# CABLE TESTING - AN OVERVIEW

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## Why Test Wiring, Components and Connectors in Electrical Products?

Production testing of insulated wiring, components and connectors can reduce waste and re-work time, optimize the manufacturing process and most importantly, ensure end-user safety. It is important to understand what levels of testing, product performance and end-user safety are required. A defective AC power cord can result in destruction of the product or worse, electrocution of the user. The manufacturer must be able to know with certainty that the product will be functional, meet customer's objectives and comply with the relevant safety requirements. These factors must be considered collectively to determine the level of testing that is necessary, whether that method is simply a quick visual inspection or a 100% test regimen including functional, low and high voltage tests.

Production testing of insulated wiring, components and connectors can reduce waste and re-work time, optimize the manufacturing process and most importantly, ensure end-user safety

It is generally accepted that a wiring harness or power cord should have effective insulation and proper connections with no miswires or intermittent faults. A component should fall within its prescribed tolerance range while an active component should be able to perform the required function or action. Similarly, a complex product (e.g. an aircraft or train) containing some or all of these elements will typically undergo a final assembly test that can include evaluation of all of the above.

Insulation, connections and intermittent faults can be verified to different degrees using low-voltage, high voltage and, where necessary, high current testing methods. Basic continuity testing can range from a very quick 'pass/fail' assessment of a wire connection to precise resistance measurement (generally this can range from a few milliohms to several ohms for a simple cable). For power cords and appliances, high-voltage testing is used to ensure the integrity of the line, neutral and ground circuits. In other cases, high current may be required to energize a component or assembly in order to evaluate it. Some of the most common types of production tests that can be performed on wired electrical products are summarized in the following table.

Table 1.

| | Test Type | Test Objective | Typical Applied Voltage Range | Typical Applied Current Range | Typical Test Duration (sec/point) | Typical 'Pass' Criterion | Typical Product Tested |
|---|---|---|---|---|---|---|---|
| Low Voltage, Low Current | Continuity | detection of unterminated or broken conductors | 5 – 50 VDC | 1-100 mA | .001 sec | R < X<br>'X' varies from mΩ to Ω | data cables, wire harnesses power cords, backplanes |
| | Isolation | detection of unintentional metal-to-metal contact between conductors | 5 – 50 VDC | 1-100 mA | .001 sec | R > X<br>'X' varies from Ω to kΩ | |
| | Miswire | detection of conductors terminated to the wrong point | 5 – 50 VDC | 1-100 mA | .001 sec | All points connected as expected | |
| | Intermittent Open/Short | detect unintended opens or shorts when mechanical force is applied | 5 – 50 VDC | 1-100 mA | Variable | No faults detected during sample cycle | |
| | 2-wire or Simplex resistance measurement | resistance measurement of values greater than 1 Ω | 5 – 40 VDC | 1-100 mA | < 1 sec | $X \le R \le Y$<br>X, Y vary from mΩ to MΩ<br>Measured accuracy of 5% or greater | Wire harnesses, cables, resistors |
| Low Voltage, High Current | 4-wire or Kelvin resistance measurement | sub Ω resistance measurement | 5 – 40 VDC | 1 mA - 5 A | < 1 sec | $X \le R \le Y$<br>X, Y vary from mΩ to Ω<br>Measured accuracy of 1% or less | precision components, IC's |
| | Functional Testing | energize components or assemblies to ensure proper operation | Varies by Product | Varies by Product | Varies by Product | Required action is performed correctly | IC's, relays, diodes, instrument panels |
| | Ground Integrity[2] | detection of poor ground connection or continuity | 12 - 20 VDC | 1 – 30 A | < 1 sec | R < X<br>X varies from mΩ to MΩ | power cords, appliances, computers |
| High Voltage, Low Current [3] | Insulation Resistance | detection of insulation defects | 250 V – 30 kVDC | 5 – 50 mA | 1 – 60 sec | 'Pass' if IR ≥ X<br>X in the MΩ to GΩ range | data cables, wire harnesses, power cords, backplanes, bulk wire, locomotives, aircraft |
| | Dielectric Withstand (HiPot) | detection of insulation defects | 250 V – 30 kVAC | 5 – 250 mA | 1 – several minutes | 'Pass' if no breakdown is detected | |
| | Skin Test (HiPot) | detection of stray conductors at the plug surface | 2.5 kV – 6.0 kVAC | 5 mA | 1 – 60 sec | 'Pass' if no arcing is detected | power cords and cord sets |

TABLE 1: TYPICAL TESTS FOR WIRED ELECTRICAL PRODUCTS [1]

1 Table 1 is intended to illustrate typical examples of production electrical tests and general test criteria. In all cases, the appropriate standard or criteria must be observed when performing these tests.

2 In the context of this paper, the production Ground Integrity test is discussed in terms of power cords and cord sets only. A separate Ground Integrity test is performed on appliances, computers and medical devices.

3 Some high voltage specifications allow DC voltage to be used in place of the prescribed AC test voltage. In these cases, the AC voltage should be multiplied by a factor of 1.414 to obtain the equivalent DC voltage.

Fortunately, modern Automated Test Equipment (ATE) offers functionality and performance that enables:

- low-voltage continuity, isolation, and intermittent fault detection/location;
- high-voltage tests including 'Dielectric Withstand' and 'Insulation Resistance';
- high-current stimulus to perform 'Ground Integrity' tests as well as high-accuracy resistance measurement and functional tests;
- measurement accuracy that is several times greater than the most sensitive components in the Product Under Test (PUT);
- guided-assembly capability (also known as "Build-Aid") to test the product as it is assembled so that a 'zero-defect' product is guaranteed;
- automatic test list/program generation based on data from CAD-CAM packages;
- integration with other automated and operator-controlled test equipment;
- test speeds in excess of several thousand measurements per second;
- test system expandability from 10 points to tens of thousands; and
- automated assembly line integration.

With many options to select from, test engineers must establish what equipment is necessary to ensure product compliance with local regulations

With all of these options to select from, the test engineer must establish what equipment is necessary to ensure product compliance with local regulations and minimize the consequences of re-work, scrap and litigation associated with the manufacture of a defective product. Can the product be adequately tested by visual inspection? Is it less expensive to reject a failed product than to take the time to repair it? Are there safety issues or compliance standards that have to be addressed? What are the legal and moral implications of a defective product reaching the end user? All of these factors must be considered when selecting the method and equipment required to cost-effectively satisfy the test objectives.

## Low Voltage, Low Current Testing

The detection of unintended opens, shorts, miswires and faults in cords, cables, wire harnesses and other components typically involves the use of low-voltage and low-current test equipment. This equipment can range from simple hand-held voltmeters, ohmmeters and ammeters, to fully automated wiring analyzers and cord testers that measure, interpret and record the results. Using a stimulus that is generally less than 5mA at 50 volts DC (and commonly ranging from 5 – 12 VDC), a voltage is applied between two points to determine whether they are connected or isolated (Figure 1).

Figure 1.

