b) **Failure of gap to sparkover.** In making the chopped-wave test, failure of the chopping gap or any external part to sparkover, although the voltage oscillogram shows a chopped wave, is a definite indication of a failure either within the transformer or in the test circuit.

c) **Noise.** Unusual noise within the transformer at the instant of applying the impulse is an indication of trouble. Such noise should be investigated.

d) **Measurement.** Measurement of voltage and current induced in another winding may also be used for failure detection.

10.4 Routine impulse test for distribution transformers

For distribution transformers, the impulse tests specified in 10.3 are design tests. This subclause defines a routine quality control test that is suitable for high-volume production-line testing. The routine impulse test for distribution transformers applies to overhead, pad-mounted, and underground liquid-immersed distribution transformers with requirements specified in IEEE Std C57.12.20, IEEE Std C57.12.23, IEEE Std C57.12.24, IEEE Std C57.12.34, IEEE Std C57.12.36, and IEEE Std C57.12.38.

10.4.1 Terminals to be tested

In routine testing, impulse tests are applied to all high-voltage line terminals. Impulse tests of the low-voltage terminals or the neutral terminal are not required. Line terminals rated more than 600 V are considered high voltage.

10.4.2 Procedure

The windings under test are connected to ground through a low-impedance shunt. The tank, the core, and either one of the low-voltage terminals or the neutral terminal are also connected to the shunt or are directly grounded. This shunt shall consist of either of the following:

a) **Ground current method.** A suitable resistance shunt or wide-band pulse current transformer is employed to examine the waveform of the ground current.

b) **Neutral impedance method.** A low-impedance shunt, consisting of a parallel combination of resistance and capacitance (RC), is employed. The voltage across this neutral impedance shunt is examined.

An impulse voltage with $1.2 \times 50\ \mu s$ waveshape and with specified crest magnitude shall be applied in each test. The tolerances, polarity, and method of determining the waveshape shall be as specified in 10.3.1.1 and 10.3.1.5. During each test, the waveform of the ground current or the voltage wave across the neutral impedance shall be examined.

The required impulse tests shall be applied using either of the test series in Method 1 (10.4.2.1) or Method 2 (10.4.2.2).

10.4.2.1 Method 1

One reduced full-wave test is performed, followed by one 100% magnitude full-wave test. The applied-voltage wave in the first test shall have a crest value of between 50% and 70% of the assigned BIL. The applied-voltage wave in the second test shall have a crest value of 100% of the assigned BIL. Failure detection is accomplished by comparing the reduced full-wave test with the 100% magnitude full-wave test, using either the ground current waveform or the neutral impedance voltage waveform. A dielectric breakdown will cause a difference in compared waveforms. Observed differences in the waveforms may be indications of failure, or they may be due to non-injurious causes. The criteria used to judge the magnitude of observed differences shall be based on the ability to detect a staged single-turn fault made by placing a loop of wire around the core leg and over the coil.

10.4.2.2 Method 2

Two full-wave tests, with crest magnitude equal to the assigned BIL, are applied to the transformer under test. A neutral impedance shunt, using suitable values of resistance and capacitance, is employed to record waveforms for comparison. The waveforms in both tests are compared with preestablished levels. A dielectric breakdown will cause a significant upturn and increase in magnitude of the voltage wave examined across the neutral impedance. The preestablished levels are based on a staged single-turn fault test, made by placing a loop of wire around the core leg and over the coil.

10.4.2.3 Failure detection

The failure detection methods described in 10.4.2.1 and 10.4.2.2 for the routine impulse test are based on the following two conditions:

a) The transformer connections during the test are such that no low-voltage windings are shorted.

b) Chopped-wave tests are not applied.

In addition to these methods of failure detection, other methods of failure detection, as described in 10.3.4.2, are also indications of failure and should be investigated.

When the test is complete and the process of failure detection is complete, the waveform records may be discarded.

