The Dielectric Voltage Withstand Test

Benefits and limitations

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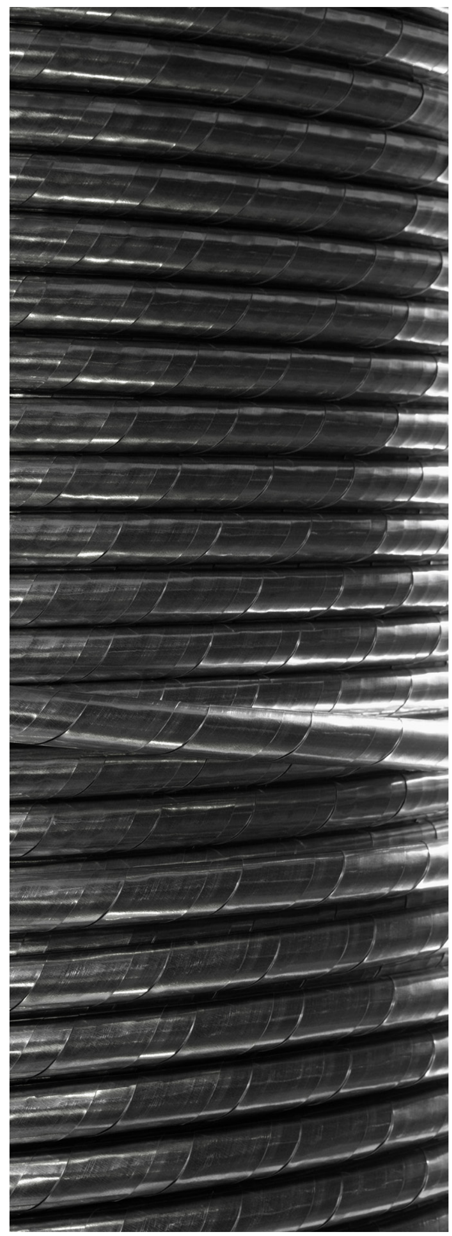
The dielectric voltage withstand test is an integral part of the product safety evaluation of electrical and electronic devices, and provides manufacturers with important information regarding the quality and appropriateness of the chosen insulation system. The test involves placing an extra-high voltage across the insulation barrier of the device for one minute. If the insulation holds the voltage, the device is deemed to have passed the test. However, if the applied voltage leads to the sudden breakdown of the insulation material and allows current to flow, the insulation is determined to be insufficient since it might pose a shock hazard to users.

While the dielectric voltage withstand test is widely used, the real objective of the test is often misunderstood, which may lead to incomplete testing or misleading test results. This white paper seeks to clarify the theory of dielectric breakdown and the objective of the dielectric voltage withstand test. It explores the applications and limitations of the test in order to better ensure its appropriate use in the product safety approval process.

The Mechanism of Insulating Materials

Current flows in a material when an electromotive force is applied that is strong enough to force the movement of electric charge. This charge movement is carried by electrons in the material, and can be measured as electric current. Metals, such as copper, have many free electrons available to transfer electric charge. This makes copper a good conductor because there is little resistance to the flow of charge and the energy lost as heat, due to current is minimal.

The performance of conductive materials is in marked contrast to that of insulating materials, which have a physical structure that prevents the easy movement of electrons. Since the electrons cannot move freely, they cannot effectively carry charge through the material. However, it is always possible to force the material to conduct by exposing it to sufficiently high voltage.



The Theory of Dielectric Breakdown

The dielectric breakdown of an insulating material is a complex physical phenomenon but it may be generally characterized as a sudden change in the resistance of the insulation under test due to the applied voltage. Simply stated, the test voltage breaks down the insulating properties of the material.

The mechanism of dielectric breakdown begins with the application of a strong electric field to the insulating material by a high voltage. Different materials require different levels of electric field in order for dielectric breakdown to occur. Metals and other conductors have free electrons without the application of any electric field, but insulating materials typically require a very high electric field to allow electrical current to flow.

When the electric field is sufficient, it energizes the insulator's electrons until they gain enough energy to cross the bandgap and move into the conduction band, dramatically increasing the conductivity of the material. This transformation is called dielectric breakdown and the electric field necessary to start the breakdown is called the dielectric strength, or breakdown strength.