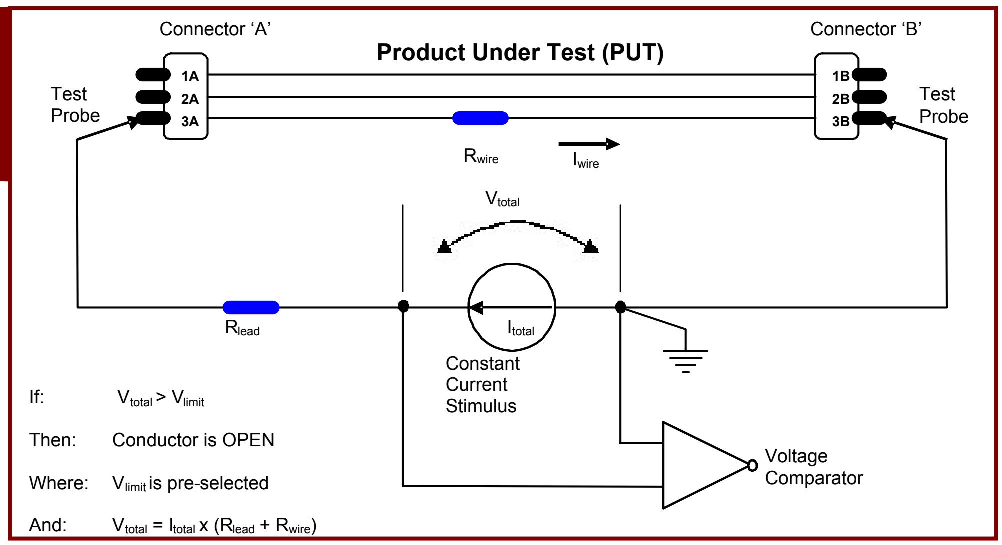


FIGURE 1: BASIC ANALOG CONTINUITY TESTING ON A 3-CONDUCTOR CABLE

Intermittent opens and shorts can be caused by a number of factors such as loose strands caused by improper crimping, damaged insulation and contaminated terminator contacts. When wiring defects exist in a complex product, it may be important to identify the type of fault, where it is located and whether or not it is intermittent. For instance, cable harnesses with multiple connectors and wire bundles can be costly to assemble and much more expensive to repair without a clear understanding of what faults exist and where they are occurring. As well, products that are subjected to flexing and vibration in service may need further evaluation to detect intermittent opens and shorts during both the production and maintenance stages.

Using the appropriate test equipment, opens and shorts can be located accurately using comparative capacitance and resistance measurements relative to all other points in the product. To identify intermittent continuity faults, a 'flex test' can be performed by applying a constant stimulus while an operator, vibration table or robot manipulates the product. The test equipment takes continuous measurements during the flex cycle and records any detection of an open or short. While this type of flex test can be a useful tool for detecting intermittent continuity, it cannot be relied on to detect loose conductor strands and improper connections. This is because the change in resistance caused by one or two loose strands is much less than the resistance change that can occur due to minor variations in temperature, connector surface condition and the total conductor length. To detect improper connections and loose strands, it is usually more reliable and practical to perform visual and mechanical inspections prior to final assembly electrical testing.

In general, the basic set of 'open/short/miswire' low-voltage, low-current tests should be used to quickly identify whether a circuit is wired properly. When a product is subjected to low-voltage, low-current tests only, the integrity of the electrical insulation is unknown and end-user safety is not likely a factor. To detect meaningful insulation breakdown between isolated conductors, higher voltages are required. Similarly, component-specific testing and high-accuracy resistance measurement must be performed as a separate test set that requires higher test current (e.g. generally above 250mA for IC's) than the levels normally used for open, short and miswire detection.

To detect meaningful insulation breakdown between isolated conductors, higher voltages are required

### *Simplex vs. Kelvin Resistance Measurement*

Resistance measurement can be used to quickly verify that two points in a cable, wire harness or other product are connected and continuous. The simplest type of resistance test uses two wires or test leads to connect the Product Under Test (PUT) into the test circuit. Referred to as 'Simplex' or '2-wire' testing, this method uses a constant current stimulus, voltage comparator and two test leads to measure resistance based on Ohm's law (i.e. V = IR) and the voltage drop across the PUT (Figure 1). This type of test is usually performed in the 5 – 40V range and is satisfied by pass criteria that can range from a few milliohms to several ohms.

When the simplex method is used, accurate resistance measurement is not likely a part of the test criteria. This type of resistance measurement will always include the actual resistance of the PUT ($R_{PUT}$) plus a second resistance component associated with the test leads ($R_{lead}$). Since the internal resistance of the voltmeter is much greater than the combined resistance of the test leads and the PUT (Figure 2), the current flow through the voltmeter will be negligible compared to the current flow through the PUT. Using Ohm's law, the total measured resistance ($R_{meas}$) will be equal to the sum of the voltage drop across the test leads and the PUT (i.e. $V_{lead} + V_{PUT}$), divided by the total current ($I_o$).

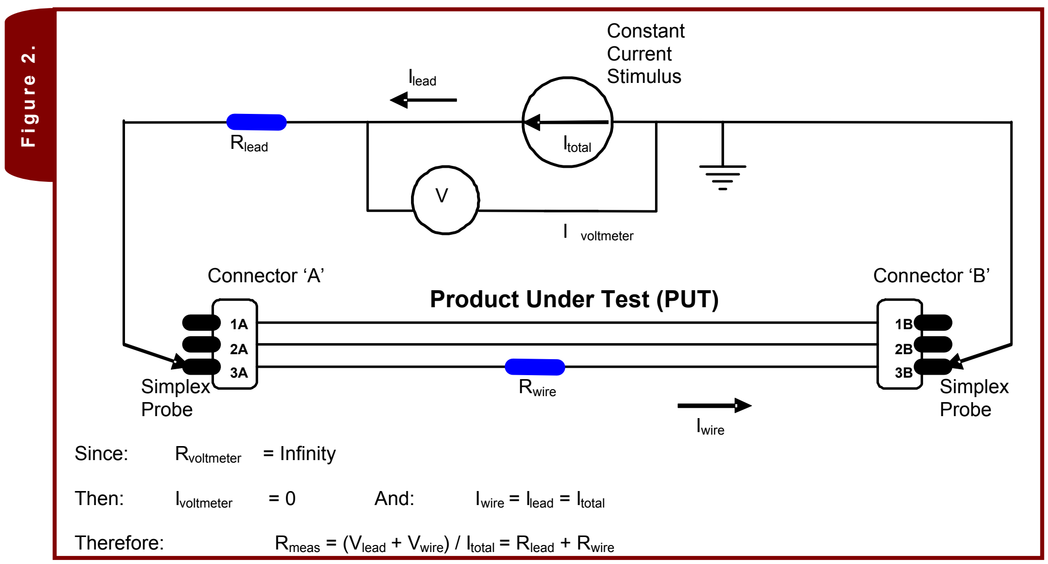


FIGURE 2: SIMPLEX OR 2-WIRE RESISTANCE MEASUREMENT CIRCUIT

High-current carrying devices and precision components that have sub-ohm resistances cannot be measured accurately using the 2-wire method if the test leads' resistance is comparable in magnitude to the resistance of the product under test (PUT). Although the resistance associated with the test leads can typically be compensated for by taring the test instrument, it is possible that the tared resistance can fluctuate with changes in temperature and humidity. In this case, it may be necessary to remove the PUT and re-tare the instrument each time a new measurement is made. When a more accurate method of performing resistance measurements is required, the '4-wire' or 'Kelvin' method can be used.

