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The Why, When and How of Electrical Safety Testing

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Electrical safety testing has been around for almost a century. Safety agencies have been testing and certifying products for almost as long. Electrical and electronic products have changed dramatically over the years, requiring the safety standards to evolve to accommodate the changes in technology.

Not all consumers and manufacturers fully understand the reasons and importance of proper electrical safety testing. Shock hazards vary in severity and range from a tingling sensation to a lethal jolt. Identifying, correcting, and eliminating shock hazards are the primary reasons for electrical safety testing. The equipment used to certify and verify a product's electrical safety has also changed over time. The technology has improved the performance, accuracy, reliability, operator protection, and data capture of test results and critical product information. The improvements to the test equipment make safety testing simpler and more efficient for the manufacturer.

Why Do We Need Electrical Safety Testing?

The obvious answer is consumer and operator protection from shock hazards. Shock hazards exist when a potential voltage and current are accessible to the operator with respect to earth ground *(FIG. 1).*

According to OSHA: a shock hazard is considered to exist at an accessible part in a circuit between the part and ground, or other accessible parts if the potential is more than 42.4 volts peak and the current through a 1,500-ohm load is more than 5 milliamperes. (Reference Occupational Safety and Health Organization (OSHA) publication 3075)

Studies have concluded that the human body can feel the sensation of an electrical shock with as little as 1.0ma of current. Since the human body is not a fixed resistance, the voltage required to produce 1.0ma of current can vary greatly based on the minimum impedance of the human body under various conditions (some models use a human body resistance value of 1K ohms up to 100K ohms). Table 1 details the effects of electrical current in the human body.

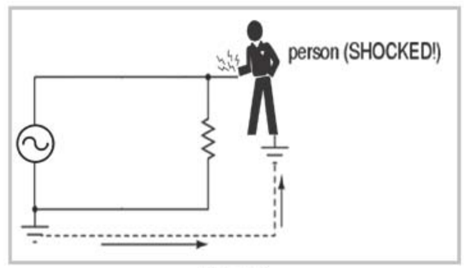

Figure 1

Effects of Electric Current in the Human Body

Current	Reaction
Below 1 milliampere	Generally not perceptible
1 milliampere	Faint tingle
5 milliamperes	Slight shock felt; not painful but disturbing. Average individual can let go. Strong involuntary reactions can lead to other injuries.
6–25 milliamperes (women)	Painful shock, loss of muscular control*
9–30 milliamperes (men)	The freezing current or " let-go" range.* Individual cannot let go, but can be thrown away from the circuit if extensor muscles are stimulated.
50–150 milliamperes	Extreme pain, respiratory arrest, severe muscular contractions. Death is possible.
1,000–4,300 milliamperes	Rhythmic pumping action of the heart ceases. Muscular contraction and nerve damage occur; death likely.
10,000 milliamperes	Cardiac arrest, severe burns; death probable

Source: W.B. Kouwenhoven, " Human Safety and Electric Shock," Electrical Safety Practices, Monograph, 112, Instrument Society of America, p. 93. November 1968.

TABLE 1

Many types of consumer electronics are battery powered and operate at "Safety extra-low voltages" which are not considered a shock hazard to the consumer. However, the chargers used to charge these batteries that plug into the wall have the potential voltage and current to be a hazard and therefore need testing for electrical safety compliance. Consider your cell phone; most of the time it presents no shock hazard to you. However, when you plug it into the charger and connect the charger to a wall outlet, you now have a possible shock hazard. If the insulation between the charger and your phone were to fail, the primary voltage applied to the charger could be present on conductive surfaces to which you have access.

Defined below are voltage levels from various sources. David Lohbeck, National Instruments--EDN, 5/11/2006, compiled this information. Most safety standards use the voltage terminology listed below. “Safety extra-low voltage” is the only condition in Table 2 that is not considered as a shock hazard. As mentioned previously in this article, *Occupational Safety and Health Organization (OSHA)* considers any potential ≥42.4Volts peak as a possible shock hazard.

