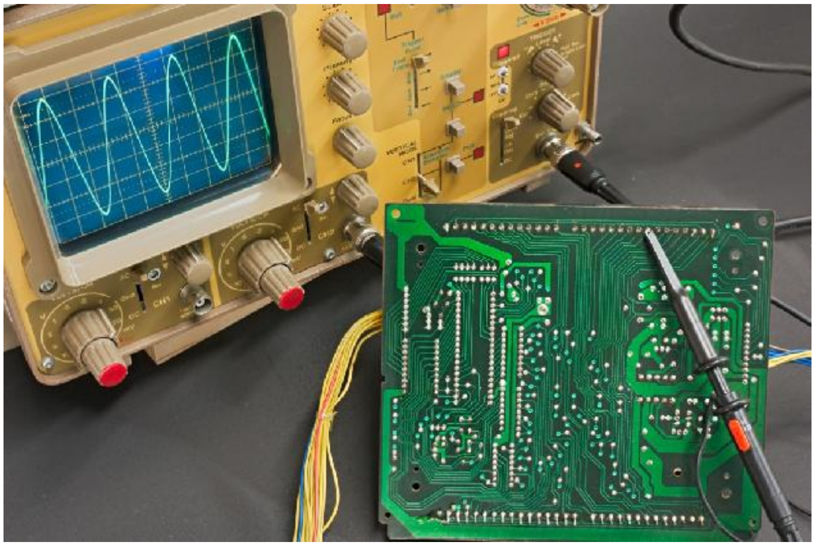

Product safety testing limits risk of shock, fire, and injury Part 1

David Lohbeck - March 1, 2013

Electricity is like the genie in a bottle. When it is contained and properly harnessed, its power is endless. However, when it escapes in an uncontrolled manner, electricity has the potential to cause harm. In addition to electric shock, electrical products can cause fires, burn injuries, explosions, or other harm (Refer to **Figure 1**). Making a product safe requires an understanding of the hazards that exist for electrical products and the safety tests required to meet product safety standards. Safety testing is performed to help ensure that electrical products do not harm the user, product, and surroundings.