Using the 4-wire (Kelvin) method, the test system uses a discrete pair of test leads to energize the component while a second pair connects the component to a high-input impedance device that actually measures the voltage drop (Figure 3). In this way, the voltage drop across the energization leads does not affect the measurement taken by the high impedance device. By combining the 4-wire Kelvin method with the use of a high current source (typically greater than 250mA), it is possible to measure resistances of less than 10 mΩ with an accuracy of +/- 1mΩ.

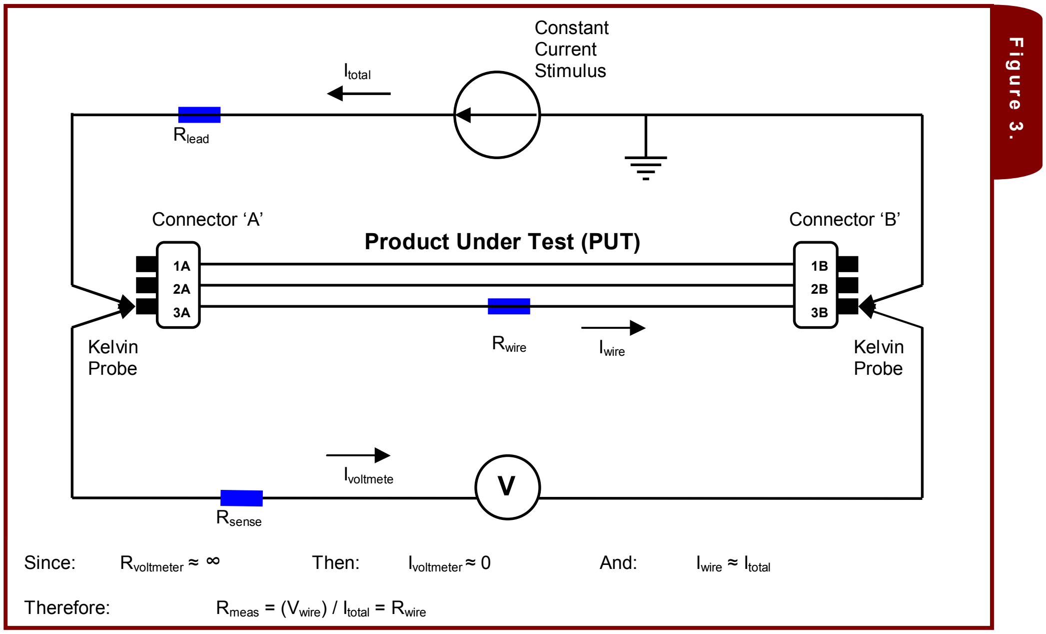


FIGURE 3: KELVIN OR 4-WIRE RESISTANCE MEASUREMENT CIRCUIT

When selecting equipment for automated testing, it is important to remember that four discrete test points are required to perform Kelvin resistance measurement while the Simplex method requires only two. This can often increase the cost and size of the test equipment significantly since the number of required test points doubles when performing Kelvin measurement on the PUT.[4] Despite this, the Kelvin method is extremely useful for high-accuracy resistance measurement, especially in sensitive components where low test voltages are required.

Component testing can be generally divided into 'active' component testing and 'passive' component testing. Active components are used to perform a specific action or group of actions in response to an energy stimulus and often require the application of current to verify their functionality (e.g. a 12V, 1A relay). Passive components such as diodes, resistors and capacitors may require simple 'PASS/FAIL' testing or they may

4 Many wiring analyzers will not allow for multiple use of its test points. In such cases, each point must be dedicated to performing a single function, such as Kelvin measurement, Simplex measurement or stimulus. All CableTest Wiring analyzers allow for any test point to be used for any function, whether for stimulus or Kelvin, Simplex, voltage or current sense.

require accuracy testing to ensure that their tolerance will be suitable for the intended end-use.

Low voltage production testing of passive components focuses on determining whether:

[a] the component is defective (i.e. the component does not lie within the required tolerance); or

[b] the wrong component has been used (e.g. a 100mΩ resistor was placed where a 1 Ω resistor should have been); or

[c] the polarity of the component is correct (e.g. diodes, capacitors, etc.).

Where passive components require tolerance testing, the tester should offer an accuracy that is several times greater than the component itself. This will prevent unnecessary component rejection that can occur if the tester is not sensitive enough to recognize that the component's tolerance is within the acceptable range.

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Although high current may often be required (e.g. greater than 250mA), component testing is typically performed at low voltages to avoid damaging embedded components that may be included in the test circuit. Components that require high voltage testing (e.g. varistors, zener diodes, LED's) must be isolated from any components that cannot withstand the associated voltage drop. Damage to such components can be avoided by careful auditing of the test circuit or the test program when automated test equipment is used. Even at low voltages, test personnel must ensure that the current is low enough to avoid damaging sensitive components such as IC's and capacitors.

## Low-Voltage, High Current Tests

### *Ground Integrity Testing in Power Supply Cords*

Ground Integrity testing ensures that: [a] the ground wire in a 3-conductor power supply cord is continuous; and [b] the ground wire can withstand a power surge from either the wall outlet or a fault in the operating product. The test objective is to create a real-world scenario that the product could experience while in service. For this reason, the "Ground Integrity Test" (Figure 4) is used to determine the quality of the earth connection by directing a high current stimulus (typically 25 - 30 Amps, 12VDC) through the ground wire while the cord tester measures resistance.

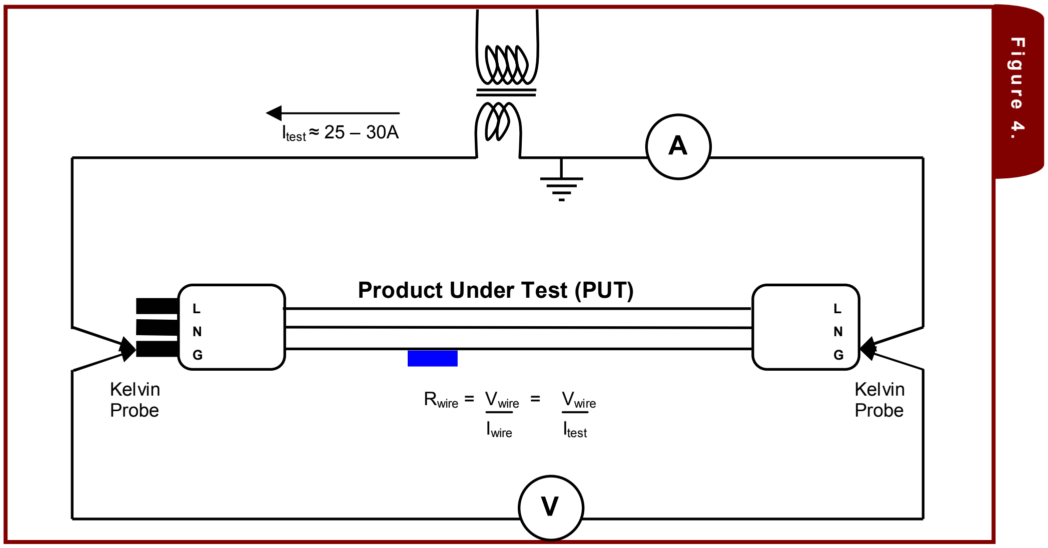


FIGURE 4: GROUND INTEGRITY TEST ON A 3-CONDUCTOR POWER CORD

In order for a power cord to pass the Ground Integrity test, the resistance (measured in Kelvin mode) must remain below the values specified by the relevant safety standard for the duration of the test (e.g. 25 A at 12 VDC for 1 minute, resistance not to exceed 100mΩ)[5].