Voltage Terms and Values:

Range	Voltage term	Value	Description
Low	Safety extra-low voltage	≤ 42.4Vpeak or ≤60Vdc	**"Safe,"** user -touchable secondary circuit designed and protected to remain under safe voltage levels in normal operation and under single fault; double insulation.
Low	Extra-Low Voltage	≤ 42.4Vpeak or ≤60Vdc	Secondary nontouchable circuit seperated from hazardous voltage by basic insulation ; not safety extra low voltage or limited -current circuit and not fault-tolerant.
Low	Low voltage	≤ 1kVac	**"Hazardous-voltage"** circuit, such as a primary circuit connected to low-voltage-mains supply such as 120/230V ac
High	Medium voltage	≤ 1kV ac to 100kVac	**"Distribution-Grid"** from substations distributed to residences and commercial buildings.
High	High Voltage	≥100kVac to ≤230kVac	**"Transmission-grid"** long-distance transmission-line voltage with typical maximum distances of approximately 300 miles (483 km)
High	Extra-high voltage	≥230kVac to ≤800kVac	**"Transmission-grid"** long-distance transmission-line voltage with typical maximum distances of approximately 300 miles (483 km)
High	Ultra-high voltage	≥800kVac to ≤2MVac	**"Transmission-grid"** long-distance transmission-line voltage with typical maximum distances of approximately 300 miles (483 km)

[1]Terms and Values are for illustration and may vary between standards.
[2]IEC 60950-1 and other standards
[3]3 NEC-NFPA 70 low voltage = 600V; ANSI/IEEE low voltage = 1 kVac; European Union (EU) Low-voltage Directive: low voltage 50V to 1kVac, 75 to 1500Vdc,
[4]ANSI C84.1 and IEEE 100.
[5]IEEE 1312 and IEEE 100.
[6] Hazardous voltage is greater than 30Vrms and 42.4Vpeak or 60Vdc. Test and measurement products are greater than 33Vrms and 48.7Vpeak or 70Vdc. National deviations may exist.

TABLE 2

When is Safety Testing Required?

At the point of manufacture, before the product is available to the end user. Manufactures of electrical and electronic products need to insure that no hazardous voltages or currents are accessible to the user. They need to test their products to determine if they meet minimum safety levels. In order to do this, they need to test against a reference or standard.

Safety agencies and panels of consumer advocates and manufacturers have developed electrical safety standards to address this issue. These standards insure that properly designed and constructed products will be electrically safe. These standards identify types of equipment and the possible shock hazards from each, the minimum requirements for protecting the consumer/operator from high voltage and leakage currents that could be detrimental to their well-being, and test methods that determine if the product's insulation system meets the minimum requirements. There is also the issue of design conformity and liability of the manufacturer.

Agencies such as Underwriters Laboratories (UL), Canadian Safety Association (CSA), and *Technischer Überwachungsverein* (TUV), to name just a few, test and certify that electrical and electronic equipment is safe to operate. Once these products are tested and proven to comply with the appropriate standard, the agency will allow the manufacturer to place a label on the unit to signify compliance or certification. These labels give consumers confidence in their equipment and confirm that the manufacturer has certified and verified the product for electrical safety.

These agencies not only test and certify the product based on a few sample units. They also routinely inspect the product at the manufacturer's facility to insure the product continues to meet the requirements whether they are building one unit or millions of units.

The manufacturer's liability rests on conformance. The manufacturer must insure conformance by testing 100% of the products they produce. Proof of compliance, including records of tests performed, are required to comply with safety agency standards.

The manufacturer is required to maintain accurate records to insure they build products with the same materials and processes on a continuous basis. The manufacturer must notify the safety agency of any changes to the material, design, or process used in manufacturing their product. If the manufacturer makes a change, safety agencies may amend the safety certification; and in some cases, the product may need to be re-certified.

Listed below with a brief description are some of the more common standards:

UL 60335-1 & IEC 60335-1

(Safety of Household and Similar Electrical Appliances)

> "This International Standard deals with the safety of electrical appliances for household and similar purposes, their RATED VOLTAGE being not more than 250 V for single-phase appliances and 480 V for other appliances. Appliances not intended for normal household use but which nevertheless may be a source of danger to the public, such as appliances intended to be used by laymen in shops, in light industry, and on farms, are within the scope of this standard. Examples of such appliances are catering equipment, cleaning appliances for industrial and commercial use, and appliances for hairdressers. As far as is practicable, this standard deals with the common hazards presented by appliances that are encountered by all persons in and around the home."