As an exception to the test sequence given in 10.1.5.1, the routine impulse test may be conducted either before or after the low-frequency dielectric tests; however, the preferred sequence is for the impulse test to precede the low-frequency dielectric tests.

10.4.3 Terminals not being tested

All high-voltage terminals not being tested shall be solidly grounded for impulse tests of the high-voltage windings. However, if two high-voltage terminals are grounded, causing a short circuit across one or more of the high-voltage windings, the failure detection sensitivity of the test may be impaired, and a single-turn fault may not be detectable. In such cases, only one high-voltage terminal should be grounded. Grounding through a low-impedance shunt for current measurements may be considered the equivalent of a solid ground. The low-voltage windings shall be solidly grounded for impulse tests of the high-voltage windings by applying the ground to only one low-voltage terminal in order to reduce the risk of a deliberate short circuit across any low-voltage winding. Selection of the low-voltage terminal to be grounded should be as follows:

a) For a single-phase three-wire connection, where X_2 would be grounded in service, terminal X_2 shall be solidly grounded and terminals X_1 and X_3 shall be open, except as provided in the paragraph that follows this list.

b) For a single-phase two-wire connection, where either X_1 or X_2 may be grounded in service, either terminal X_1 or X_2 shall be solidly grounded and the remaining terminal shall be open, except as provided in the paragraph that follows this list.

c) For a three-phase four-wire connection, where X_0 would be grounded in service, terminal X_0 shall be grounded and terminals X_1, X_2, and X_3 shall be open, except as provided in the paragraph that follows this list.

d) For a three-phase three-wire delta connection, only one of the low-voltage terminals X_1, X_2, or X_3 shall be solidly grounded and the two remaining terminals shall be open, except as provided in the paragraph that follows this list.

For series multiple or other low-voltage connections not covered specifically above, the low-voltage windings shall be grounded in accordance with the principle of grounding the winding without causing a direct short circuit across any low-voltage winding and preferably selecting the terminal that will be grounded in service.

It is permissible to limit the voltage to ground of any low-voltage terminal by connecting a resistor across the low-voltage windings. This resistor shall be sized to limit the induced voltage to less than 80% of the BIL of the terminal. Current flowing in the limiting resistor shall not interfere with the ability to detect a staged single-turn fault.

10.4.4 Windings for series or multiple connections

For high-voltage windings with series or multiple connections, the routine impulse test shall be conducted on each connection at its assigned BIL.

10.4.5 Windings for delta or wye connections

For high-voltage windings with delta or wye connections, the routine impulse test shall be conducted on each connection at its assigned BIL.

10.4.6 Tap connections

For windings with taps, the routine impulse test shall be performed in the tap connection for shipment in accordance with Clause 10 of IEEE Std C57.12.00-2021.

10.5 Low-frequency tests

Low-frequency tests shall be performed in accordance with the requirements of 5.10, Table 3, and Table 4 of IEEE Std C57.12.00-2021.

For distribution transformers and Class I power transformers, the low-frequency test levels are developed by the applied-voltage and induced-voltage tests described in 10.6 and 10.7, or combinations thereof. The induced-voltage test may involve either single-phase or three-phase excitation.

For single-phase transformers with a BIL of 150 kV or less that have only one high-voltage bushing, the high-voltage neutral terminal permanently connected to ground, and no secondary windings permanently grounded, no applied-voltage test is required. These transformers shall receive an induced-voltage test between the high-voltage terminal and ground with duration of 7200 cycles but not less than 15 s. This voltage shall be 1000 V plus 3.46 times the rated transformer winding voltage, but in no case shall the line-to-ground voltage developed exceed 40 000 V for 125 kV BIL or 50 000 V for 150 kV BIL. An applied-potential test shall be applied to all windings that are not permanently grounded.

For Class II power transformers, the low-frequency tests involve a special induced test as described in 10.8 and applied-voltage tests as described in 10.6.