Thus, dielectric breakdown is a dramatic and sudden increase in the conductivity of a material due to an applied voltage.

Leakage Current vs. Dielectric Current

Figure 1 illustrates a simple insulation model which applies to every electrical and electronic device.

The resistor accounts for resistive current through the insulation and the capacitor accounts for capacitively coupled currents. For modern insulation material, the insulation resistance is very large, so resistive current is typically several orders of magnitude lower than the capacitively coupled current. The spark gap represents the avalanche (breakdown) phenomenon, where a good insulator turns bad after a certain voltage is reached.

When a voltage is applied to an electrical or electronic device, the natural capacitance of the insulation charges, resulting in the flow of current. If a DC voltage is applied, the charging occurs only when voltage is first applied. The DC voltage charges the capacitance and the capacitive charging current is then reduced to near zero.

For 60 Hz AC voltages, the charging and discharging of this capacitance occurs 60 times each second, so the capacitive charging current remains at a steady-state level and never goes to zero. This is known as capacitive leakage current. For modern electronic devices, the resistive leakage current is normally very small, so the overall leakage current of such devices is dominated by the capacitive effect. To protect users from injury, many product safety standards set limits for the allowable leakage current. A typical leakage current limit is 0.5mA at 60 Hz and at the rated voltage.

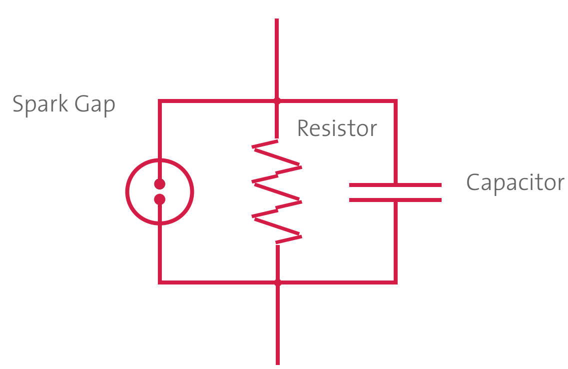


Figure 1: Basic insulation scheme in electrical products

Electrical and electronic devices also exhibit current analogous to leakage current during dielectric testing. However, since the dielectric test voltage is much higher, the current will be higher as well because the capacitive charging current increases in proportion to the increased voltage. Using the example from above, a device with a leakage current of 0.5mA at 120 Vac would be expected to have approximately 5.2mA dielectric current during a 1240 Vac dielectric test.

To avoid confusion, this paper uses the term "leakage current" when describing leakage current when the circuit is at rated voltage and "dielectric current" when describing the analogous current when the circuit is exposed to the dielectric test voltage.

The dielectric strength test is not intended to evaluate the amount of leakage current, as these two tests have fundamentally different objectives and compliance criteria. The leakage current limit is only applicable to the leakage current test, and only at the rated voltage.

Objective of the Dielectric Voltage Withstand Test

The human heart is controlled by the body's nervous system using electrical impulses. Even small currents passing through the heart can interrupt this control, leading to ventricular fibrillation and in the most severe instances, to death. Thus, the most fundamental requirement of electrical safety is to provide sufficient separation between the human body and hazardous currents to avoid interrupting the heart's normal function.

In addition to ventricular fibrillation, the human body may also exhibit an involuntary startle reaction and/or muscle contraction in reaction to currents that pass through parts of the body. These reactions can lead to hazards from the uncontrolled body movements than can occur when a person is subjected to the unpleasant nerve and muscle stimulation of electric current. Current passing through the body may also cause muscle contractions that make it impossible to let go of the electrical source.

Protecting humans from hazardous currents is typically accomplished by preventing contact with any electrical circuits that carry sufficient voltage and current to shock the user. To isolate these circuits from human contact, electrical and electronic devices employ electrical insulation, the quality of which must be sufficient for the working voltage throughout the expected life of the device. The dielectric voltage withstand test is performed in order to verify the capability of the insulation.

Air is the most readily available electrical insulator, and through-air spacing requirements (also known as "clearance") are defined in many product safety standards in order to maintain voltage separation. Spacings across the surface of an insulating material are known as over-surface spacings or "creepage" and are often defined in applicable standards. However, even in cases where a device complies with the defined through-air and over-surface spacing requirements, the overall insulation system must be tested by the application of the dielectric voltage withstand test to the insulation system.