Most standards require that a Ground Integrity test must be performed on all grounded 3-prong power supply cords. In terms of end-user safety, verification of ground continuity is considered to be one of the most important safety tests that a manufacturer can perform on a power supply cord.

## High Voltage, Low Current Testing

High voltage testing is the most effective method of ensuring that isolated conductors in an electrical product will perform as designed at the rated voltage and current levels. In many cases, the performance of these tests by the manufacturer is required by law and is critical to ensuring the safety of the end-user. Whether the 'Product Under Test' (PUT) is a simple power cord or an aircraft control panel, the main objective of high voltage testing is to ensure that the end user will not be exposed to electrocution or other hazard should an electrical fault occur.

5 EN 60950, 2nd ed., "Safety of Information Technology Equipment, including Electrical Business Equipment", CENELEC, Brussels, 1992.

The high voltage tests most commonly performed during the production process include the insulation resistance and dielectric strength tests. These tests are typically performed at voltages above 250V. Unlike low voltage tests[6] that are used to verify product functionality, circuit continuity, isolation and component tolerance, these tests are used to verify the integrity of the insulation between conductors in the PUT.

Each of these high voltage tests may use a number of methods, such as measuring and monitoring the leakage current that flows through a conductor's insulation to determine whether the PUT has satisfied the test criteria. The main difference between the insulation resistance and the dielectric strength tests is the method used to evaluate the insulation's integrity. The insulation resistance tests are primarily performed in DC[7], while the dielectric strength is primarily performed in AC. While the insulation resistance test primarily measures the DC resistance associated with the leakage current between two or more conductors when high voltage is applied, the dielectric strength test primarily monitors the leakage current and other parameters to detect arcs between two or more conductors when high voltage is applied[8].

Typically, the acceptable leakage current for an electrical product is defined in standards published by a governing safety agency

### *Insulation Resistance Test*

An 'Insulation Resistance' (IR) or 'Megger' test can ensure that the insulation between isolated conductors will maintain a resistance that limits the flow of leakage current to an acceptable level when high voltage is applied. Typically, the acceptable leakage current for an electrical product is defined in standards published by a governing safety agency. The objective of the IR test is to ensure that the cable, cord or component is suitable [a] for safe use by an end-user; and/or [b] for correct performance when installed into the product or operating environment.

Typically, IR testing is conducted at voltages above 250 VDC. The test fails when the product's insulation resistance falls below the acceptable limit while a test voltage is applied for a specific time period (e.g. 1000VDC is applied for 10 seconds; IR must not fall below 10MΩ during the test period). IR failure typically occurs well before an arc between conductors occurs. Since IR testing does not stress a conductor's insulation to the point of dielectric breakdown, it is generally considered to be non-destructive and

6 Low voltage testing is commonly carried out below 50V and typically between 5 to 12 VDC.

7 CableTest equipment can perform IR measurements in AC by neutralizing the capacitive current component.

8 CableTest equipment will detect arcs during an IR test. Likewise, it can report the total or neutralized leakage current during a dielectric strength test.

can be used both during production testing as well as at any point thereafter to re-confirm the integrity of the insulation.

The IR test involves the application of an AC or a DC voltage across the conductors of the PUT as shown in Figure 5. A conductor's insulating material is characterized by its dielectric resistance or IR. The resistance of the insulation is typically measured in terms of the leakage current that passes through it when high voltage is applied.

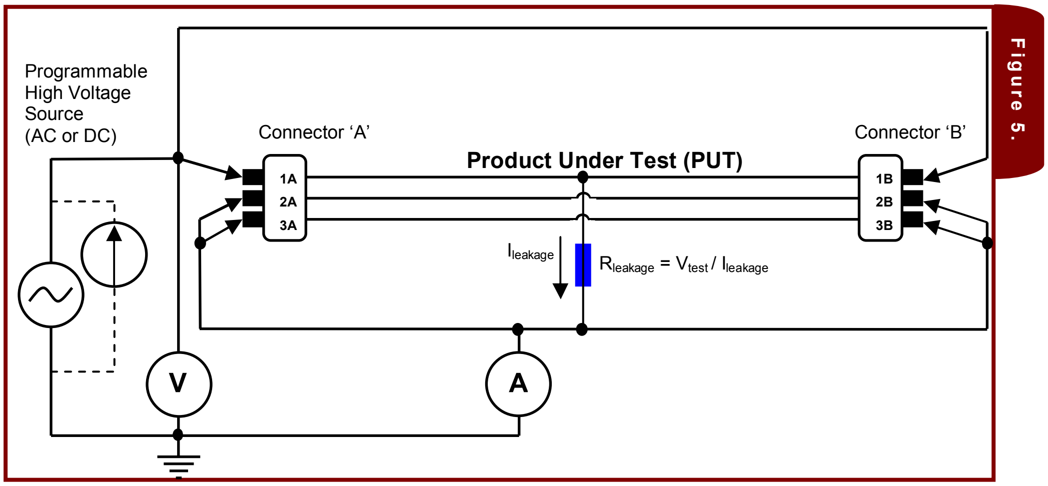


FIGURE 5: INSULATION RESISTANCE TEST ON A 3-CONDUCTOR CABLE

The current that flows through the PUT when this high voltage is applied is known as the leakage current and the insulation resistance is calculated based on Ohm's law as the quotient of the applied voltage divided by the leakage current (i.e. R = V/I).

During an AC HiPot test, isolated conductors create a capacitive circuit as well as a resistive circuit when energized by high voltage. While the leakage current associated with the conductors' insulation resistance is in phase with the applied voltage, there is also a capacitive current associated with the charging of the isolated conductors. Since the total current measured when an AC voltage is applied equals the vector sum of the resistive (or 'real') current and the capacitive (or 'reactive') current, the test equipment must be able to eliminate or 'neutralize' the capacitive component of the current measurement in order to obtain accurate insulation resistance measurements. This is particularly true in cases where the capacitive current is much larger than the resistive current (Figure 6).

Figure 6.