10.5.1 Induced-voltage test for transformers with series or multiple connections

Transformers with windings that have multiple connections (series-parallel or delta-wye) and whose connections each have a nominal system voltage of 25 kV or above shall receive two induced tests, one in each connection. If more than one winding has such multiple connections, then the connections in each of the windings shall change between the tests, and the manufacturer shall determine the relative connections for each test. The test voltage and duration (Class I—7200 cycle or Class II—one-hour test) shall be contingent on the system voltage level of the high-voltage winding for the connection being tested. In all cases, the last induced test shall be for the connection with the highest test voltage.

10.6 Applied-voltage tests

10.6.1 Duration, frequency, and connections

The test shall be performed at low frequency (<500 Hz), and the duration of the test shall be 1 min.

The winding being tested shall have all its parts joined together and connected to the line terminal of the testing transformer.

All other terminals and parts (including core and tank) shall be connected to ground.

10.6.2 Relief gap

A relief gap set at a voltage 10% or more in excess of the specified test voltage may be connected during the applied-voltage test.

10.6.3 Application of test voltage

The voltage should be started at one quarter or less of the full value and be brought up gradually to full value. After being held for the time specified in 10.6.1, it should be reduced gradually before the circuit is opened.

10.6.4 Failure detection

Careful attention should be maintained for evidence of possible failure, such as an indication of smoke and bubbles rising in the insulating liquid, an audible sound such as a thump, or a sudden increase in test circuit current. Any such indication should be carefully investigated by observation, by repeating the test, or by other tests to determine whether a failure has occurred.

10.7 Induced-voltage tests for distribution and Class I power transformers

10.7.1 Test duration

The induced-voltage test shall be applied for 7200 cycles, or 60 s, whichever is shorter.

10.7.2 Test frequency

As an induced-voltage test applies greater than rated volts-per-turn to the transformer, the frequency of the impressed voltage shall be high enough to limit the flux density in the core to that permitted by 4.1.6.1 of IEEE Std C57.12.00-2021. The minimum test frequency to meet this condition is given in Equation (27).

$$\text{Minimum test frequency} = \frac{E_t}{1.1 \times E_r} \times \text{rated frequency} \tag{27}$$

where

E_t is the induced voltage across winding (V)
E_r is the rated voltage across winding (V)

10.7.3 Application of voltage

The voltage should be started at one quarter or less of full value and be brought up gradually to full value. After being held for the time specified in 10.7.1, it should be reduced gradually before the circuit is opened.

10.7.4 Grounding of windings

When a transformer has one end of the high-voltage winding grounded, the other windings should be grounded during the induced-voltage test. This ground on each winding may be made at a selected point of the winding itself or of the winding of a step-up transformer that is used to supply the voltage or that is connected for the purpose of furnishing the ground.

10.7.5 Need for additional induced tests

When the induced test on a winding results in a voltage between terminals of other windings in excess of the low-frequency test voltage specified in Table 3 or Table 4, as applicable, of IEEE Std C57.12.00-2021, the other winding may be sectionalized and grounded. Additional induced tests shall then be made to give the required test voltage between terminals of windings that were sectionalized.

10.7.6 Failure detection

Careful attention should be maintained for evidence of possible failure, such as an indication of smoke and bubbles rising in the insulating liquid, an audible sound such as a thump, a sudden increase in test circuit current, or an appreciable increase in partial discharge level. Any such indication should be carefully investigated by observation, by repeating the test, or by other tests to determine whether a failure has occurred.

10.7.7 Special induced voltage test for distribution and Class I power transformers with a wound core

This test to detect improper core grounding applies to distribution transformers and Class I power transformers, with a wound core, low–high winding construction, and having a high-voltage winding voltage of 25 kV (15 kV to ground) or greater. Note that this test is intended only for detection of inadequate core grounding issues and not for accessories like dead front bushings, tap-changers, current limiting fuses, or dual-voltage switches, which may have difficulty passing this test at 100 pC. The transformer may or may not contain such components. If the transformer fails the test with such components, the components may be removed or bypassed and the test re-run. The test shall be conducted on a transformer with functionally similar core grounding.