The applied voltage for the dielectric voltage withstand test is usually much higher than the working voltage of the device to accommodate transient overvoltages, such as voltage surges and switching transients. This provides a safety margin for production variations and the aging of the material.

The objective of the dielectric voltage withstand test is to establish the minimum level of electrical insulation necessary to prevent human contact with a potentially harmful voltage and resulting current. In addition, the dielectric voltage withstand test may reveal faults in mechanically damaged insulation or the presence of a foreign material (such as water) which may bridge the insulation. This test is often used after mechanical abuse or temperature tests to confirm that the product has maintained its insulating capabilities.

The dielectric voltage withstand test is also used on the manufacturing production line to identify material and workmanship defects in assembled devices.

Trip Current During the Dielectric Voltage Withstand Test

When dielectric breakdown occurs, the loss of the insulation material's resistance causes the current to go from a low dielectric current level to a much higher breakdown current. This change in the level of dielectric current has traditionally been monitored by a current-sensitive circuit, which trips-out the test equipment when the current exceeds the test equipment's trip sensitivity setting. This approach has the significant advantages of being simple and inexpensive and has been used for many years. However, although this method works reasonably well a closer analysis reveals potential limits to its use.

The Problem of False Failures

The use of a trip current setting to determine dielectric breakdown is based on the assumption that current above the trip setting is indicative of dielectric breakdown. While this is true in many cases, there are instances in which a current above the trip-out threshold is not indicative of a breakdown at all. It may actually be reflective of the natural dielectric current of the tested device. Thus, the following dilemma: Trip-out might indicate dielectric breakdown (a failure condition) or it might merely indicate dielectric current above the trip- current setting (not a failure condition). This uncertainty may lead to test results deemed unacceptable, when the results actually mask a favorable outcome (See Figures 2 and 3).

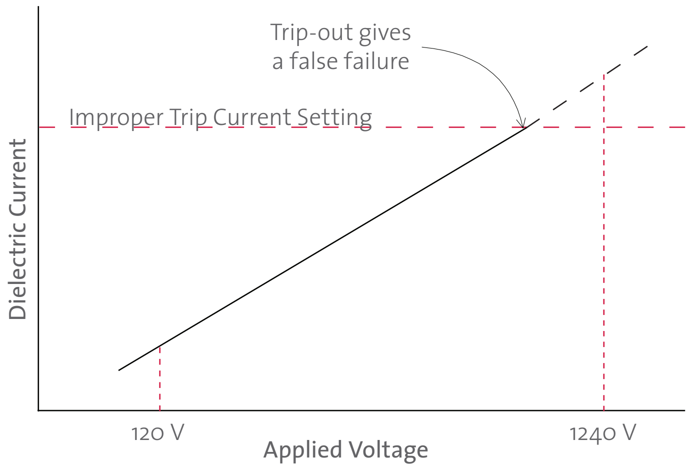


Figure 2

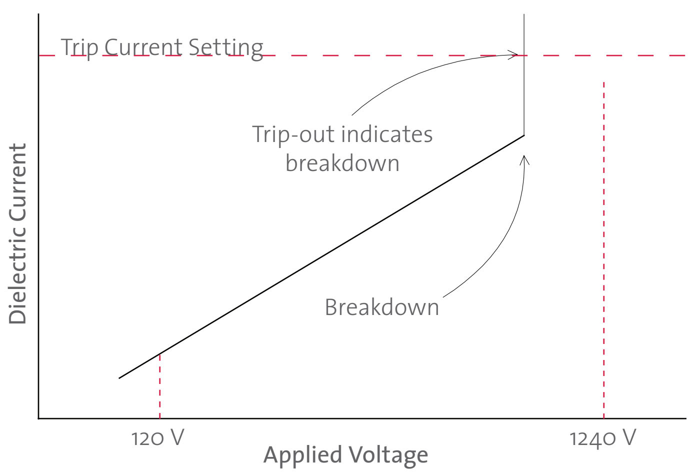


Figure 3

Because the dielectric test is intended to evaluate the insulation system, no limit is specified for dielectric current. Thus, there is no correct trip-out current setting for determining failure. In practice, the only valid determining criterion for failure is "breakdown." The precise value of dielectric current which flows is unimportant; what is important is the sudden, dramatic increase in the dielectric current, indicating that insulation breakdown has occurred. It is for this reason that most product safety standards do not specify a trip current threshold for the dielectric test.