Almost everyone in America encounters some type of household appliance multiple times per day. These appliances consist of ovens, refrigerators, toasters, coffee makers, juicers, washers and dryers, and more. To ensure the safety of users, all of these products should be electrical safety tested.

UL60950 & IEC60950-1

(General Requirements for Safety of ITE (Information Technology Equipment))

"This standard is applicable to mains-powered or battery-powered information technology equipment, including electrical business equipment and associated equipment, with a RATED VOLTAGE not exceeding 600 V and designed to be installed in accordance with the Canadian Electrical Code, Part I, CSA C22.1; CSA C22.2 No. 0; the National Electrical Code, NFPA 70; and the National Electrical Safety Code, IEEE C2."

Examples of equipment that are in the scope of this standard are:

Generic product type	**Specific example of generic type**
banking equipment	monetary processing machines including automated teller (cash dispensing) machines (ATM)
data and text processing machines and associated equipment	data preparation equipment, data processing equipment, data storage equipment, personal computers, plotters, printers, scanners, text processing equipment, visual display units
data network equipment	bridges, data circuit terminating equipment, data terminal equipment, routers
electrical and electronic retail equipment	cash registers, point of sale terminals including associated electronic scales
electrical and electronic office machines	calculators, copying machines, dictation equipment, document shredding machines, duplicators, erasers, micrographic office equipment, motor-operated files, paper trimmers (punchers, cutting machines, separators), paper

	jogging machines, pencil sharpeners, staplers, typewriters
other IT equipment	photo printing equipment, public information terminals, multimedia equipment
postage equipment	mail processing machines, postage machines
telecommunication network infrastructure equipment	billing equipment, multiplexers, network powering equipment, network terminating equipment, radio base stations, repeaters, transmission equipment, telecommunication switching equipment
telecommunication terminal equipment	facsimile equipment, key telephone systems, modems, PABX's, pagers, telephone answering machines, telephone sets (wired and wireless)

Information technology equipment is one of the most commonly used types of products available today. All of these products are at some point connected to a voltage potential that could present a shock hazard. When connected to a voltage that is high enough to present a hazard to the operator, they need to be certified, and verified to be safe. Some of the tests required for certification and verification are Dielectric Withstand Test (Hipot Test), Insulation Resistance Test, and Leakage Current Test, to name just a few.

IEC 60065-1

(Video / Audio Equipment General Safety Requirements)

"This International Safety Standard applies to electronic apparatus designed to be fed from the MAINS, from a SUPPLY APPARATUS, from batteries or from REMOTE POWER FEEDING and intended for reception, generation, recording or reproduction respectively of audio, video and associated signals. It also applies to apparatus designed to be used exclusively in combination with the above-mentioned apparatus. This standard primarily concerns apparatus intended for household and similar general use. It also covers COMMERCIAL APPARATUS and PROFESSIONAL APPARATUS which may also be used in places of public assembly such as schools, theatres, places of worship and the workplace. PROFESSIONAL APPARATUS intended for use as described above is also covered unless falling specifically within the scope of other standards may be evaluated to requirements in this standard, or to the requirements in UL 1419. This standard concerns only safety aspects of the above apparatus; it does not concern other matters, such as style or performance. This standard applies to the above-mentioned apparatus, if designed to be connected to the TELECOMMUNICATION NETWORK or similar network, for example by means of an integrated modem. "

Almost every household in America has multiple video products such as DVD Player/Recorders, LCD/LED/Plasma TV's, Audio amplifiers, Stereo's, etc.

IEC 60601-1

(Medical Electrical Equipment General Safety Requirements)

"This Standard applies to the safety of MEDICAL ELECTRICAL EQUIPMENT (as defined in Sub-clause 2.2.15). Although this standard is primarily concerned with safety, it contains some requirements regarding reliable operation where this is connected with safety.

SAFETY HAZARDS resulting from the intended physiological function of EQUIPMENT covered by this standard are not considered. Appendices in this standard are not mandatory unless made so by an explicit statement in the main text."