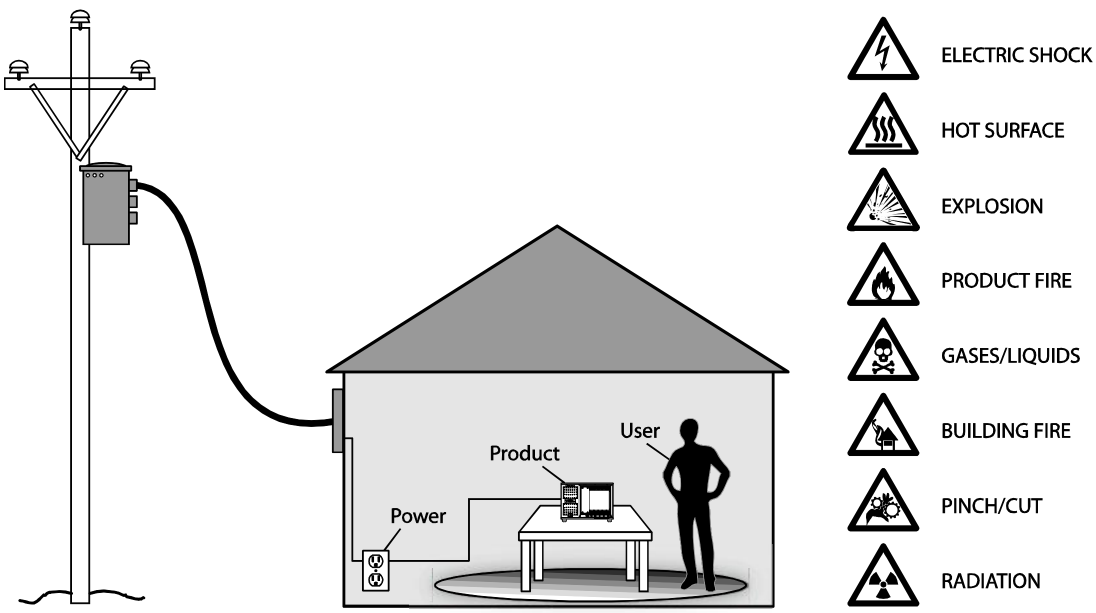

FIGURE 1 Hazards posed by electrical products

Product safety standards are used to test and evaluate products for safety compliance. It is important to use the appropriate standard. The relevant safety standard for test and measurement equipment (TME) is IEC 61010-1 and for information technology equipment (ITE) the standard is IEC 60950-1. Limits can differ between safety standards. The most common voltage limits are 30 Vrms, 42.4 Vpk and 60 VDC.

There are numerous safety tests with over fifty tests in the TME standard and over sixty tests for the ITE standard. The actual number of required tests is dictated by the design, rating, use environment, and potential hazards of the product, as well as by the applicable product safety standard. Examples of product safety tests include dielectric voltage withstand, temperature, leakage current, and impact.

This article describes the importance of safety testing. It also presents a step-by-step guide about performing safety tests with pass/fail criteria for each test. This article introduces important product safety tests, known as Type tests, which are performed for safety design verification. It also describes production tests, known as Routine tests, which are important product safety tests performed during the manufacturing process to uncover production related safety defects.

Part 1 of this article will cover the following electrical product safety tests:

- Dielectric Voltage Withstand Test – Hipot
- Grounding Continuity Test
- Input Power Test
- Limit Values for Accessible Parts Test
- Leakage Current Test

Part 2 of this article covers the following mechanical safety tests as well routine, production, safety testing:

- Temperature Test
- Cooling Abnormal Test
- Component Abnormal Test
- Enclosure Impact Test
- Routine Tests – Withstand and Continuity

The following safety terms and definitions apply for the purposes of this article:

Hazard—Potential source of harm, such as electric shock, burn, fire, explosion, and others.

Type Test—Test of one or more products, test samples, to show the design meets safety standards.

Routine Test— Test of each product in manufacturing, typically at the end of the production process.

Hazardous LIVE Voltage—Voltage > 30 Vrms, 42.4 Vpk and 60 VDC; risk of shock, burn, or fire. Voltage limits can differ between safety standards. The most common limits are 30 Vrms, 42.4 Vpk and 60 VDC (ITE, others).

Extra-low Voltage (ELV)—Voltage ≤ 30 Vrms, 42.4 Vpk and 60 VDC; no risk of shock.

Hazardous Energy—Power > 150 VA (TME) and > 100 VA (ITE); risk of burn or fire.

MAINs—AC or DC power distribution system to which the product is intended for connection to power.

Single Fault (Abnormal)—One fault present, such as a component short, which could cause a hazard.

Rating—Set of rated values and operating conditions, such as voltage, current, and temperature.

Normal Use Condition—Operation according to product ratings and instructions; maximum loading for tests.

Extended Use Condition—Operation according to extended ratings, such as above 40 °C environment (TME).

Insulation—Safety isolation required to protect against shock, such as Basic, Supplemental, and Double/Reinforced.

Protective Earth (PE)—A main PE terminal of a product that is required to be earthed, grounded, for safety purposes.

Note: This article is an introduction and overview of product safety testing. Product safety standards take precedence over any information presented in this article. Refer to the relevant product safety standards for the specific testing requirements. Product safety design is addressed in the standards and other articles (Refer to Related Articles).

Dielectric Voltage Withstand Test

A shock or fire hazard can exist when a product operates at hazardous LIVE voltage, such as when the power is derived from a wall outlet of 120 VAC/60 Hz in North America or 230 VAC/50 Hz in Europe. The operational, rated, voltage of the product can be a continuous input or output voltage.

Electrical products are also stressed by temporary overvoltages from power lines. Overvoltages can occur when an electric motor starts or stops, or when a transient travels on power lines to the product or user.

