57 113-1991, IEEE C57 124-1991, and IEEE 1434-2005.)

1.4 The test method can be applied to multi-terminal insulation systems, but at some loss in accuracy, especially where the insulation of inductive windings is involved.

1.5 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precaution statements are given in Sections 8 and 14.

## 2. Referenced Documents

2.1 *ASTM Standards:*[3]

D149 Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies

D618 Practice for Conditioning Plastics for Testing

D2275 Test Method for Voltage Endurance of Solid Electrical Insulating Materials Subjected to Partial Discharges (Corona) on the Surface

D3382 Test Methods for Measurement of Energy and Integrated Charge Transfer Due to Partial Discharges (Corona) Using Bridge Techniques

2.2 *Other Documents:*

AEIC CS5-87 Specifications for Thermoplastic and Cross-linked Polyethlene Insulated Shielded Power Cables Rated 5 through 35 kV (9th Edition) October 1987[4]

ICEA T-24-380 Guide for Partial Discharge Procedure[5]

IEEE 48 Standard Test Procedures and Requirements for High Voltage Alternating Current Cable Terminations[6]

IEEE 1434-2005 Guide to the Measurement of Partial Discharges in Rotating Machinery[6]

IEEE C57 113-1991 Guide for PD Measurement in Liquid-Filled Power Transformers and Shunt Reactors[6]

IEEE C57 124-1991 Recommended Practice for the Detection of PD and the Measurement of Apparent Charge in Dry-Type Transformers[6]

## 3. Terminology

3.1 *Definitions:*

[1] This test method is under the jurisdiction of ASTM Committee D09 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.12 on Electrical Tests.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this test method.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from the publication department of the Association of Edison Illuminating Companies, 600 N. 18th St., PO Box 2641, Birmingham, AL 35291-0992.

[5] Available from the Insulated Cable Engineers Association, Inc., PO Box 440, South Yarmouth, MA 02664.

[6] Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., P.O. Box 1331, Piscataway, NJ 08854-1331, http://www.ieee.org.

***A Summary of Changes section appears at the end of this standard**

3.1.1 The following terms are presented in a developing sequence; it is best that they be read in their entirety:

3.1.2 *ionization*—the process by which electrons are lost from or transferred to neutral molecules or atoms to form positively or negatively charged particles.

3.1.3 *partial discharge (corona)*—an electrical discharge that only partially bridges the insulation between conductors. This electrical discharge, which is governed by the transient gaseous ionization process, can assume the form of either a spark characterized by a narrow discharge channel or a diffused glow having an expanded or substantially broadened discharge channel. The partial discharges occur in gas filled cavities occluded within insulating systems and are initiated whenever the voltage across the cavities changes by a value equal to their breakdown voltage (**5**).

3.1.4 *corona*—visible partial discharges in gases adjacent to a conductor. This term has also been used to refer to partial discharges in general.

3.1.5 *continuous partial discharges (continuous corona)*—discharges that recur at rather regular intervals; for example on approximately every cycle of an alternating voltage or at least once per minute for an applied direct voltage.

3.1.6 *partial discharge (corona) inception voltage (PDIV [CIV])*—the lowest voltage at which continuous partial discharges above some stated magnitude (which may define the limit of permissible background noise) occur as the applied voltage is gradually increased (Note 1). Where the applied voltage is alternating, the PDIV is expressed as $1/\sqrt{2}$ of the peak voltage. Many test and specimen parameters can affect this value, and in some cases reproducibility may be difficult to achieve.

NOTE 1—Many factors may influence the value of the PDIV and PDEV including the rate at which the voltage is increased or decreased as well as the previous history of the voltage applied to the specimen. In many cases it may be difficult to obtain the same value with subsequent tests.

Moreover, the “continuous” character of the partial discharges is sometimes quite difficult to define, and an arbitrary judgment in this respect may lead to different values of the PDIV or PDEV.

3.1.7 *partial discharge (corona) extinction voltage (PDEV [CEV])*—the highest voltage at which partial discharges above some stated magnitude no longer occur as the applied voltage is gradually decreased from above the inception voltage (see Note 1). Where the applied voltage is alternating, the PDEV is expressed as $1/\sqrt{2}$ of the peak voltage. Many test and specimen parameters can affect this value, and in some cases reproducibility may be difficult to achieve.

3.1.8 *partial discharge pulse voltage ($V_t$)*—the terminal pulse voltage resulting from a partial discharge represented as a voltage source suddenly applied in series with the capacitance of the insulation system under test, and that would be detected at the terminals of the system under open-circuit conditions. The shape, rise time, and magnitude of the voltage $V_t$ of the partial discharge pulse are dependent upon the geometry of the cavity, its size, nature of its boundaries, the type of gas and the pressure within as well as the parameters of the transmission medium between the discharge site and the partial discharge pulse detector. The partial discharge pulses of the spark-type discharge will have substantially shorter rise times than those of the glow-type (**10**).

3.1.9 *partial discharge quantity (terminal corona charge) ($Q_t$)*—the magnitude of an individual discharge in an insulation system expressed in terms of the charge transfer measured at the system terminals. The measured charge is in general not equal to the charge transferred at the discharge site, and does have a relation to the discharge energy. For a small specimen that can be treated as a simple lumped capacitor, it is equal to the product of the capacitance of the insulation system and the partial discharge pulse voltage, that is:

$$Q_t = C_t V_t \tag{1}$$

where:

$Q_t$ = partial discharge quantity, C,
$C_t$ = capacitance of the specimen insulation system, F, and
$V_t$ = peak value of the partial discharge pulse voltage appearing across $C_t$, V.

3.1.10 *partial discharge (corona) level*—the magnitude of the greatest recurrent discharge during an observation of continuous discharges.

3.1.11 *average discharge (corona) current ($I_t$)* —the sum of the absolute magnitudes of the individual discharges during a certain time interval divided by that time interval. When the discharges are measured in coulombs and the time interval in seconds, the calculated current will be in amperes.

$$I_t = \frac{\sum_{t_0}^{t_1} Q_1 + Q_2 + ------ Q_n}{t_1 - t_0} \tag{2}$$

where:

$I_t$ = average current, A,
$t_0$ = starting time, s,
$t_1$ = completion time, s, and
$Q_1$, $Q_2$, $Q_n$ = partial discharge quantity in a corona pulse 1 through n, C.