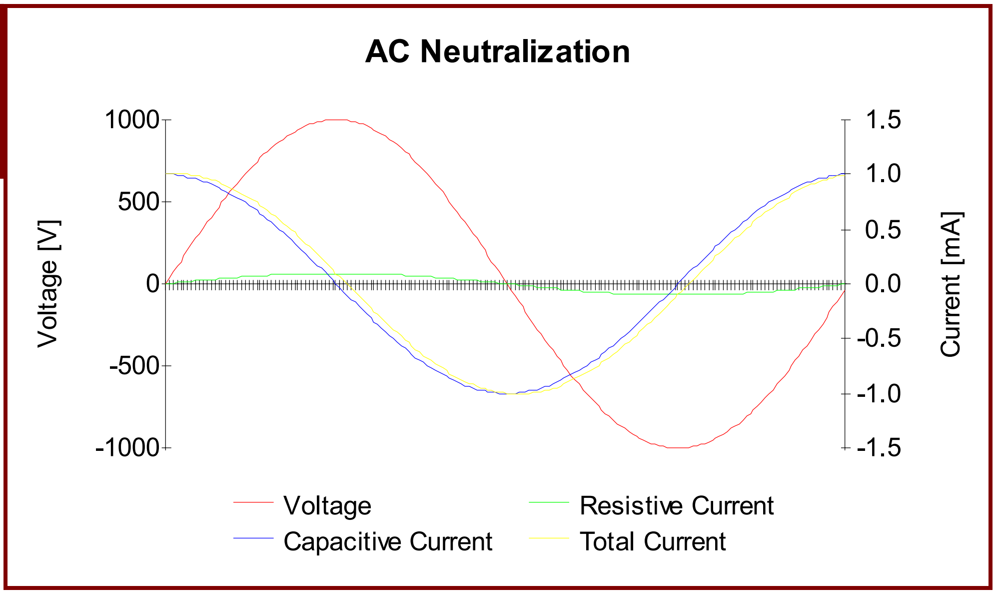


FIGURE 6: EFFECT OF CAPACITANCE ON AC LEAKAGE CURRENT MEASUREMENT

Where test standards allow, DC HiPot testing can eliminate the error associated with capacitive current since only resistive leakage current across the conductors' insulation flows once the conductors are fully charged. At the beginning of the IR test when DC voltage is applied, a delay or 'dwell' period is often required while the insulated conductors become increasingly charged with current as shown in Figure 7, below. During the charging period, capacitive current can represent the largest component of the total current if the voltage ramp up rate does not allow the product sufficient time to discharge. In this case, the leakage current cannot be accurately measured while the PUT is charging. As a result, the IR test should not begin until the voltage has reached the specified HiPot limit and the leakage current has stabilized.

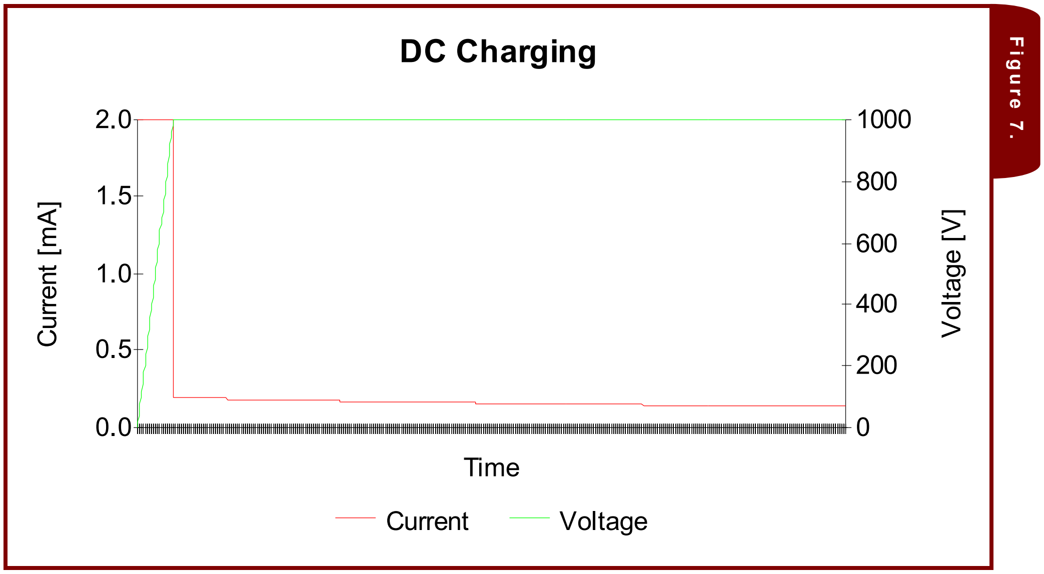


FIGURE 7: CURRENT RESPONSE DURING DC CHARGING OF INSULATED CONDUCTORS

Once the voltage stabilizes and the conductors are fully charged, a 'soak' period may be required while the insulation material absorbs trace amounts of remaining capacitive current associated with the polarization of the conductors. During the soak period, the capacitive current decays as the insulator saturates (Figure 8).

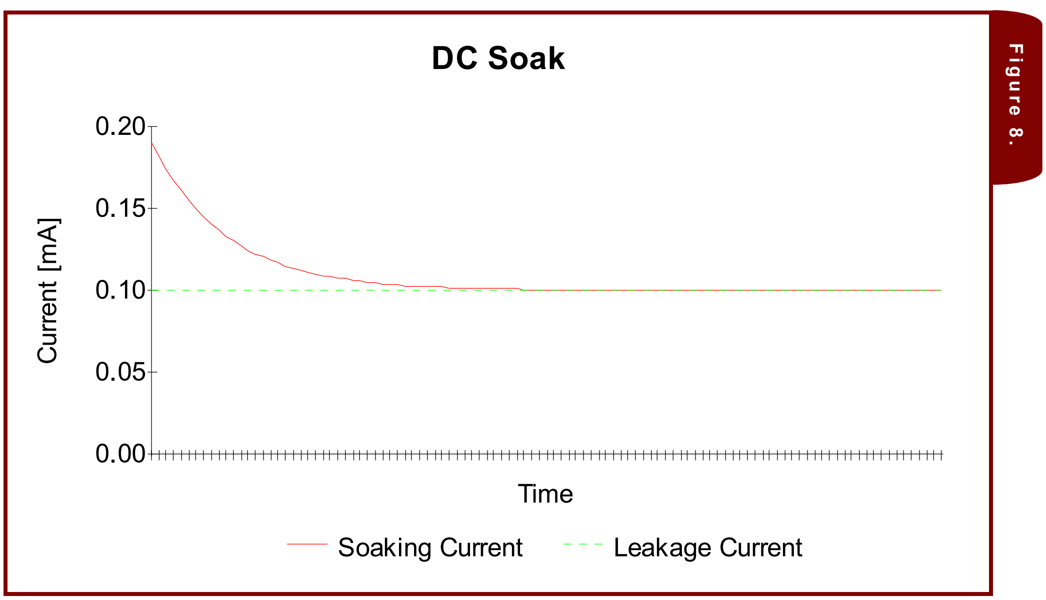


FIGURE 8: CURRENT RESPONSE AFTER DC CHARGING OF INSULATED CONDUCTORS

At the end of the soak period, a stable current will flow through the insulation between conductors and this can be measured as the true leakage current. It is this current that should be used to calculate the actual insulation resistance of the PUT.

Where the humidity levels allow the insulation to retain moisture, it is possible that IR testing will fail a good product due to higher than normal levels of leakage current flowing through the moisture-affected insulation. In this situation, it may be necessary to extend the 'soak' period until any moisture dissipates and the insulating material regains its normal dielectric properties. Once the leakage current stabilizes, it is possible to perform an accurate IR test on the insulation.

To ensure IR measurement accuracy, the tester's leads should have good shielding and be as short as possible to avoid the generation of electrostatic discharge or capacitance buildup that could affect the measurement procedure. It is also important that the selected HiPot tester allows the user to control the high voltage ramp rate as well as the 'dwell' and 'soak' times.