Insulation, isolation, provides protection from shock hazards posed by the products operational voltage and power line overvoltages. Insulation between LIVE circuits and user accessible parts is formed by Basic and Double/Reinforced spacings and/or solid insulation. The dielectric voltage withstand test, high-potential or hipot, produces a high voltage that stresses the insulation of the product to verify its function (Refer to **Figure 2** for insulation diagrams).

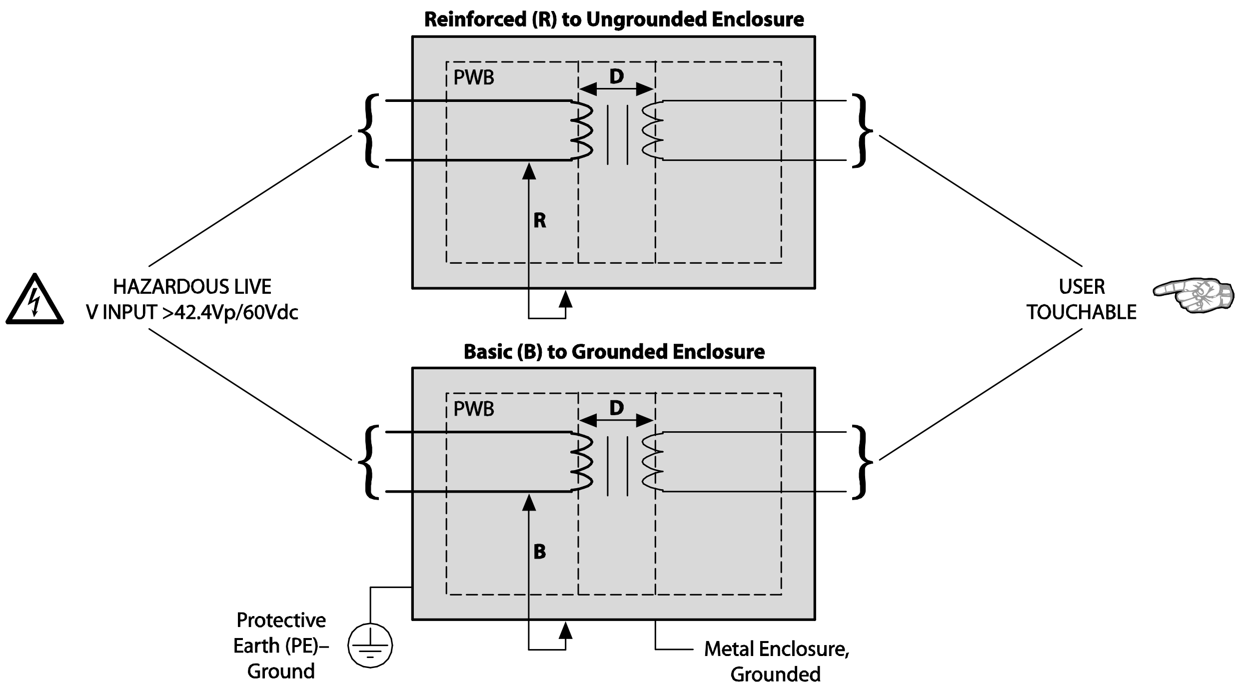

FIGURE 2 Insulation Diagrams – Basic (B), Double (D), and Reinforced (R)

Two dielectric voltage withstand tests are typically performed: 1) hipot between hazardous-voltage circuits and user-touchable extra-low voltage (ELV) secondary circuits, and 2) hipot between hazardous-voltage circuits and ground (enclosures, PE, etc.). Reinforced applies to the Lines-to-Ground value if the metal enclosure is un-grounded (**Figure 2**). The hipot test voltage and AC vs. DC varies depending on the standard and application, such as 3,000 VAC (double/reinforced), lines-to-secondaries, for test #1 and 1,500 VAC (basic) lines-to-ground for test #2. Refer to **Figure 3** for Hipot Test Setup and **Table 1** for Dielectric Test Voltage Examples.