3.1.12 *quadratic rate*—the sum of the squares of the individual discharge magnitudes during a certain time interval divided by that time interval. The quadratic rate is expressed as $(\text{coulombs})^2$ per second.

3.1.13 *partial discharge (corona) energy (W)*— the energy drawn from the test voltage source as the result of an individual discharge. It is the product of the magnitude $Q$ of that discharge and the instantaneous value $V$ of the voltage across the test specimen at the inception of the discharge (**11**). Thus the discharge energy of the $i$th pulse is:

$$W_i = Q_i V_i \tag{3}$$

where:

$W_i$ = the discharge energy, W·s( = J),
$Q_I$ = the partial discharge magnitude, (see 3.1.9), and

$V_i$ = the instantaneous value of the applied test voltage at the time of the discharge, V.

3.1.14 *partial discharge (corona) power loss (P)*— the summation of the energies drawn from the test voltage source by individual discharges occurring over a period of time, divided by that time period.

$$P = \frac{1}{T} \sum_{i=1}^{i=m} Q_i V_i \tag{4}$$

where:

$P$ = the discharge power, W,
$T$ = the time period, s,
$m$ = the number of the final pulse during T, and
$Q_i V_i$ = the discharge energy of the ith pulse (see 3.1.13).

When partial discharge pulse-height analysis is performed over a one-second interval, then the power dissapated, P, can be determined from:

$$P = \sum_{j=1}^{i} n_j Q_j V_j \tag{5}$$

where:

$P$ = pulse discharge power loss, W,
$n_j$ = recurrence rate of the jth discharge pulse in pulses/second.
$Q_j$ = the corresponding value of the partial discharge quantity in coulombs for the particular pulse.
$V_j$ = instantaneous value of the applied voltage in volts at which the jth discharge pulse takes place (**6**).

If the assumption (**12**) is made that $V_j \Delta C_j \simeq C_t \Delta V_j$ (where $\Delta C_j$ is incremental capacitance rise in $C_t$ due to the drop $\Delta V_j$ in $V_j$ as a result of the *j*th discharge), then the above summation must be multiplied by ½ . However, this assumption is not usually borne out in practice.

3.1.15 *partial discharge apparent power loss ($P_a$)*—the summation over a period of time of all corona pulse amplitudes multiplied by the rms test voltage.

$$P_a = I_t V_s \tag{6}$$

where:

$P_a$ = apparent power loss in time interval $(t_1 - t_0)$, W,
$I_t$ = average corona current, A, and
$V_s$ = applied rms test voltage, V.

3.1.16 *partial discharge (corona) pulse rate (n)*—the average number of discharge pulses that occur per second or in some other specified time interval. The pulse count may be restricted to pulses above a preset threshold magnitude, or to those between stated lower and upper magnitude limits.

3.1.17 *partial discharge pulse*—a voltage or current pulse that occurs at some designated location in a circuit as a result of a partial discharge.

## 4. Summary of Test Method

4.1 A specimen insulation system is energized in a test circuit by a high-voltage source. A partial discharge (corona) in the specimen will cause a sudden charge transfer and a resulting voltage pulse at the specimen terminals. Calibrate a measuring instrument coupled to the terminals to respond to the voltage pulse in terms of the charge transferred at the terminals.

## 5. Significance and Use

5.1 The presence of partial discharges (corona) at operating voltage in an insulation system has the potential to result in a significant reduction in the life of the insulating material. Some materials are more susceptible to such discharge damage than others. This characteristic can be investigated using Test Method D2275.

5.2 The presence of partial discharges (corona) in an apparently solid insulation is a potential indication of the existence of internal cavities. Partial discharge tests have been useful in the design and inspection of molded, laminated, and composite insulation, as well as specimens in the form of cables, capacitors, transformers, bushings, stator bars, and rotating machines (**1**), (**2**), (**3**), (**4**), (**5**), (**6**), (**7**), (**8**), (**9**), (**13**), and (**12**). (See also AEIC CS5-87, ICEA T-24-380, IEEE 48, IEEE C57 113-1991, IEEE C57 124-1991, and IEEE 1434-2005.)

5.3 Partial discharge (corona) inception and extinction voltages are used in the determination of the limiting voltage at which an insulation system will operate free of such discharges. The extinction voltage is often substantially lower than the inception voltage. Where the operating voltage is below the inception voltage but above the extinction voltage, it is possible that a transient over-voltage will initiate discharges which then continue until the voltage is lowered below the extinction voltage. Inception and extinction voltages depend upon many factors, including temperature and the rate at which the voltage is changed. After a time at a voltage, it is possible that discharges will start and stop in a nonuniform and unpredictable fashion, especially for discharges within cavities in certain materials, in particular if the discharge degradation products formed are conductive (**1**), (**5**).

5.4 The magnitude (pulse height) of a partial discharge is an indication of the amount of energy that it dissipates in the insulation system. Partial discharge magnitude and pulse rate are useful in estimating the rate, or change of rate, at which deterioration is produced.

5.5 In general, the occurrence of partial discharges is not directly related to the basic properties of a solid insulating material, but usually results from overstressing of gaseous occlusions or similar imperfections or discontinuities in an insulating system. It is possible that partial discharges will originate at locations such as on the leads or terminals without resulting in any hazard within the main part of the insulation system.

## 6. Interference

6.1 It is possible that radiated or conducted electrical disturbances from sources other than the test specimen will interfere with the measurement of partial discharges. The magnitude of disturbances reaching the measuring instrument must be kept small relative to the most sensitive measurements to be made.

6.2 The following techniques are useful to reduce interference from radiation: (*a*) shielding the test circuit or (*b*) conducting the test in a shielded room. The following technique is useful to reduce interference by conduction: the use of a low-pass filter in the voltage supply circuit.

6.3 It is possible that corona on the connecting leads between the test voltage source and the specimen will interfere with the measurement. Such interference is likely to be avoided if the leads are smooth-surfaced and of sufficient diameter, with spherical terminals.

6.4 It is often possible to identify interference from the display of an oscilloscope coupled to the measuring circuit, with its horizontal deflection relating to the instantaneous value of the test voltage. For example, pulses that appear only during the negative half-cycle of the alternating test voltage are often the result of corona originating on the connecting lead or terminal rather than the result of partial discharges within the specimen.