10.7.7.1 Minimum test duration and application of voltage

Partial discharge (PD) is to be measured as an apparent charge in picocoulombs (pC). One reading shall be made at the end of each interval. The minimum test durations and application of voltages are as follows:

a) Voltage shall be raised to 100% of rated volts for 30 s, and PD shall be measured and recorded.
b) Voltage shall be raised to 110% of rated volts for 30 s, and PD shall be measured and recorded.
c) Voltage shall be raised to 150% of rated volts for 60 s, and PD shall be measured and recorded.
d) Voltage shall be lowered to 140% of rated volts for 60 s, and PD shall be measured and recorded.
e) Voltage shall be lowered to 130% of rated volts for 60 s, and PD shall be measured and recorded.
f) Voltage shall be lowered to 120% of rated volts for 60 s, and PD shall be measured and recorded.
g) Voltage shall be lowered to 110% of rated volts for 10 min, and PD shall be measured and recorded.

10.7.7.2 Test frequency

The test frequency shall be in accordance with 10.7.2.

10.7.7.3 Grounding of windings

Windings shall be grounded in accordance with 10.7.4.

10.7.7.4 Failure detection

The test is considered passed if PD recorded in step g) of 10.7.7.1 does not exceed 100 pC. Judgment shall be used in test intervals such that momentary excursions beyond 100 pC may be acceptable; however, at the end of step g) of 10.7.7.1, PD shall not exceed 100 pC.

NOTE—Normally, transformers will pass the test if they are equipped with outside core grounds and with shielded and grounded inside outer core loops. In cases where pass–fail is marginal at the 110% voltage level, it is useful to continue reducing voltage until partial discharge is extinguished. Core gassing results in bubbles between core laminations that push liquid out and leave only gas that ionizes at much lower voltages than the insulating liquid. Hence, core gassing usually results in partial discharge extinction well below rated voltage. Most other components in the transformer behave more linearly and do not persist with partial discharge at or below rated voltage.

10.8 Induced-voltage test for Class II power transformers

10.8.1 General

Each Class II power transformer shall receive an induced-voltage test with the required test levels induced in the high-voltage winding. The tap connections shall be chosen, when possible, so that test levels developed in the other windings during the one-hour test are x times their maximum operating voltages, as specified in Table 4 of IEEE Std C57.12.00-2021, where x (also referred to as the “overvoltage factor” in the text that follows) is the ratio of the test voltage on the high-voltage winding to the maximum operating voltage.

For a transformer built with a single magnetic core holding all windings, all windings are excited at a unique induction level, often referred to as “volts-per-turn.” During an induced-voltage test, with the transformer connected and excited as in service, all windings are excited at the same overvoltage factor, regardless of what tap is selected. Each winding turn receives the same voltage. The tap connections shall be chosen, when possible, such that voltages developed across other windings meet or exceed the required overvoltage factor.

The situation is quite different when transformers are equipped with auxiliary devices with separate magnetic cores, such as preventive autotransformer (reactor), series (booster) transformer, or series regulator. Different magnetic cores can be excited at different levels during operation or testing. In certain tap positions, these auxiliary devices do not have their core excited at all and no voltage appears across their windings. For such cases, the selection of the tap-changer position shall be guided by the principles described below. One exception is when such auxiliary devices are not excited on a permanent basis but used only as transitional devices. If equalizing windings are used, the highest voltage impressed across the preventive autotransformer will occur in either the bridging or non-bridging positions. This is because the preventive autotransformer is energized in all tap positions (bridging and non-bridging).

NOTE 1—Equalizing windings are described in IEEE Std C57.131 and IEC 60214-1.