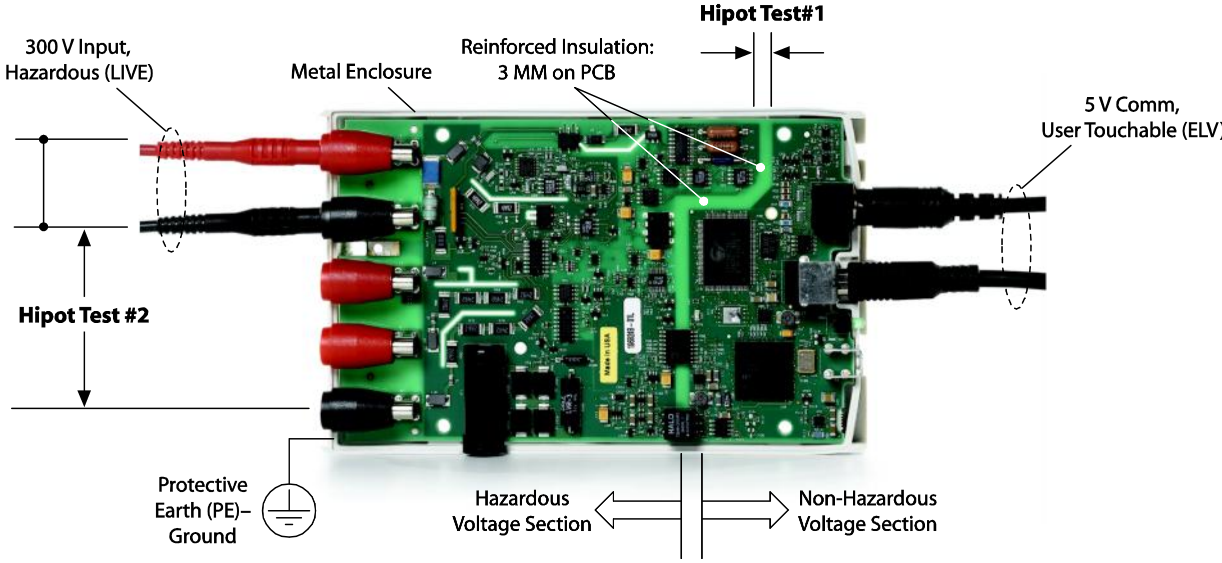

FIGURE 3 Hipot Test Setup (note product enclosure top cover removed for illustration)

Follow these steps for the Dielectric Voltage Withstand Test:

1. Set up the unenergized test sample with the power switch in the ON position.
2. Subject the test sample to 48 hours of preconditioning in a chamber \with stirred air so that there is no precipitation; with relative humidity (RH) and temperature:
   a) TME: 93% RH 3% RH and 40 °C ±2 °C temperature, or ITE: 91% - 95% RH and 20 °C – 30 °C, ±1 °C.
3. Set the test voltage for AC or DC

a. AC is the typical test voltage default.

4. Calculate the test equipment leakage setting by dividing the hipot value by 120 kΩ, such as 3,000 Vrms ÷ 120 kΩ = 25 mA setting.
5. Hipot test #1 – Lines-to-Secondaries (Refer to **Figure 3**):
   a. Connect the test equipment high-voltage lead (red) to the test sample LIVE circuit/conductors and neural line, which are shorted together.
   b. Connect the test equipment return lead (black) to the test sample secondary (ELV/SELV) circuits, which are tied together.
   c. Perform withstand test #1: The test voltage is raised gradually from 0 V to the specified voltage for Reinforced (**Table 1**) within a ramp time of five seconds and held for 60 seconds dwell time. (Some standards allow five seconds dwell time, however 60 seconds is most commonly used.)
6. Hipot test #2 – Lines-to-Ground (Refer to **Figure 3**):
   a. Connect the test equipment high-voltage lead (red) is to test sample LIVE circuit/conductors and neutral line, which are shorted together.
   b. Connect the test equipment return lead (black) to the test sample metal enclosure (PE ground).
   c. Perform withstand test #2: The test voltage is raised gradually from 0 V to the specified voltage for Basic (grounded enclosure) or Reinforced (non-grounded enclosure) (**Table 1**), within a ramp time of five seconds and held for 60 seconds dwell time. (Some standards allow five seconds dwell time, however 60 seconds is most commonly used.)
7. Test Results: No flashover of Clearance or breakdown of insulation shall occur. An audio alarm and visual indicator signifies a Fail result.