6.5 It is usually possible to control interference by the use of time window circuits that suppress the measuring device input during the portion of the test voltage wave when partial discharges do not occur. Using this technique take care to avoid the loss of wanted signals. Other more sophisticated interference suppression techniques of signal processing can be used **(1)** .

6.6 Some interference sources are characterized by well defined three dimensional distributions of discharge pulse magnitude, its phase relationship to the applied voltage and its recurrence rate or, alternatively, their pulses exhibit certain pulse shape attributes. Neural networks can be taught to recognize these specific features of the interference generated discharge pulse patterns and distinguish them from the actual discharge pulse patterns emanating from the cavities within the insulating systems **(14)**.

## 7. Apparatus

7.1 *Test Voltage Supply:*

7.1.1 The voltage supply must be capable of energizing the test circuit, including the specimen, over a range of voltages to the maximum desired test value. The requirements in Test Method D149 are recommended. The frequency of the supply voltage shall preferably be the frequency that will be used in service of the specimen.

7.1.2 The voltage supply must not introduce into the measuring circuit pulses of sufficient magnitude to interfere with the most sensitive measurement. The internal impedance including the shunt capacitance of the voltage supply must not significantly reduce the sensitivity of the measurement. To assist in meeting these two requirements, insert a supply impedance, preferably in the form of a low-pass filter, in the output circuit of the voltage supply.

7.1.3 The voltage supply shall include a voltmeter that responds to the peak voltage applied to the test circuit and permits measurements of the voltage directly across the insulation system.

7.2 *Coupling Capacitor* ($C_{cc}$)—The capacitance value of this capacitor is selected in relation to other circuit components to realize the desired circuit sensitivity (see circuit sensitivity expressions in X1.1). A value of 100 pF is often satisfactory for low-capacitance specimens. For higher capacitance specimens, a value of 2500 pF is found to be adequate. In general, a higher capacitance value will improve circuit sensitivity but will require increased charging current from the test voltage supply. The coupling capacitor shall not introduce into the circuit pulses of sufficient magnitude to interfere with the most sensitive measurement.

7.3 *Measuring Impedance:*

7.3.1 The measuring impedance shall have a value at test frequency that is low in comparison with other circuit elements to prevent the appearance of an excessive portion of the test voltage at the input terminals of the measuring device. The measuring impedance is usually inductive or resistive.

7.3.2 An inductive impedance, shunted by stray capacitance (consisting of connection cables and component mountings), produces an oscillatory response to a partial discharge pulse. The persistence of the oscillations facilitates pulse observation, but reduces resolution between pulses. Resolution can be changed by the use of a shunting resistor to damp the oscillation or by modifying the frequency response of the discharge measuring system.

7.3.3 A resistive impedance, shunted by stray capacitance, produces an exponentially decaying step response to a discharge pulse. A resistive impedance is used to provide maximum pulse resolution and where the impedance must be adjusted, as in a bridge circuit.

7.4 *Measuring Devices:*

7.4.1 A cathode-ray oscilloscope is used to display and measure the discharge pulses that appear across the measuring impedance. The pulses are amplified by the vertical deflection amplifier, which must respond to the important frequency components of the pulses. Bandwidth in the range from 25 kHz to several hundred thousand Hz have been found satisfactory. The height of the vertical deflection caused by a partial discharge can be related to the discharge magnitude. In a common arrangement, the vertical deflections are superimposed on an elliptical oval trace synchronized with the test voltage. Thus the point on the voltage wave at which each discharge occurs can be visualized. Equip the oscilloscope with a beam-brightening or pulse-stretching circuit to facilitate the observation of peak deflections.

7.4.2 The partial discharge level can be measured by a peak-reading voltmeter connected across the measuring impedance. The meter must be able to respond accurately over a range of pulse rates between 1 and at least 1000 per second.

7.4.3 The average discharge current can be measured by an instrument that responds to the average value of the rectified discharge pulses that occur in a certain time interval. Take precautions to avoid oscillations in the measuring circuit that could reduce accuracy. Alternatively, determine the average discharge current from a pulse height distribution curve (see 7.4.7).

7.4.4 The quadratic rate can be measured by an instrument that responds to the mean square value of the discharge pulses that occur in a certain time interval. A suitable rectifier or a thermal detector is suitable provide the squaring function.

7.4.5 The apparent discharge power loss can be determined from the area under a pulse height distribution curve (see 7.4.7). A useful approximation of the discharge power loss for an alternating test voltage is obtainable from an instrument that responds to the product of the average discharge current and the RMS value of the test voltage.

NOTE 2—Method A of Test Methods D3382 is suitable to determine power loss due to continuous partial discharges under alternating voltage. Alternatively, Method B of Test Methods D3382 is suitable to obtain discharge energy per cycle in joules and then multiplying by the frequency to obtain the loss in watts.

7.4.6 A pulse counter responsive to either positive or negative pulses is suitable to measure the partial discharge (corona) pulse rate, *n*. A rectifier bridge is suitable to obtain total pulse counts of the combined positive and negative pulse responses. Suitable pulse-shaping circuits applied across the measuring impedance must be employed to ensure that each discharge pulse is recorded as a single event. When oscillatory responses are involved, a demodulation circuit with proper active filtering constitutes an effective means for obtaining smooth pulses having a single polarity (**13**). When high pulse resolution is desired and the pulses are already unidirectional but contain superimposed high-frequency oscillations, multivibrator circuits are suitable to carry out pulse shaping (**15**). The insertion of an amplifier with a suitable bandwidth between the measuring impedance and the pulse-shaping circuit will provide adequate sensitivity. A controlled gating system is suitable to prevent the counting of pulses below selected magnitude levels. For example, in high ambient noise environments it will be potentially useful to avoid counting pulses below a preset level.

7.4.7 Single- or multichannel pulse-height analyzers can be utilized to obtain curves of the partial discharge pulse rate, *n*, as a function of the discharge magnitude, *Q*. The area under such pulse height distribution curves is given by

$$A(n, Q) = \int_0^\infty n(Q)dQ \qquad (7)$$

and is dimensionally equal to the corona current and is proportional to the partial discharge power loss. As in the case of pulse counters (7.4.6), the use of proper pulse shaping and amplification circuitry is of the utmost importance to ensure a meaningful pulse-height analysis.