For transformers equipped with a series (booster) transformer, preventive autotransformer (reactor), or any other device, the selected tap position of the load tap-changer (LTC) shall be the one that produces the highest voltage across the windings of the series transformer, preventive autotransformer, and other auxiliary devices as applicable. There can be a conflict of choosing such a tap position when more than one such device is present. In such a case, the selected tap position of the LTC should be the best compromise so that all devices are tested with overvoltage. One common example is the case where a series transformer and preventive autotransformer are both present. In this case, the tap selected shall be the one that is closest to the position that produces the highest voltage across the windings of the series transformer and simultaneously excites the preventive autotransformer, which is typically a bridging position (not applicable when the preventive autotransformer is energized only during transition).

In order to test the series (booster) transformer, preventive autotransformer, and other devices, at the required minimum overvoltage factor, the voltage developed on the terminals of other windings may exceed the one-hour level mentioned in Table 4 of IEEE Std C57.12.00-2021. In such cases, an alternative tap position may be selected by agreement between the manufacturer and the purchaser to avoid overstressing components such as bushings. Annex D shows examples that can serve as a guide to select the LTC tap position for transformers having series (booster) transformer and/or preventive autotransformers.

For certain types of devices such as series reactors used as current limiting devices, there is no voltage developed across their windings during the induced voltage test as these devices are only excited when current flows in their windings. There is no option available to apply any overvoltage for these devices during the induced test.

NOTE 2—The selection of the tap-changer position for induced test should be agreed upon between manufacturer and purchaser prior to design to avoid conflicts during final acceptance tests.

10.8.2 Test procedure

The voltage shall first be raised to the one-hour level and held for a minimum of 1 min or until a stable partial discharge level is obtained to verify that there are no partial discharge problems. The level of partial discharges shall be recorded just before raising the voltage to the enhancement level. The voltage shall then be raised to the enhancement level and held for 7200 cycles. The voltage shall then be reduced directly to the one-hour level and held for 1 h.

During this 1 h period, partial discharge measurements shall be made at 5 min intervals. Partial discharge acceptance criteria shall be based on each line terminal rated 69 kV and above. These measurements shall be made in accordance with 10.9.

The pressure inside the transformer tank during the induced test shall not be increased by artificial means for the purpose of reducing the PD level. The liquid level and pressure inside of the transformer tank and/or conservator tank shall be configured such that the oil head pressure during the induced test does not exceed the pressure under usual service conditions. Any exceptions that increase tank pressure by more than 3.5 kPa (0.5 psi) over normal operating pressure, such as the use of an elevated test facility conservator tank, requires customer approval prior to test. A note shall be added to the certified test report confirming this approval.

NOTE—Increasing the pressure for diagnostic purposes, such as to identify and possibly reduce suspected bubbles in the liquid, may be done as a remedial step to diagnose a source of high PD. To be considered valid, the test needs to be repeated with no added pressure as stated previously.

10.8.3 Connections

The transformer shall be excited exactly as it will be in service. The voltage may be induced from any winding or from special windings or taps provided for test purposes. Single-phase transformers shall be excited from single-phase sources. Three-phase transformers shall be excited from three-phase sources. The neutral terminals and other terminals that are normally grounded in service shall be solidly grounded. This will stress all of the insulation at the same per unit of overstress.

10.8.4 Frequency

The test frequency shall be increased, relative to operating frequency, as required to avoid core saturation. The requirements in 10.7.2 are also applicable in the case of this induced test.

10.8.5 Failure detection

Failure may be indicated by the presence of smoke and bubbles rising in the insulating liquid, an audible sound such as a thump, or a sudden increase in the test current. Any such indication shall be carefully investigated by observation, by repeating the test, and by other diagnostic tests to determine whether a failure has occurred. In terms of interpretation of partial discharge measurements, the results shall be considered acceptable and no further partial discharge tests required under the following conditions:

a) The magnitude of the partial discharge level does not exceed 250 pC during the 1 h test period.

b) The increase in partial discharge levels during the 1 h period does not exceed 50 pC.

c) The partial discharge levels during the 1 h period do not exhibit any steadily rising trend, and no sudden sustained increase in the levels occurs during the last 20 min of the test.