Notes about the above:

- Some standards, such as for ITE, allow a DC test voltage equal to the VAC peak voltage instead of VAC test voltage; VAC x 1.414 = VDC.
- In addition to hipot testing, products must also meet safety design requirements for insulation spacings; clearances and creepages.
- Hipot tests are repeated, at Basic values without humidity preconditioning, after abnormal tests in subsequent sections.
- Some standards allow five seconds dwell time, however 60 seconds is most commonly used.

TABLE 1 DIELECTRIC TEST VOLTAGE EXAMPLES[1]				
Working Voltage (Input Rating) a.c. rms or d.c.	BASIC and SUPPLEMENTARY Insulation	REINFORCED Insulation	BASIC and SUPPLEMENTARY Insulation	REINFORCED Insulation
	1 minute a.c. test voltage		1 minute d.c. test voltage	
TME: ≤ 150[2]	1,350 (840)[4]	2,700 (1,390)[4]	1,900	3,800
TME: > 150 ≤ 300[2]	1,500 (1,390)[4]	3,000 (2,210)[4]	2,100	4,200
ITE: ≤ 210V[3]	1,000	2,000	1,414	2,828
ITE: > 210 ≤ 420[3]	1,500	3,000	2,121	4,242

[1]The above voltages are examples; refer to the standards for actual voltages, additional voltages, and requirements.
[2]TME voltages based on Table 5 of IEC 61010-1:2010.
[3] ITE voltages based on Clause 5.2 and Table 5B of IEC 60950-1:2005.
[4]Values in brackets apply to test and measurement circuits, non-Mains, according to IEC 61010-2-030 Corrigendum 1: May 2011.

Grounding Continuity Test

Accessible parts, such as metal enclosures, must be prevented from becoming hazardous LIVE in the event of a single fault condition. The purpose of the grounding continuity test is to verify that user-exposed metal parts/enclosures are properly connected to PE ground so that if there is an insulation fault, current flows through a low resistance ground and trips a fuse or breaker instead of flowing through the user. A fault can occur in various ways including a broken wire, loose screw or nut, component failure, or short, any of which can bridge LIVE voltage to a user-touchable enclosure or parts. The integrity of the protective bonding is assured when the structural parts of the product are directly and reliably connected to the earth-ground path. The grounding continuity, protective bond, test verifies low impedance, low resistance, of the protective bonding.

Ground test equipment, supplying a maximum 12 VAC/DC with current set for 25 A or 40 A, is used for the grounding continuity test. For plug-connected products, the test current is 40 A for a one minute dwell (2 minute for ITE) for the U.S./Canada or 25 A for international, or a current equal to twice the rated current of the product, whichever is greater. If the product contains an overcurrent protection device (fuses, circuit-breakers, etc.) for all poles of the MAINs supply, the test current can be twice the rated current of the overcurrent protection device. The measured result of grounding continuity is a resistance value of the contact surfaces, such as 0.1 Ω maximum for a 40 A continuity test. Maximum impedance of 0.2 Ω for products with non-detachable power cords. The author recommends the 40 A/2 minute test to cover products internationally.

Follow these steps for the Grounding Continuity Test:

1. Set up the test so current is passed between the test sample earth (ground) terminal and each accessible part where protective bonding is required.
   a. Select accessible metal parts where maximum resistance to ground is expected.
   b. Connect the test equipment current lead (red jack) to the test sample AC inlet/cord ground pin.
   c. Connect the test equipment's return lead (black jack) to accessible metal part.
   d. Set the test equipment for 25 A/1 minute (U.S. and international) or 40 A/2 minute (Canada), as appropriate.
2. Perform the continuity test:
   a. The final measured impedance will be displayed.
   b. Verify that the current, and impedance in ohms, are within the limits in following test results.
3. Test Results:
   a. Resistance shall not exceed 0.1 Ω for plug-connected equipment when 25 A/1 minute or 40 A/2 minute is applied.
   b. The maximum resistance is 0.2 Ω for products with non-detachable power cords; the power cord is included in this test.
   c. An audio alarm and visual indicator signifies a Fail result.