Computerized techniques are frequently followed to obtain partial discharge pulse phase-resolved data (**14**). A digital partial discharge detector is utilized for the acquisition of all the quasi-integrated pulses; it then sorts and quantifies the discreet pulses by their magnitude, Q, the corresponding phase angle or discharge epoch, φ, with respect to the applied sinusoidal voltage at which they occur and their respective recurrence rate, n. An analysis software is then employed to plot the bivariate distribution of (Q~φ~n). From the resulting three dimensional plot, the univariate distributions of (Q~φ) and (n~φ) can be obtained; alternatively, they can be measured directly by means of hardware.

7.5 *Calibration Capacitor* ($C_c$)—It is important that the calibration capacitor not exceed 200 pF. If its position in the test circuit subjects it to the test voltage, the capacitor shall not introduce into the measuring circuit discharge pulses of sufficient magnitude to interfere with the most sensitive measurement, and it must have a voltage rating equal to the highest test voltage.

7.6 *Calibration Pulse Generator*—The pulse generator must have an output impedance of not more than 100 Ω capable of withstanding the charging current at test voltage of the calibration capacitor. When connected to the circuit the generator must produce pulses having a rise time of 0.1 µs or less and a decay time to half crest of greater than 1 ms. Provision must be made for determining the crest value of the output pulse. A square-wave generator that meets these requirements is a satisfactory pulse source. The maximum repetition rate of the pulse generator shall be 12.5 kHz.

## 8. Hazards

8.1 The portion of the test area that includes the test specimen and other components of the test circuit to be energized at high voltage shall be blocked from easy access and marked by warning signs. Doors or gates to this area shall be provided with switches interlocked with the test voltage supply system.

8.2 Provision shall be made for the remote (automatic) grounding of the high-voltage circuit. The high-voltage circuit shall not be approached unless a ground is applied. This precaution is especially important when direct-voltage tests are employed, since the circuit may remain charged at high voltage after the energizing source is interrupted.

8.3 Surge voltage protectors must be applied to those parts of a measuring circuit that must be accessible during the measurement, such as the measuring device and calibration pulse generator, to minimize danger from accidental high voltage which could result from the failure of the test specimen, high-voltage calibration capacitor, or other circuit element. The instrumentation must be enclosed in a grounded case.

8.4 It is recommended that the safety practices as outlined in paragraph 2.0 to 2.8 of Ref. (**16**) be followed.

## 9. Sampling

9.1 Because this test method is used on a variety of insulating materials and systems, no one sampling procedure can be specified. Material specification methods will often provide guidance. For some insulation systems, each production unit is tested individually as a quality control measure.

## 10. Test Specimens

10.1 It is acceptable for specimens to be entire insulation systems with normally included electrodes. It is acceptable to make discharge measurements between any two insulated sets of conductors or metallic parts. It is acceptable for other conductors or metallic parts to be or not to be grounded, but their disposition shall be noted in the report.

10.2 Where the test specimen does not have its own electrode system, temporary electrodes must be applied. There shall be no cavities between an electrode and the surface of the specimen insulation, since discharges in such cavities cannot be distinguished from partial discharge within the specimen. A film of insulating paste or grease spread on the surface of the insulation before applying the electrode is helpful in preventing discharges at this location.

10.3 When the test specimen is energized in air, it is possible that corona will occur in the air at the edges of the electrodes. If the measurement is to be confined to internal discharges, methods of suppressing edge corona include immersion of the test specimen in a suitable dielectric fluid, or by covering the edges with a thick coat of insulating paste or grease.

## 11. Arrangement of Apparatus

11.1 Some common circuit arrangements are shown in Figs. 1-3. In these figures the test specimen is represented by capacitor $C_t$, the calibration capacitor by capacitance $C_c$, and the coupling capacitor as capacitance $C_{cc}$. Optional connections for the calibration circuit are indicated by broken lines. It is acceptable to disconnect the calibration circuit during the application of high voltage to the test specimen (see 12.4).

11.2 The circuit of Fig. 1 can be used when it is convenient to have one terminal of the specimen grounded. This circuit arrangement also provides an improvement in the signal-to-noise ratio. The circuit of Fig. 2 is suitable for specimens of small dimensions that can be easily isolated from ground. The circuit of Fig. 3 is advantageous for minimizing interference conducted from the test voltage supply. In this circuit the measuring impedance is composed of two adjustable resistance sections, one section in series with the test specimen and the other in series with the coupling capacitor. Proper balancing of the resistance values can substantially reduce the level of conducted interference appearing across the input terminals of the measuring device.

11.3 Precautions must be taken to avoid corona on the high-voltage connecting leads (see 6.3).

11.4 Stray capacitance between connecting leads and between leads and ground generally reduces the maximum achievable sensitivity of the test circuit. Leads shall be well spaced from each other and from ground.

## 12. Calibration

12.1 A calibration procedure is carried out to establish a scale factor relating the response of the measuring device to the magnitude of a discharge pulse. Since the response of the measuring device is affected by the value and location of the various test circuit components, the calibration must involve the entire test circuit. Recalibration is required for each test specimen (except for specimens of the same dimensions and capacitance) or when any other test circuit component is changed or relocated.

12.2 In the calibration procedure, a calibration circuit consisting of a calibration pulse generator in series with a calibration capacitor is connected to the test circuit. The calibration circuit produces a pulse resulting in equivalent response in the detection system to a partial discharge pulse. The value of charge ($Q$) in picocoulombs is equal to the product of the crest voltage ($E$) in volts of the pulse produced by the calibration generator, and the capacitance ($C_c$) in picofarads of the calibration capacitor. From the observed response of the measuring device, a scale factor relating the calibrating pulse response to the partial discharge response can be established. By adjustment of the sensitivity of the measuring device, it is possible to make its response to correspond to a precalibrated magnitude scale. It is acceptable to apply the scale factor as determined for a given calibration pulse magnitude to all magnitudes within the linear response range of the measuring device.

12.3 Two methods of calibration can be carried out, (*1*) direct, (*2*) indirect. In the direct method, the calibration is performed with the calibration signal being applied directly across the terminal of the test specimen as in Fig. 1 and Fig. 3 connection *A*. When the calibration capacitor is to remain in the circuit during test, the calibration capacitor must be able to withstand the highest test voltage and have partial discharge with a lower level than the specimen to be tested. When the calibration capacitor is not to remain connected to the specimen high-voltage terminal during application of test voltage, a correction of the system sensitivity must be made to compensate for its removal. See Appendix X1 for correction factor.