Judgment should be used on the 5 min readings so that momentary excursions of the partial discharge readings caused by cranes or other ambient sources are not recorded. Also, the test may be extended or repeated until acceptable results are obtained.

A failure to meet the partial discharge acceptance criterion shall not warrant immediate rejection, but it shall lead to consultation between purchaser and manufacturer about further investigations.

10.9 Partial discharge measurement

10.9.1 Internal partial discharges

Apparent internal partial discharges (apparent charge) shall be measured at the terminals of the transformer windings under test and reported in units of picocoulombs (pC).

Where agreed to by both the purchaser and the manufacturer, radio influence voltage (RIV) measurements may be used in lieu of, or in conjunction with, apparent charge measurements. The procedure for RIV measurements is included in Annex A.

10.9.2 Instrumentation

A partial discharge meter shall be used to measure the apparent charge generated by any internal partial discharges. The partial discharge detector, based on IEEE Std C57.113, is used to measure the partial discharge levels at the terminals. The partial discharge meter shall be coupled to the line terminal(s) of the winding(s) under test through the voltage tap of the bushing(s) or through a suitable coupling capacitor connected in parallel with the bushing. General principles and circuits are described in IEEE Std C57.113.

External shielding may be used to avoid air corona, such as may occur at the bushing terminals or grounded projections. Radio-frequency chokes or tuned filters may be used to isolate the transformer under test and the partial-discharge-measuring circuit from the remainder of the test circuit, including its energy source.

10.9.3 Calibration

The test circuit shall be calibrated according to IEEE Std C57.113.

10.10 Insulation power-factor tests

The insulation power factor is the ratio of the power dissipated in the insulation in watts to the product of the effective voltage and current in voltamperes when tested under a sinusoidal voltage and prescribed conditions.

The methods described in this standard are applicable to distribution and power transformers of present-day design that are immersed in an insulating liquid.

10.10.1 Preparation for tests

The test specimen shall have the following:

a) All windings immersed in insulating liquid.

b) All windings short-circuited.

c) All bushings in place.

d) The average temperature of the windings and insulating liquid should be between 10 °C and 40 °C, but preferably as close to 20 °C as practical. The top liquid temperature shall be measured and recorded.

10.10.2 Instrumentation

The insulation power factor may be measured by special bridge circuits or by the voltampere-watt method. The accuracy of measurement should be within ±0.25% insulation power factor, and the measurement should be made at or near a frequency of 60 Hz.

10.10.3 Voltage to be applied

The voltage to be applied for measuring insulation power factor shall not exceed half of the low-frequency test voltage given in Table 3 or Table 4 of IEEE Std C57.12.00-2021 for any part of the winding or 10 000 V, whichever is lower.

10.10.4 Procedure

Insulation power-factor tests shall be made from windings to ground and between windings as shown in Table 4.

Table 4—Measurements to be made in insulation power-factor tests

Method I **Test without guard circuit**[a]	**Method II** **Test with guard circuit**[a]
Two-winding transformers[b]	Two-winding transformers[b]
High to low and ground	High to low and ground
Low to high and ground	High to ground, guard on low
High and low to ground	Low to high and ground
—	Low to ground, guard on high
Three-winding transformers[b]	Three-winding transformers[b]
High to low, tertiary, and ground	High to low and ground, guard on tertiary
Low to high, tertiary, and ground	High to ground, guard on low and tertiary
Tertiary to high, low, and ground	Low to tertiary and ground, guard on high
High and low to tertiary and ground	Low to ground, guard on high and tertiary
High and tertiary to low and ground	Tertiary to high and ground, guard on low
Low and tertiary to high and ground	Tertiary to ground, guard on high and low
High, low, and tertiary to ground	High and low to tertiary and ground
	High and tertiary to low and ground

NOTE 1—Although the real significance that can be attached to the power factor of liquid-immersed transformers is still a matter of opinion, experience has shown that the power factor is helpful in assessing the probable condition of the insulation when good judgment is used.