Input Power Test

Electrical products must bear power rating markings, such as voltage, current, and frequency, to inform users of the product's intended power input and limitations. The ratings must be visible from the exterior enclosure of the product. The input power test compares the product rating markings to the actual measured input power. Calculating the product's input power does not substitute for testing and measurements.

Follow these steps for the Input Power Test. Refer to **Figure 4**:

1. Set up test sample for operation at maximum configuration and power consumption.
    a. All accessories, plug-in PCB cards installed, and outputs loaded to achieve maximum power draw.
    b. Connect the test sample to a variable voltage and frequency supply source that can operate at 10% of the voltage range.

    For example, if the input rating marking is 100 - 230 VAC, 8.0 - 4.0A, 50/60 Hz, then inputs of 90 VAC and 254 VAC are applied and recorded.
2. Perform the input test:
    a. Take the measurements after the current has stabilized, typically after one minute.
    b. Measure the voltage and current at +10% and -10% of the rated voltage, at the appropriate frequency(s), and record the voltage and current values.
    c. Ignore transients.
3. Test Results: The measured power consumption cannot exceed the marked rating by more than 10%.

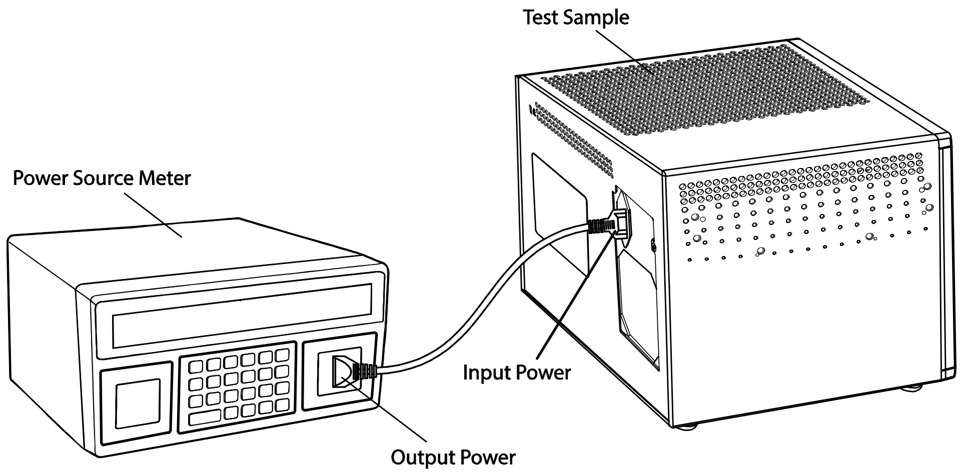

FIGURE 4 Input-power test set-up

Limit Values for Accessible Parts Test

Products must be designed to protect users against risk of electric shock during the normal and abnormal operational conditions of the product. Voltages above 30 Vrms, 42.4 Vpk and 60 VDC during normal operation are considered hazardous LIVE and can pose a risk of electric shock. The abnormal operation limit is 50 Vrms, 70 Vpk and 120 VDC.

Users shall not access, touch, hazardous LIVE voltages during the products normal use or during an abnormal condition. Abnormal tests are presented in subsequent sections.