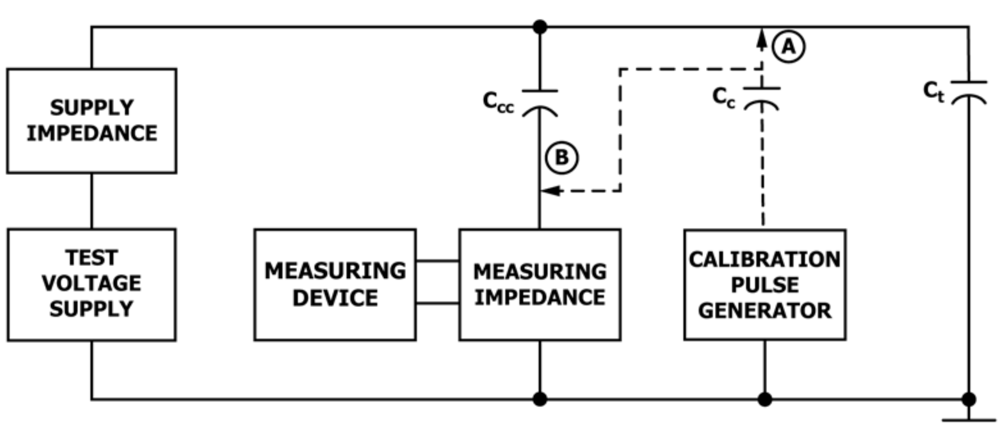


FIG. 1 Circuit No. 1

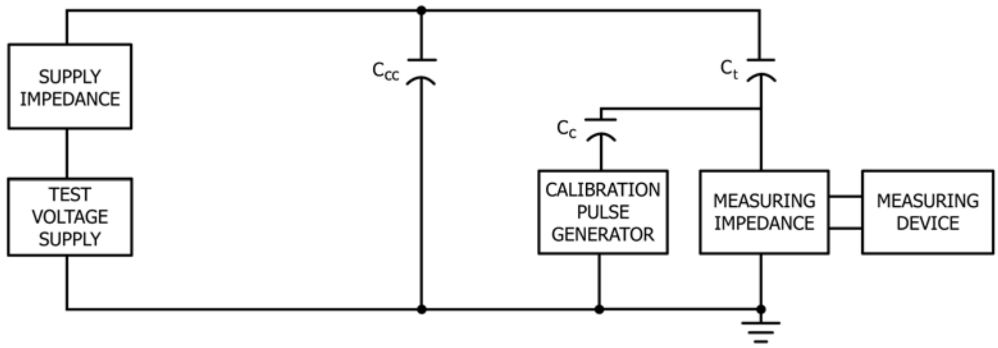


**FIG. 2 Circuit No. 2**

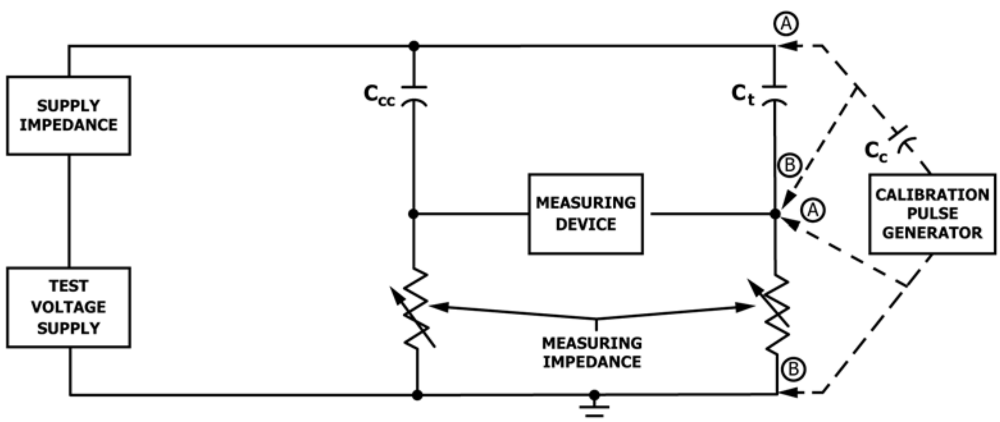


**FIG. 3 Circuit No. 3**

12.4 When the calibration capacitor is disconnected, reconnect it as in Fig. 1 and Fig. 3 connection *B*, and Fig. 2 to perform an indirect method of calibration and determine a correction factor. The ratio of the sensitivity determined by the direct to indirect method is called the correction factor. By maintaining the measuring device sensitivity constant when going from the direct to indirect methods and adjusting the calibration pulse generator output, the correction factor can be made to equal unity.

12.5 To calibrate a device for the measurement of pulse rate, average discharge current, or quadratic rate, a square-wave generator is a suitable way to supply the calibration pulses. The frequency ($f$) of the generator shall be in the 50 to 5000-Hz range. A pulse-rate measuring device shall indicate a value of $2f$, since each wave generates one positive and one negative pulse. A device for measuring the average discharge current shall indicate a value of $2\ fQ$ picoamperes, where $Q$ is the picocoulomb magnitude of the calibration charge (after correction, if appropriate, see 12.4 and 12.5). Similarly, a device for measuring quadratic rate shall indicate a value of $2fQ^2$.

## 13. Conditioning

13.1 The occurrence and magnitude of partial discharges (corona) is influenced by environmental conditions such as temperature, pressure, humidity, previous electrification, and the dielectric properties of the immersing fluid. Unless the specimen is designed for use in some special environment, partial discharge tests shall be made with the specimen in air under standard laboratory conditions described in Practice D618.