However, if the expected leakage current is known, then a common procedure is to set the trip-out threshold at 20 times the maximum leakage current limit. This multiplier includes a factor of 10 for the approximate ratio of the dielectric test voltage divided by the normal operating voltage, and a factor of 2 for variability. If the current exceeds this higher trip-out level, it is likely the result of a dielectric failure, and not the expected current flowing in the leakage current path from the application of the dielectric test voltage.

To summarize, tripping of the dielectric tester only signifies that the trip current setting of the tester has been exceeded. Therefore, this result should not be automatically interpreted to mean that breakdown has occurred and further testing or evaluation should be conducted. This further evaluation may include several different investigative paths, including DC dielectric testing, use of dielectric testers with arc detection, specialized diagnostic testers and reapplication of the dielectric withstand test voltage to locate the site of the breakdown.

AC vs. DC Dielectric Testing

The objective of dielectric testing can be met with DC as well as AC voltages. In fact, many product safety standards already include DC voltages in their dielectric test methods. When testing with DC voltage, the metered voltage must be set for a voltage equal to 1.414 times the AC test voltage, since the AC voltage measurement is an RMS value. The actual peak voltages from the AC wave are 1.414 times the metered AC RMS value. Thus, the DC test voltage is equal to the highest peak AC voltage.

With a DC test, steady-state dielectric current will be much lower because the product's capacitance is charged only once. This occurs at the beginning of the voltage application. If the test voltage is raised slowly, the charging current will be low and, once the test voltage stabilizes, there will be very little current flow. This is an advantage because the trip-out limit of the dielectric tester can be set lower without causing false alarms.

If the voltage is ramped up too quickly, the capacitive charging current may create false failures. Trip-out during DC voltage ramp-up must be examined to determine if the cause of the trip-out is normal charging current. Repeating the test with a doubled ramp time may provide a simple testing solution.

Some products contain electromagnetic interference filters, which may add capacitance. To accommodate these filters, the leakage current limit in some product safety standards is 3.5 mA. The expected current during a dielectric test might be as high as 3.5 mA times 1240 V / 120V = 36 mA ac rms. With this heavy loading, some dielectric testers are not able to deliver enough voltage across the terminals to perform the test. However, if a DC test is used, the capacitive current is just the one-time charging current. Once the capacitance is charged, the dielectric tester requires only a small current load that the tester can easily supply. In the case of high leakage current limits, replacing the AC test with a DC test may be necessary, unless the AC dielectric tester has enough capacity to deliver the test voltage under heavy current load.

There is one disadvantage to DC testing, which becomes evident at the end of the test. Once DC testing has been completed, the inherent capacitance of the device under test has been fully charged and now poses a potential shock hazard. Accordingly, certain products may need to be discharged via a short with a bleeder resistor, adding another step and complexity to the DC dielectric test.

Summary

The dielectric voltage withstand test can provide important insight into the capabilities and limits of a device's insulation system. However, it is important to remember that the objective of the test is only to evaluate the insulation's electrical strength. The current during the dielectric test should not be evaluated against the device's leakage current limits, since the dielectric test is performed at a much higher voltage.

It is common for dielectric test equipment to use a current trip-out limit to indicate dielectric failure. When the tripping device is properly set to allow the expected current to flow through an acceptable dielectric current path, the dielectric test equipment will give trustworthy results. However, in cases where the expected current is not known or the trip-out threshold is selected generically, the trip- out may produce a false failure result. Thus, trip-out by itself should not be assumed to indicate a true dielectric breakdown.

An indication of trip-out should always be followed by an investigation into the root cause of the trip-out. Such an investigation will then lead to an invaluable discussion as to the fundamental quality of the device's electrical insulation system.

For additional information about The Dielectric Voltage Withstand Test — Benefits and Limitations white paper, please contact Paul W. Brazis Jr., PhD, Research Manager, Electrical Hazards at paul.brazis@us.ul.com.