Follow these steps for the Limit Values for Accessible Parts Test. Refer to **Figure 5**:

1. Select a true RMS digital multimeter (DMM) to measure all user accessible circuits and conductive parts.
2. Select test points, such as metal connector pins and sockets, connector shells, enclosures, and similar circuits, to determine if they are hazardous LIVE voltage.
3. Set up the test by connecting the DMM COM/Grd lead (black) to earth ground.
4. Connect the DMM V-Ω lead (red), to measure voltages, Vrms and VDC, for each accessible conductive part.
5. Energize the test sample at +10% of the input voltage rating with maximum loading as described in the Input Power Test.
6. Perform the Limit Values for Accessible Parts test:
   a. Record the highest VAC and VDC value for each part.
   b. Take measurements at both normal and reversed polarity of the input power.
7. Test Results: Measured voltages shall not exceed 30 Vrms, 42.4 Vpk and 60 VDC; normal condition.

   Notes on the above:
   - The Limit Values for Accessible Parts Test is repeated after the abnormal tests in subsequent sections of this article.
   - Limits can differ between safety standards. The most common normal operation voltage limits are 30 Vrms, 42.4 Vpk and 60 VDC (ITE).
   - The Limit Values for Accessible Parts Test is repeated after the abnormal tests in subsequent sections of this article. The measured voltage shall not exceed 50 Vrms, 70 Vpk and 120 VDC (ITE) after abnormal tests.

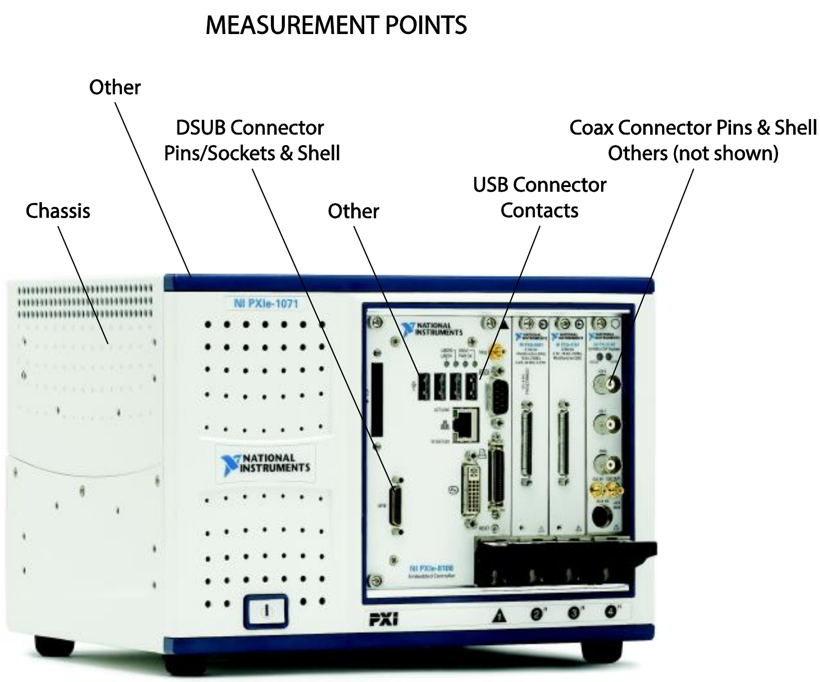

FIGURE 5 Voltage and current measurement of accessible parts

Leakage Test

Excessive leakage current, touch current, can cause a shock hazard when a person touches conductive parts of an electrical product. The human body is a conductor that can perceive current as low as 50 µA. A pull-away reaction occurs at 0.5 mA, and freezing or can't let go current can occur as low as 5 mA. Ventricular fibrillation leading to death is possible at 20 mA. Higher voltages cause larger currents and more severe electric shocks. Products must be designed so that neither the touch-current nor the PE ground current can create an electric shock hazard. Leakage current is measured on products using hazardous LIVE voltage. There are special meters that

simulate the impedance, resistance, of the human body, 500 Ω. The leakage current test does not apply to VDC supplied products.