## 14. Procedure

14.1 **Warning**—*It is possible that lethal voltages will be present during this test. It is essential that the test apparatus, and all associated equipment potentially electrically connected to it, be properly designed and installed for safe operation. Solidly ground all metal parts that any person might come into contact with during the test. Provide means for use at the completion of any test to ground any parts which: were at high voltage during the test; have the potential to have acquired an induced charge during the test; have the potential to retain a charge even after disconnection of the voltage source. Thoroughly instruct all operators in the proper way to conduct the test safely. When making high voltage tests, particularly in compressed gas or in oil, it is possible that the energy released at breakdown will be sufficient to result in fire, explosion, or rupture of the test chamber. Design of test equipment, test chambers, and test specimens shall be such as to minimize the possibility of such occurrences, and to eliminate the possibility of personal injury.*

14.2 **Warning—** *Ozone is a physiologically hazardous gas at elevated concentrations. The exposure limits are set by governmental agencies and are usually based upon recommendations made by the American Conference of Governmental*

*Industrial Hygienists.*[7] Ozone is likely to be present whenever voltages exist which are sufficient to cause partial, or complete, discharges in air or other atmospheres that contain oxygen. Ozone has a distinctive odor which is initially discernible at low concentrations but sustained inhalation of ozone can cause temporary loss of sensitivity to the scent of ozone. Because of this it is important to measure the concentration of ozone in the atmosphere, using commercially available monitoring devices, whenever the odor of ozone is persistently present or when ozone generating conditions continue. Use appropriate means, such as exhaust vents, to reduce ozone concentrations to acceptable levels in working areas.

14.3 *Partial Discharge (Corona) Inception Voltage*—Set the sensitivity of the measuring device so that a partial discharge quantity of 1 pC will produce a readable value above background noise on either the discharge meter or the oscilloscope. See 3.1.6 and Note 1. If background noise is too great for this, see Note 3. Apply an increasing test voltage to the test specimen, starting at a value well below the expected inception voltage. Continue the increase until a predetermined voltage is reached or until continuous discharges (3.1.5) occur. The rate of test voltage increase must be low enough to permit a differentiation between intermittent and continuous discharges. The minimum test voltage at which continuous discharges, exceeding some stated magnitude, occur is the partial discharge inception voltage (see Note 1).

NOTE 3—When the device capacitance is too high (for example, >0.1 µFd), a partial discharge quantity of 1 pC will generally be in the background noise, even with low noise equipment. Since most specifications on equipment require determination of the PDEV at 5 pC, (for instance, AEIC CS5-87, and ICEA T-24-380) and the most sensitive requirement is 3 pC (for instance, IEEE 48), the ability to read 1 pC above background noise is not essential. It is, however, desirable.

14.4 *Partial Discharge Extinction Voltage (PDEV):*

14.4.1 Set the sensitivity of the test equipment as in 14.3.

14.4.2 Raise the applied voltage to a level at least 30 % above PDIV but not exceeding the maximum voltage set by the specification (for instance, the ac withstand test voltage), and then gradually lower the applied voltage at a rate not exceeding 2000 V/s until all discharges above a specified level cease.

14.4.3 The voltage at which the final pulse above the specified level occurs is the partial discharge extinction voltage (PDEV).

14.4.4 For a direct voltage test, it is possible that the inception and extinction voltages will be the same.

14.4.5 For alternating voltage tests on certain materials the extinction voltage will be significantly lower than the inception voltage (See Note 1). This lowering is probably caused by one of the following:
(*1*) Trapped surface charge on the specimen, (*2*) localized heating within the specimen, (*3*) creation of gas filled cavities within the specimen from the partial discharges that occur after the inception voltage is reached. The partial discharge inception voltage, $V_{io}$, can be expressed as:

$$V_{io} = V_b[1 + (C'/C_v)] \quad (8)$$

Where $V_b$ is the breakdown voltage of the cavity, having a capacitance, $C_v$, and C' is the capacitance of the dielectric material in series with the cavity. The corresponding partial discharge extinction voltage, $V_e$, is then given by:

$$V_e = (V_b/2)[1 + (V_r/V_b)] \quad (9)$$

Where $V_r$ is the residual voltage across the cavity that is given by the value to which the voltage across the cavity collapses at breakdown. Examination of Eq 9 shows that the lowest value that $V_e$ can assume is $V_{io}/2$ when $V_r = 0$; while its highest value occurs as in the limit, $V_r$ approaches the magnitude of $V_b$, in which case $V_e$ becomes equal to $V_{io}$. Large values of $V_e$ are found to be associated with pseudoglow discharges, indicating increased space charge accumulation on the cavity surfaces (**1**) and (**17**). Note that pseudoglow discharges are similar in their behavior to pulse discharges of the spark-type, except that they have broadened discharge channels characterized by a diffused glow. In some cases, their rise times will be too long to be detected by conventional partial discharge pulse detectors, necessitating the use of partial detection methods described in Test Methods D3382 (**1**), (**5**).

14.5 *Other Partial Discharge (Corona) Measurements*—Measurements of partial discharge (corona) magnitude, level, average discharge current, and quadratic rate and power loss, when required, are made at a specified test voltage, usually based on the expected operating voltage of the test specimen. Obtain the reading of the measuring device promptly after application of the test voltage. Specific programs for application of test voltage with time must be established for those specimens in which the magnitude of discharges had a marked time dependency and for those specimens which are highly susceptible to discharge damage.

## 15. Report

15.1 Report the following information:

15.1.1 Identification of the test specimen or description of the material tested and the electrode system used. Disposition of electrodes if there are more than two,

15.1.2 The specimen capacitance as measured at or near the supply frequency unless implicit in 15.1.1,

15.1.3 Ambient temperature, relative humidity, barometric pressure, and immersing fluid type and temperature if other than air,

15.1.4 A description of any method used to suppress exernal corona,

15.1.5 Inception and extinction voltages, if required, together with a statement of the test voltage frequency and the sensitivity of the measuring device as used in the determination. All correction factors shall be reported.

15.1.6 Partial discharge (corona) level at specified test voltages. When a zero level is reported, the sensitivity of the measuring device shall also be reported as described in 15.1.5, and

15.1.7 The results of measurements of any other partial discharge quantities described in this method that are required. The test voltages at which the measurements were made shall also be included in the report.

[7] Located in Bldg. D-7 at 8500 Glenway Drive, Cincinnati, OH 45211.

## 16. Precision and Bias

16.1 For measurements made by this test method where discharge magnitudes are involved, the precision is affected by the characteristics of the discharge pulses, and is related to the size, shape, internal pressure, and surface conductivity of the discharging cavities. Since these parameters vary between cavities and for different insulating materials, no specific precision can be stated for the method. The precision figures given below are estimates meant to serve as a guide.

16.2 *Inception and Extinction Voltages*— For a given sensitivity of the measuring device, the precision to which partial discharge (corona) inception and extinction voltages can be determined is substantially that of the measurement of the test voltage. This test method anticipates the use of commercially available instrumentation that will permit the measurement of test voltage within a precision range of ±3 % (see Note 1).