The Dielectric Strength test applies a voltage that is greater than the product's rated operating voltage for a specific period of time during which dielectric breakdown must not occur

### *Dielectric Strength Test*

The Dielectric Strength test applies a voltage that is greater than the product's rated operating voltage for a specific period of time during which dielectric breakdown must not occur. This test is also known as a 'dielectric voltage withstand', 'breakdown' or 'HiPot' test. The dielectric strength test is one of the most common methods used by manufacturers to ensure the integrity of a conductor's insulation.

Dielectric breakdown occurs when a conductor's insulating material fails to act as a dielectric barrier to current flow and is characterized by the onset of arcing. The voltage that can be applied before an arc occurs between isolated conductors is referred to as the 'dielectric withstand voltage' (DWV). The primary objectives of the DWV or HiPot test are:

1. to ensure that the insulation will be able to resist overvoltages and current spikes while in normal service; and
2. to detect potential insulation defects that may have been imparted during the manufacturing and assembly process.

The HiPot test is performed by applying a high AC or DC voltage across the high potential line and the low potential or 'ground' line of the product. Traditionally, HiPot testing is performed by energizing one conductor (or net) and grounding all other nets. If there is a high voltage breakdown, it is clearly between that wire (or net) and at least one of the other nets. This method is known as the "Linear" HiPot test.

## HiPot Tests for Power Cords

The conventional or Linear HiPot test on a 3 conductor power cord is performed by connecting the Line (L) to the tester's high voltage lead and the power cord's Neutral (N) and Ground (G) to the tester's ground lead (Figure 9). High voltage is then applied to the power cord as specified in the relevant test standard.

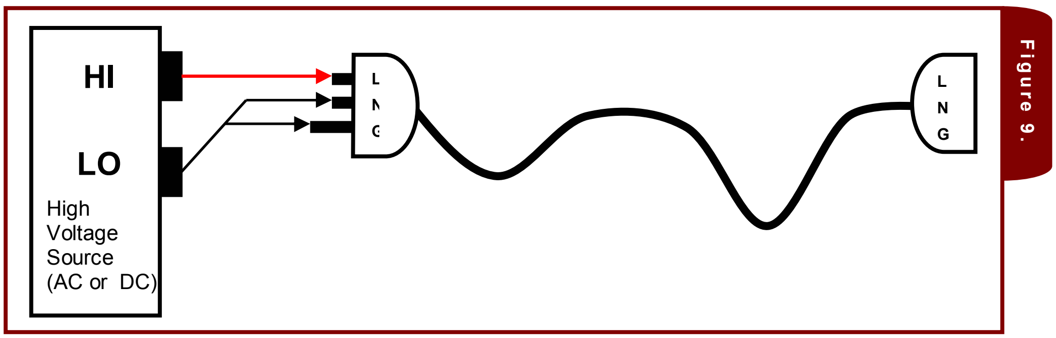


FIGURE 9: SIMPLIFIED HIPOT TEST ON A 3-CONDUCTOR POWER CORD

During the moulding of the power cord plug, it is possible for loose conductor strands to approach or penetrate the surface or 'skin' of the plug moulding. These stray strands can expose the end-user to shock hazard and possibly electrocution if they are not identified. To prevent this from occurring, a HiPot test known as the 'Skin Test' was developed for the power cord industry to detect stray strands that lie immediately below or protrude through the plug insulation. The Skin Test is performed by connecting the power cord's Line (L), Neutral (N) and Ground (G) to the tester's high voltage lead and the cord's plug housing to the tester's ground lead using conductive foam to encapsulate the entire plug surface (Figure 10). High voltage is then applied. If an arc is detected, the cord is typically destroyed by removal of the plug using some form of guillotine or cut-off knife. Similarly, cords that pass these tests are often marked with a colored dot or thermal stamp on the tested plug face.[9]

9 CableTest offers a complete line of automated testers for the production testing of power supply cords. For more information, please visit the CableTest website at www.CableTest.com .

Figure 10.

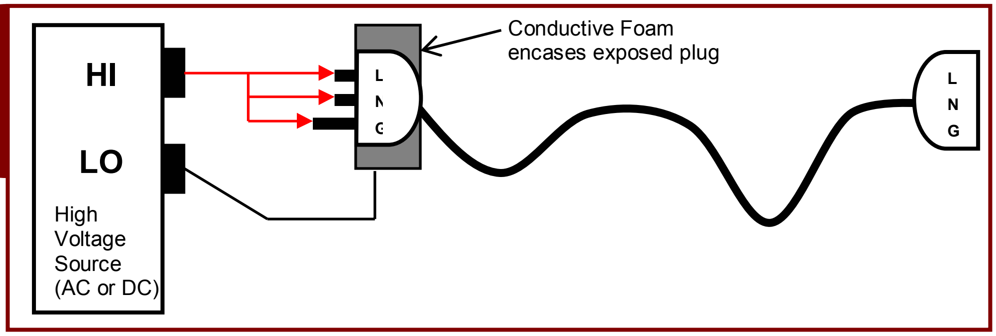


FIGURE 10: SIMPLIFIED SKIN TEST ON A 3-CONDUCTOR POWER CORD

## HiPot Testing of Cable Harnesses, Backplanes and Other Wired Products

While the Linear HiPot method conclusively detects all insulation breakdown faults in the PUT through sequential testing of each discrete wire (or net), it can be a very time-consuming process when a product has many nets and no high voltage faults (but must be tested nonetheless). In such cases, the 'Mass' HiPot routine offers an equally thorough but much faster method of verifying the IR and DWV characteristics of the PUT. To illustrate this, a simplified HiPot test setup using a 16-net cable is shown in Figure 11.

Figure 11.

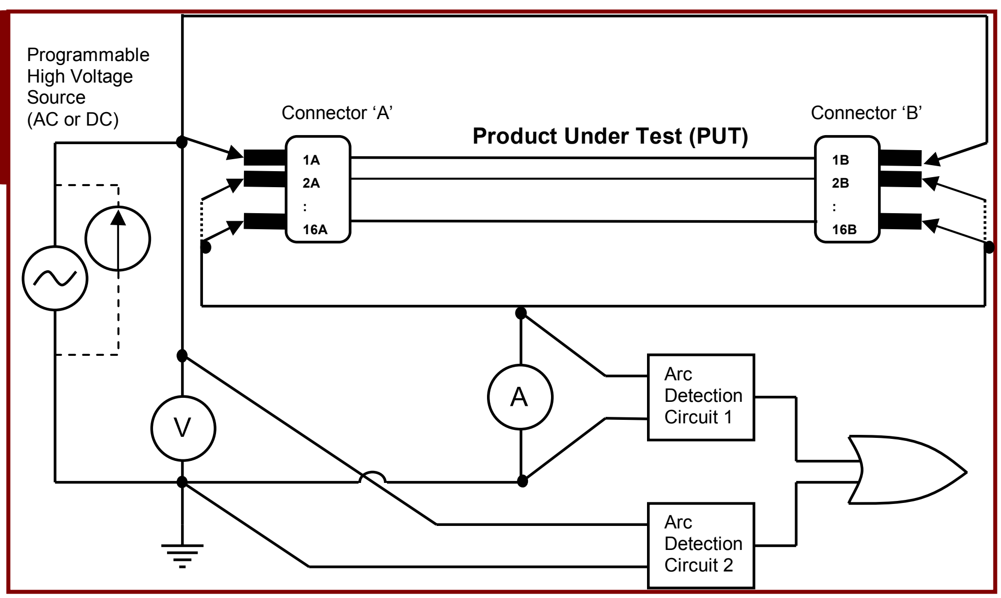


FIGURE 11: DIELECTRIC STRENGTH OR HIPOT TEST ON A 16-CONDUCTOR CABLE

To completely test each line in the cable shown in Figure 11, the test device must repeat the HiPot process 16 times as shown in Table 2 below.

| Test Cycle | Conductor (Net) Number | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 1 | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2 | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3 | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4 | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - |
| 5 | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - |
| 6 | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - |
| 7 | - | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - |
| 8 | - | - | - | - | - | - | - | + | - | - | - | - | - | - | - | - |
| 9 | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - | - |
| 10 | - | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - |
| 11 | - | - | - | - | - | - | - | - | - | - | + | - | - | - | - | - |
| 12 | - | - | - | - | - | - | - | - | - | - | - | + | - | - | - | - |
| 13 | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - | - |
| 14 | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - |
| 15 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - |
| 16 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + |

Table 2.