Follow these steps for the Leakage Test:

1. Set up the test as shown in **Figure 6**.
2. Set the test sample voltage input for 110% of the product voltage rating, such as at 264 VAC for a 240 VAC product rating.
3. Open the PE ground circuit switch.
4. Perform leakage test:
   a. Measure leakage current from the test sample enclosure/ground to the PE ground.
   b. Leakage is measured in all possible input line polarities, ground conditions and power switch positions:
      i. Normal and reversed polarities.
      ii. Power switch open and closed.
      iii. Grounds open and closed.
5. Test Results:
   a. Leakage current limit is 0.5 mA rms sinusoidal or 0.7 mA rms non-sinusoidal during the normal operation with 0.5 mA most commonly used.
   b. Leakage current limit is 3.5 mA rms sinusoidal or 5.0 mA rms during protective conductor abnormal condition, such as with the PE grounding conductor opened.
   c. Test results: test sample shall not exceed the 0.5 mA limit during normal operation.

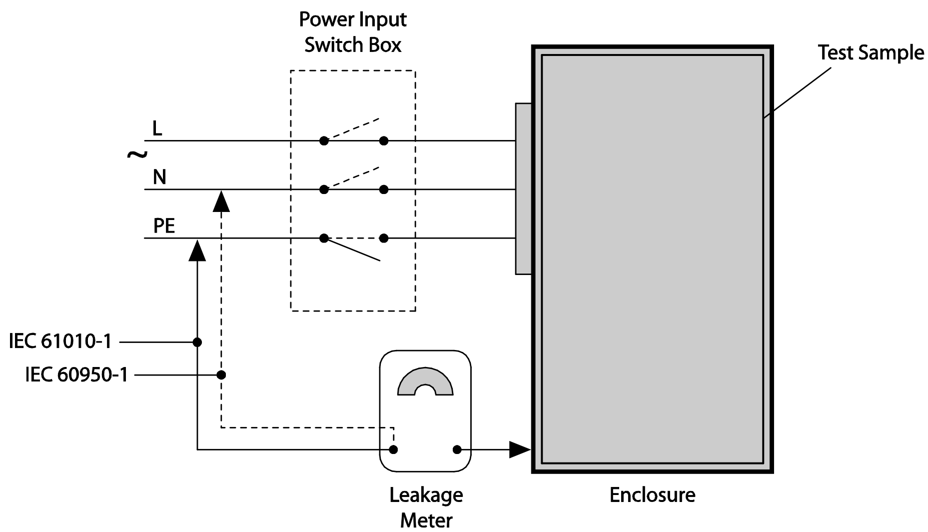

FIGURE 6 Leakage current test diagram

Conclusion

We have covered five important electrical product safety tests in Part 1 of this article. The extent and number of tests can vary between products, depending upon the design, rating, use environment, and potential hazards of the product. There may be more or less testing required to meet the standards than are presented here.

It is important to realize that product safety Type testing during the design phase and Routine testing in production helps manufacturers ensure that their products meet safety standards prior to distribution to the consumer, thus avoiding production delays or costly recalls if the product is discovered to be non-compliant with the safety standards.

Most importantly, products that successfully pass safety testing reduce potential hazards for the user, product, and surroundings.

Part 2 of this article will cover mechanical safety tests and manufacturing safety tests, including temperature, abnormals, and impact.

Note: Product safety standards take precedence over any information presented in this article. There are additional safety design requirements, including insulation, construction, components, user documentation, and labeling that must be considered when evaluating a product for safety compliance.

Artwork by Chris Hamberlin National Instruments

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David Lohbeck is Principal Safety Engineer at National Instruments (Austin, Texas). Lohbeck is also an ANSI Lead Assessor and Technical Expert where he assesses product Certification Bodies (CBs) and CB Test Laboratories (CBTLs). Previously he has worked for Motorola, Dell and TUV in the field of international product safety, machine safety, and electromagnetic compatibility (EMC). Lohbeck has published numerous articles on safety and EMC, and has been honored as a EDN Innovation Finalist in the "Best Contributed Article" category for his Sept 2004 article entitled Safety isolation protects users and electronic instruments and for his 2006 article Hazardous-voltage primer. David Lohbeck is author of CE Marking Handbook: A Practical Approach to Global Safety Certification (eBooks.com).

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