16.3 *Partial Discharge (Corona) Magnitude and Level*—The precision of a measurement of the magnitude of individual discharge pulses or of the level of continuous discharges depends on an accurate knowledge of the test voltage, the calibration pulse voltage, the capacitance of the calibration capacitor, and the frequency response of the measuring instrument. The characteristics of the discharge pulses are also a factor (see 16.1). Because of the many factors affecting the precision, it is possible that the precision range will approach ±10 %.

16.4 *Other Discharge Quantities*—The measurement of discharge quantities, such as the average discharge current and the quadratic rate, is subject to error in the magnitude of the pulses furnished to the measuring device, and also to error in the processing function of the device. it is possible that the precision range for measurements of these quantities will approach ±20 %.

16.5 *Bias*—A statement of bias for this test method cannot be made since there is no standard specimen that can be measured with this method.

## 17. Keywords

17.1 average discharge (corona) current ($I_t$) ; calibration pulse; corona; continuous partial discharges (continuous corona); discharge magnitude; ionization; partial discharge apparent power loss ($P_a$); partial discharge (corona); partial discharge (corona) energy ($W$); partial discharge (corona) extinction voltage; partial discharge (corona) inception voltage (CIV); partial discharge (corona) level; partial discharge (corona) power loss ($P$) ; partial discharge (corona) pulse rate (n); partial discharge pulse; partial discharge pulse voltage ($V_t$); partial discharge quantity (terminal corona charge); pulse height; quadratic rate

## APPENDIX

**(Nonmandatory Information)**

### X1. SENSITIVITY EXPRESSIONS FOR CIRCUITS OF FIGS. 1 TO 3

X1.1 Sensitivity as used in this Appendix is the ratio of the crest value of the voltage pulse appearing at the input terminals of the measuring device to the crest value of a calibration or discharge pulse occurring elsewhere in the test circuit. Sensitivity expressions may be developed in terms of the capacitances of the circuit components. Such expressions are helpful in the evaluation of the effect that any circuit component has on the sensitivity.

X1.2 For a test circuit arrangement that provides an equal sensitivity to both calibration and discharge pulses, the scale factor derived from the calibration procedure may be directly applied to the measurement of partial discharges in the test specimen. For test circuit arrangments that result in different sensitivity, the response of the measuring device must be modified by a scale factor equal to the ratio of the sensitivities.

X1.3 In the development of the expressions listed below, the assumption was made that both the calibration pulse and the discharge pulse have sufficient rates of rise so that the initial voltage distribution throughout the circuit is determined only by the circuit capacitances.

X1.4 The symbols used in this appendix are as follows:

$V_I$ = crest voltage at the measuring impedance, V
$V_t$ = terminal corona-pulse voltage, V
$V_c$ = crest voltage of calibrating pulse, V
$C_t$ = capacitance of test specimen, pF
$C_{cc}$ = capacitance of coupling capacitor, pF
$C_i$ = shunt capacitance across the measuring impedance, pF
$C_s$ = stray capacitance between high-voltage load and ground, pF

NOTE X1.1—$C_s$ cannot be evaluated and must be estimated or neglected.

$C_c$ = capacitance of calibrating capacitor, pF
$H_c$ = maximum deflection from normal trace produced by calibration pulse, cm
$S$ = circuit sensitivity to partial discharge signal
$S_c$ = circuit sensitivity to calibration signal
$SF$ = sensitivity scale factor for circuit of Fig. 1A, Fig. 1B, and Fig. 2
$CF$ = sensitivity correction factor for circuits of Fig. 1
$CF'$ = sensitivity correction factor for circuit of Fig. 1A when calibration capacitor is removed

X1.5 Circuit sensitivity is defined as the fraction of the terminal corona-pulse voltage that appears across the coupling impedance for measurement. The circuit sensitivity is not used in the calculation of results and is included only to show the effect of circuit capacitances on the sensitivity. The circuit sensitivity and scale factor expressions are:

X1.5.1 Fig. 1*A:*

$$S = \frac{C_t C_{cc}}{(C_t + C_c + C_s)(C_{cc} + C_i) + C_{cc} C_i} \quad \text{(X1.1)}$$

$$S_c = \frac{C_c C_{cc}}{(C_t + C_c + C_s)(C_{cc} + C_i) + C_{cc} C_i} \quad \text{(X1.2)}$$

$$SF = \frac{C_t}{C_c} \quad \text{(X1.3)}$$

X1.5.2 Fig. 1*B:*

$$S = \frac{C_t C_{cc}}{(C_t + C_s)(C_i + C_{cc} + C_c) + C_{cc}(C_i + C_c)} \quad \text{(X1.4)}$$

$$S_c = \frac{C_c C_{cc}}{(C_t + C_s)(C_i + C_{cc} + C_c) + C_{cc}(C_i + C_c)} \quad \text{(X1.5)}$$

$$SF = \frac{C_t}{C_c} \quad \text{(X1.6)}$$

X1.5.3 Fig. 2*:*

$$S = \frac{C_t(C_s + C_{cc})}{C_t(C_s + C_c + C_{cc} + C_i) + (C_s + C_{cc})(C_c + C_i)} \quad \text{(X1.7)}$$

$$S_c = \frac{C_t C_c}{C_t(C_s + C_c + C_{cc} + C_i) + (C_s + C_{cc})(C_c + C_i)} \quad \text{(X1.8)}$$

$$S_F = \frac{C_{cc} + C_s}{C_c} \quad \text{(X1.9)}$$

X1.5.4 Fig. 3—The circuit sensitivity for Fig. 3 when used as a straight system with a measuring impedance is the same as Fig. 2. When used as shown in the bridge configuration at null, there is a no difference between sensitivity and partial discharge signals and calibration signals in either *A* or *B* configuration, and therefore no scaling or correction factors are required.