NOTE 2—In interpreting the results of power-factor test values, the comparative values of tests taken at periodic intervals are useful in identifying potential problems rather than an absolute value of power factor.

NOTE 3—A factory power-factor test will be of value for comparison with field power-factor measurements to assess the probable condition of the insulation. It has not been feasible to establish standard power-factor values for liquid-immersed transformers for the following reasons:

a) Experience has indicated that little or no relation exists between power factor and the ability of the transformer to withstand the prescribed dielectric tests.
b) Experience has shown that the variation in power factor with temperature is substantial and erratic so that no single correction curve will fit all cases. The power factor should be reported along with the top liquid temperature measured and the bottom liquid temperature if available. No temperature correction should be applied. Temperature correction of the power factor results for trending basis may be applied by the purchaser.
c) The various liquids and insulating materials used in transformers result in large variations in insulation power-factor values.

[a] In this table, the term *guard* signifies one or more conducting elements arranged and connected on an electrical instrument or measuring circuit to divert unwanted currents from the measuring means.
[b] Permanently connected windings, such as in autotransformers and regulators, shall be considered as one winding.

10.11 Insulation resistance tests

Insulation resistance tests shall be made when specified. Insulation resistance tests are made to determine the insulation resistance from individual windings to ground or between individual windings. Insulation resistance tests are commonly measured in megohms or may be calculated from measurements of applied voltage and leakage current.

NOTE 1—The insulation resistance of electrical apparatus is of doubtful significance compared to the dielectric strength. It is subject to wide variation in design, temperature, dryness, and cleanliness of the parts. When the insulation resistance falls below prescribed values, it can, in most cases of good design and where no defect exists, be brought up to the required standard by cleaning and drying the apparatus. Therefore, the insulation resistance may be useful to indicate whether the apparatus is in suitable condition for application of dielectric test.

NOTE 2—The significance values of insulation-resistance tests generally require some interpretation, depending on the design and the dryness and cleanliness of the insulation involved. When a purchaser decides to make insulation resistance tests, it is recommended that insulation resistance values be measured periodically (during maintenance shutdown) and plotted. Substantial variations in the plotted insulation resistance values should be investigated for cause.

NOTE 3—Insulation resistances may vary with applied voltage, and any comparison should be made with measurements at the same voltage.

NOTE 4—Under no circumstances should tests be made while the transformer is under vacuum.

10.11.1 Preparation for tests

The test specimen shall have the following:

a) All windings immersed in insulating liquid
b) All windings short-circuited
c) All bushings in place
d) Temperature of windings and insulating liquid near (the reference temperature of) 20 ºC

10.11.2 Instrumentation

Insulation resistance may be measured using the following equipment:

a) A variable-voltage dc power supply with means to measure voltage and current (generally in microamperes or milliamperes)
b) A megohmmeter

NOTE—Megohmmeters are commonly available with nominal voltages of 500 V, 1000 V, and 2500 V; dc applied test equipment is available at higher voltages.

10.11.3 Voltage to be applied

The dc voltage applied for measuring insulation resistance to ground shall not exceed a value equal to the rms low frequency applied voltage allowed in 10.6.

NOTE 1—Partial discharges should not be present during insulation resistance tests because they may result in erroneous values of insulation resistance.

NOTE 2—When measurements are to be made using dc voltages exceeding the rms operating voltage of the winding involved (or 1000 V for a solidly grounded wye winding), a relief gap may be employed to protect the insulation.

10.11.4 Procedure

Insulation-resistance tests shall be made with all circuits of equal voltage above ground connected together. Circuits or groups of circuits of different voltage above ground shall be tested separately. Examples of procedures include the following:

a) High voltage to low voltage and ground, low voltage to high voltage and ground.
b) Voltage should be increased in increments, typically 1 kV to 5 kV, and held for 1 min while the current is read.
c) The test should be discontinued immediately if the current begins to increase without stabilizing.
d) After the test has been completed, all terminals should be grounded for enough time to allow any trapped charges to decay to a negligible value.