TABLE 2: 'LINEAR HIPOT' TEST SEQUENCE FOR A 16-CONDUCTOR CABLE

Using the Linear HiPot method on the 16-conductor cable, the total test time would be 16 minutes if the required dwell time was 1 minute per test cycle. If the PUT had 500 nets, the test time would be 8.3 hours if the same 1 minute dwell time and Linear HiPot routine was applied. In practice, the dwell time for a HiPot test can range from 1 second to several minutes depending on the industry and the governing safety agency requirements.

The Mass HiPot routine can dramatically reduce the test time by grouping and energizing multiple wires (or nets) simultaneously relative to a second group that is connected to the ground of the wiring analyzer. The grouping of nets is performed using a binary algorithm to minimize the number of test cycles required to fully test the PUT as shown in Table 3.

Table 3.

| Test Cycle | Conductor (Net) Number | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + |
| 2 | + | + | + | + | + | + | + | + | - | - | - | - | - | - | - | - |
| 3 | + | + | + | + | - | - | - | - | + | + | + | + | - | - | - | - |
| 4 | + | + | - | - | + | + | - | - | + | + | - | - | + | + | - | - |
| 5 | + | - | + | - | + | - | + | - | + | - | + | - | + | - | + | - |

TABLE 3: 'MASS HIPOT' TEST SEQUENCE, 16-CONDUCTOR CABLE WITH NO FAULTS

Using a 1 minute dwell time, it would take only 5 minutes to HiPot the 16-net cable and only 9 minutes to HiPot a 500-net product assuming that no faults are detected.[10]

It is important to realize that the Mass HiPot routine is only intended to detect IR and DWV faults among a group of nets being tested and should not be relied on to isolate the defective net. Once a fault is detected among a group of nets, a recursive binary or linear HiPot cycle must be performed on each net in the last group tested. An example of this routine is shown in Table 4 on the next page.

10 For further discussion of the Mass HiPot routine, the document "CableTest Systems – Mass HiPot Methodology' is recommended and may be obtained by contacting CableTest or visiting www.CableTest.com .

| Test Cycle | Net Number Condition | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Pass! | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + |
| 2 | ARC? | + | + | + | + | + | + | + | + | - | - | - | - | - | - | - | - |
| 2a | Pass! | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2b | Pass! | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2c | ARC! | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2d | Pass! | - | - | F | + | - | - | - | - | - | - | - | - | - | - | - | - |
| 2e | Pass! | - | - | F | - | + | - | - | - | - | - | - | - | - | - | - | - |
| 2f | Pass! | - | - | F | - | - | + | - | - | - | - | - | - | - | - | - | - |
| 2g | Pass! | - | - | F | - | - | - | + | - | - | - | - | - | - | - | - | - |
| 2h | Pass! | - | - | F | - | - | - | - | + | - | - | - | - | - | - | - | - |
| 3 | Pass! | + | + | F | + | - | - | - | - | + | + | + | + | - | - | - | - |
| 4 | ARC? | + | + | F | - | + | + | - | - | + | + | - | - | + | + | - | - |
| 4a | Pass! | + | - | F | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4b | Pass! | - | + | F | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4c | Pass! | - | - | F | - | + | - | - | - | - | - | - | - | - | - | - | - |
| 4d | Pass! | - | - | F | - | - | + | - | - | - | - | - | - | - | - | - | - |
| 4e | Pass! | - | - | F | - | - | - | - | - | + | - | - | - | - | - | - | - |
| 4f | Pass! | - | - | F | - | - | - | - | - | - | + | - | - | - | - | - | - |
| 4g | Pass! | - | - | F | - | - | - | - | - | - | - | - | - | + | - | - | - |
| 4h | ARC! | - | - | F | - | - | - | - | - | - | - | - | - | - | + | - | - |
| 5 | Pass! | + | - | F | - | + | - | + | - | + | - | + | - | + | F | + | - |

TABLE 4: ARC BETWEEN 2 NETS OF 16-NET CABLE (LINEAR HIPOT SEARCH FOR FAULT)

Where:

| | |
|---|---|
| + | Mass HiPot Test Cycle – Nets set to 'high' state. |
| - | Mass HiPot Test Cycle – Nets set to 'low' state. |
| + | Linear HiPot Test Cycle – Nets set to 'high' state. |
| - | Linear HiPot Test Cycle – Nets set to 'low' state. |
| F | Fault Detected – The defective net is excluded from all subsequent HiPot test cycles. |

Based on the example shown in Table 4 and assuming a 1 minute dwell time was used, it could take over 20 minutes to detect a fault in a 16-conductor cable using the Mass HiPot routine. Although the Mass HiPot routine can sometimes be slower than the Linear method when a high voltage fault exists, the product defect rate is usually low and the overall time saved when testing 'good' product using Mass HiPot outweighs the time lost when a defective product is encountered.

Two common guidelines for selecting the HiPot test voltage are:

1. the HiPot voltage is set equal to three times the PUT's rated voltage; or
2. the HiPot voltage is set equal to two times the PUT's rated voltage plus 1000V.

One of the safest methods of applying this load involves the application of half the rated voltage instantly and then potentio-dynamically ramping up to the final test voltage over a specified time period (commonly 10 seconds). Once the final test voltage is reached, it is typically held for a period that can range from seconds to minutes. When an AC load is applied in this manner, it is important that the test voltage is switched on at zero crossings to minimize the stress applied to the PUT when dielectric breakdown occurs as shown in Figure 12, below.

Figure 12.