X1.5.5 The circuit sensitivity correction factor for conversion from calibration by Fig. 1A to Fig. 1B is:

$$CF = \frac{(C_t + C_s)(C_i + C_{cc} + C_c) + C_{cc}(C_i + C_c)}{(C_t + C_s + C_c)(C_{cc} + C_i) + C_{cc} C_i} \quad \text{(X1.10)}$$

X1.5.6 The circuit sensitivity correction factor for conversion from calibration by Fig. 1A with calibrating capacitor then removed because of limited test voltage rating is:

$$CF' = \frac{(C_t + C_c + C_s)(C_{cc} + C_i) + C_{cc} C_i}{C_{cc}(C_t + C_s + C_i) + C_i(C_t + C_s)} \quad \text{(X1.11)}$$

X1.6 Oscilloscope deflection sensitivity is defined as the value of the terminal corona-pulse voltage or terminal corona charge required to produce a deflection of unit height on the oscilloscope. The deflection sensitivity is calculated from the measured deflection to a calibrating pulse of known magnitude, with a factor included to account for the different circuit locations of the calibrating pulse generator and of the test specimen. The deflection sensitivity must be scaled to account for the location the calibration signal is injected relative to the location of the partial discharge signal in the circuit. This is the scale factor. The deflection sensitivity may also require correction to account for the change of location of the calibration signal insertion location. This is the correction factor. The oscilloscope deflection sensitivity and factors are:

X1.6.1 Fig. 1*A:*

$$\text{Deflection sensitivity, V/cm} = (V_c/H_c)(C_c/C_t) \quad \text{(X1.12)}$$

$$\text{Picocoulombs per centimetre} = \frac{V_c}{H_c} \times C_c \quad \text{(X1.13)}$$

X1.6.2 Fig. 1*B:*

$$\text{Deflection sensitivity, V/cm} = \frac{V_c C_c}{H_c C_t}\left(1 + \frac{C_i + C_s}{C_{cc}}\right) \quad \text{(X1.14)}$$

$$\text{Picocoulombs per centimetre} = \frac{V_c C_c}{H_c}\left(1 + \frac{C_i + C_s}{C_{cc}}\right) \quad \text{(X1.15)}$$

X1.6.3 Fig. 2*:*

$$\text{Deflection sensitivity, V/cm} = \frac{V_c C_c}{H_c C_t}\left(1 + \frac{C_t}{C_{cc} + C_s}\right) \quad \text{(X1.16)}$$

$$\text{Picocoulombs per centimetre} = \frac{V_c C_c}{H_c}\left(1 + \frac{C_t}{C_{cc} + C_s}\right) \quad \text{(X1.17)}$$

X1.7 The expressions for sensitivity in X1.5 for Fig. 1 show that when the value of the calibration capacitor is equal in value to the specimen capacitance, there is direct comparison between the calibration signal and the partial discharge signal. The expressions for Fig. 2 indicate that there will be direct comparison if the stray capacitance from the high voltage to ground is negligible and the value of the coupling capacitor is equal to the value of the calibration capacitor.

X1.8 The expressions for *CF* and *CF′* indicate that the correction factors are quantities dependent upon all the circuit components and cannot be made to be equal unity by a simple choice of circuit values.

## REFERENCES


**(1)** Bartnikas, R., and McMahon, E. J., *Engineering Dielectrics, Volume 1, Corona Measurement and Interpretation, ASTM STP 669*, ASTM, 1979, (www.astm.org/digitallibrary).

**(2)** *Symposium on Corona, ASTM STP 198, ASTM*, 1956, (www.astm.org/digitallibrary).

**(3)** Eager, G. S., and Bahder, G., "Discharge Detection in Extruded Polyethylene Insulated Power Cables," IEEE Transactions on Power Apparatus and Apparatus and Systems PAS-86: 10–34, January 1967.

**(4)** Goossens, R. E., "Progress Report of Study Committee No. 2 on High Voltage Cables," *Proceedings* of CIGRE, Report No. 21-01, Appendix 4, Paris, 1968, pp. 23–25.

**(5)** Bartnikas, R., "Partial Discharges: Their Mechanism, Detection and Measurement," IEEE Trans. on Dielectrics and Electrical Insulation Vol. 9, 2002, pp. 763-808.

**(6)** Narbut, P., "Transformer Corona Measurement Using Condenser Bushing Tap and Resonant Measuring Circuits," IEEE Trans. on Power Apparatus and Systems, Vol. PAS-84, 1965, pp. 652-657.

**(7)** Vaillancourt, G.H., Malewski, R., and Train, D., "Comparison of Three Techniques of PD Measurement in Power Transformers," IEEE Trans. on Power Apparatus and Systems, Vol. PAS-104, 1985, pp. 900-909.

**(8)** Fruth, B. and Gross, D., "PD Generation, Transmission and Acquisition", Proc. IEEE Sci. Meas. Tech., Vol. 142, 1995, pp. 22-28.

**(9)** Bartnikas, R., and Morin, R., " Multistress Aging of Stator Bars with Electrical, Thermal, and Mechanical Stresses as Simultaneous Acceleration Factors," IEEE Trans. on Energy Conversion, Vol. 19, 2004, pp. 702-714.

**(10)** Bartnikas, R., "A Comment Concerning the Rise Time of Partial Discharge Pulses," IEEE Trans. on Dielectrics and Electrical Insulation, Vol. 12, 2005, pp. 196-202.

**(11)** Whitehead, S., "Dielectric Breakdown of Solids," Oxfords, 1951.

**(12)** Vogel, F. J., "Corona Measurements and Their Interpretation Applied to Oil Insulated Transformers." 1972 IEEE Winter Power Meeting, Paper T72 093-8.

**(13)** Bartnikas, R., "Pulsed Corona Loss Measurement in Artificial Voids and Cables," CIGRE *Proceedings*, Part II, Paris, 1966, Paper 202, pp. 1–37

**(14)** Sahoo, N.C., Salama, M.M.A., and Bartnikas, R., "Trends in Partial Discharge Pattern Classification," IEEE Trans. on Dielectrics and Electrical Insulation, Vol. 12, 2005, pp. 248-264.

**(15)** Bartnikas, R., and Levi, J. H. E., "Improved Pulsed Discharge Rate Measuring Apparatus for Ionization Discharge Studies at Low Frequencies," *Review of Scientific Instruments*, RSINA, Vol 39 September 1966, pp. 1245–1251.

**(16)** Densley, J., "Recommended Safety Practices in High Voltage and High Power Testing," IEEE PSIM P510/D4.

**(17)** Bartnikas, R. and Srivastava, K.D., *Power and Communication Cables*, IEEE Press/J. Wiley and Sons, New York, 2003.


## SUMMARY OF CHANGES

Committee D09 has identified the location of selected changes to this test method since the last issue, D1868 – 07, that may impact the use of this test method. (Approved Nov. 1, 2013)

(*1*) Eliminated non mandatory language.