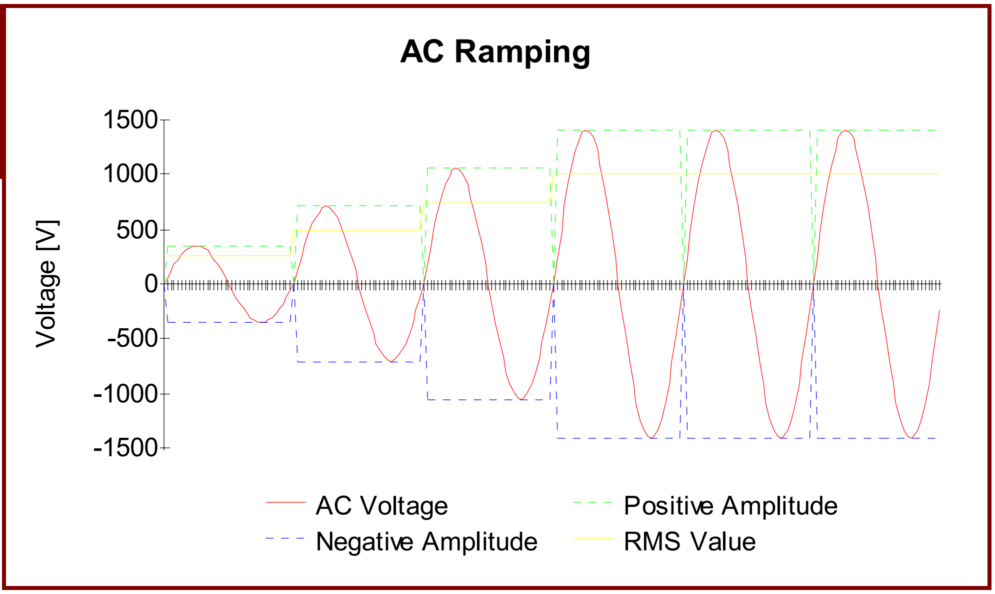


FIGURE 12: AC VOLTAGE RAMPING PRIOR TO HIPOT TESTING

In production testing environments where it may be impractical to HiPot each product for 1 minute, a common rule of thumb is to apply 110 to 120% of the test voltage that is normally held for 1 minute, for a period of 1 – 2 seconds. As these rules vary by safety agency and product-class, the applicable standard must always be observed.

HiPot testing is perhaps the best method of detecting improperly insulated or damaged conductors. This type of defect cannot be identified using low-voltage/low-current tests. Nonetheless, it is generally accepted as good practice to perform fault location at low voltages (c.f. Table 1) before HiPot testing. Whenever possible, it is easier, safer and less expensive to identify, locate and repair a short before high voltage is applied.

## High Voltage Setting: AC or DC?

The issue of whether AC or DC voltage should be used can be confusing since there are advantages and disadvantages associated with both methods. While, most standards allow the use of either AC or DC voltage, some require the use of both. In many cases where AC testing is specified, the regulating body does not allow its substitution with a DC test.

In many cases where AC testing is specified, the regulating body does not allow its substitution with a DC test

Although the power cord industry typically requires AC testing prior to product acceptance branding, AC HiPot testing is often avoided where the use of DC HiPot methods are allowed. This may be due to the increased cost, potential for shock hazard and the risk of damaging certain types of insulation when testing with AC high voltage. Despite these potential disadvantages, AC HiPot testing can be faster than DC methods since it is unnecessary to soak or discharge the PUT. This is especially true when the PUT is highly capacitive (e.g. wire bundles, filter connectors, trains, aircraft, etc.). As well, the use of AC voltage during the HiPot test can be more effective than DC voltage since it stresses the insulation equally in both voltage polarities. An AC test voltage can be replaced with an equivalent DC voltage by applying a 1.414 rms conversion factor to the AC voltage. As an example, a test specification calling for the application of 1000VAC for 1 minute may be satisfied by applying 1500 VDC (1414 VDC rounded up) for 1 minute, assuming the substitution is allowed by the customer or applicable codes and specifications.

## Testing Guidelines and EU Standardization

The general guideline for HiPot testing requires that test voltage is based on a factor of three times the rated operating voltage, or two times the operating voltage plus 1000 volts

Guidelines and standards for electrical testing of wire harnesses, backplanes, cords and components vary by industry, regulatory agency and product. For example, most power-cord manufacturers observe standards that are set by the relevant safety agency and by other manufacturers that use the power cords as part of a larger product or system (e.g. computers, appliances, medical devices). In the aerospace, military and transportation sectors, the general guideline for HiPot testing commonly requires that test voltage is based on a factor of three times the rated operating voltage, or two times the operating voltage plus 1000 volts. Similarly, good practice in high volume data cable and wire harness industries typically calls for repetitive low voltage testing for intermittent faults, HiPot testing at 1000 VDC (where pitch ≥ 0.05") and crimp force monitoring. Although there are many excellent guidelines concerning test voltages, acceptable current limits and insulation resistance levels for production testing, manufacturers must observe and comply with the relevant safety standard in the area where the product will be sold. Typically safety and regulatory agencies operate at the national level and the standards set forth by one agency are not always recognized by the equivalent agency in another country. In recent years, growing emphasis has been placed on 'harmonization' of these national regulatory standards to minimize barriers to international trade.

In an effort to facilitate trade in the European Union (EU), specific directives were created to regulate all manufacturers that wish to sell product in the EU market.[11] The Low Voltage Directive (LVD) was created to ensure the quality and safety of electrical products that operate in the voltage range between 50 – 1000 VAC (or 75 – 1500 VDC). Certain products are exempted from the LVD including electrical equipment for medical purposes, electricity meters, and "specialized electrical equipment, for use on ships, aircraft or railways which complies with the safety provisions drawn up by international bodies in which the Member States participate."[12]

Products described by the Low Voltage Directive cannot be sold in the EU unless they comply with harmonized safety standards that are recognized by a National Certification Body (NCB) under the Certification Body (CB) scheme. The CB scheme is based on the use of IEC standards by participating countries worldwide. In the UK for example, ASTA and BSI are recognized NCB's that grant conformity certificates to electrical products based on harmonized product safety standards. Some of the harmonized standards as defined by the CB scheme are summarized in the following table.

Table 5.

| Harmonized Standard | Product Category |
|---|---|
| EN 60950 | Information Technology Equipment |
| EN 60601 | Medical Equipment |
| EN 60335 | Domestic Appliances |

TABLE 5: EXAMPLES OF HARMONIZED PRODUCT SAFETY STANDARDS

## Production Test Program Management

The foundation of a good production testing program requires not only an understanding of the relevant industry test standards, but also equipment that is capable of performing the tests effectively and efficiently. The test program must be developed to ensure that the test specification meets and exceeds the relevant standards for product performance

11 To demonstrate compliance with the LVD and other EU directives, a manufacturer's products must bear the 'CE' mark.

12 The Low Voltage Directive (LVD), 73/23/EEC, Annex II

and safety. It is also critical to the manufacturing process that the level of test appropriately reflects the costs and liabilities associated with the target defect rate, whether it is 10% or 0%.

Appropriate test equipment should be selected on the basis of budget and production efficiency requirements as well as safety and performance test specifications. In some cases, the required level of product testing can be performed using a hand-held multi-meter or it may require advanced functionality such as PLC-integration, CAD/CAM test program generation and SPC test data analysis for process and quality control optimization. Where low-voltage and HiPot testing is required for quality and/or safety reasons, documentation of test results is critical to prove that the PUT is actually compliant with the necessary regulations. All CableTest wiring analyzers are capable of producing fully traceable records using microprocessor control and data-logging software. For many years, CableTest equipment has been integrated into assembly line test stations with the data for each test stored and downloaded automatically onto a network server within the production facility for storage and analysis.

Appropriate test equipment should be selected on the basis of budget and production efficiency requirements as well as safety and performance test specifications

While there are many different types of equipment available to perform the required tests in accordance with a specified standard, it is ultimately the product's complexity, production method and intended end-use that determine whether it is practical to perform tests manually using simple instruments or whether more sophisticated automated test equipment (ATE) is needed.

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