Due to increased longevity, global diseases, and continuing research into new treatments and procedures, companies have been developing more electronic equipment for supporting the medical industry. These products have to be evaluated based on usage. Some medical equipment may be used in close proximity to a patient and some equipment may actually be electrically connected to a patient, such as EKG heart and EEG brain wave monitors.

How Do You Certify and Verify That Your Products are Safe?

Test equipment manufacturers have created test equipment especially designed to perform the tests as defined in the safety agency standards. These tests consist of the following:

AC & DC HIPOT or DIELECTRIC WITHSTAND TEST

A typical Hipot tester or Dielectric Withstand tester will apply an AC or DC high voltage potential between the input live AC wires and AC ground or the ungrounded metal enclosure. The test passes if the measured current during this test does not exceed the specified maximum allowable current; usually this current is set for 5ma or less, depending on the safety standard you are following.

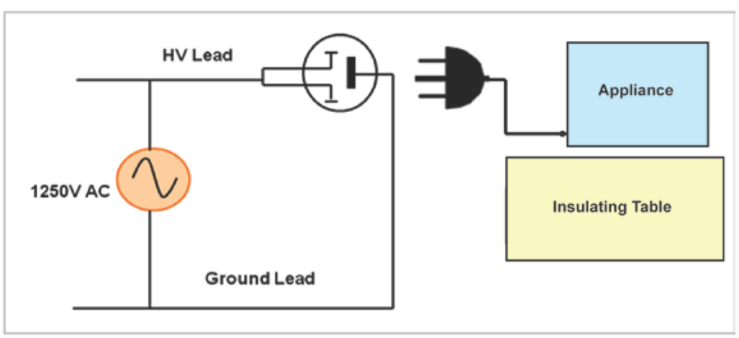

Figure 2

LEAKAGE CURRENT TEST

There are different types of leakage currents. The minimum allowable leakage current for each of these differ based on the associated safety standard. The most critical standard for leakage current is for Medical Equipment (ref. IEC 60601-1). In the 60601-1 safety standard leakage is defined as:

Earth Leakage Current: current flowing from the mains part through or across the insulation into the protective earth conductor.

Enclosure Leakage Current: current flowing from the enclosure, or parts thereof, excluding applied parts, accessible to the operator or patient in normal use, through an external conductive connection other than the protective earth conductor to earth or to another part of the enclosure.

Patient Leakage Current: current flowing from the applied part via the patient to earth or flowing from the patient via an F-Type applied part to earth originating from the unintended appearance of a voltage from an external source on the patient.

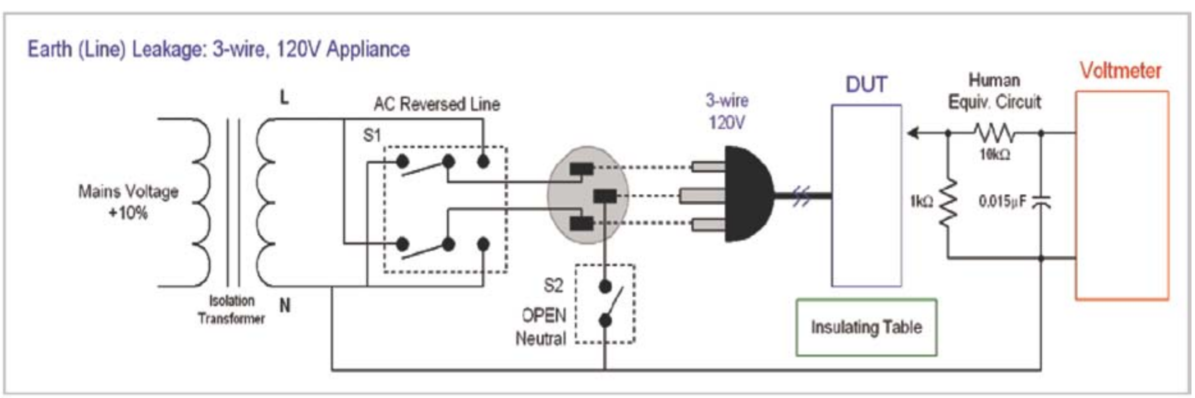

Figure 3

INSULATION RESISTANCE TEST (IR)

IR testing is very similar to Hipot testing. In simple terms, it is the applied voltage divided by the measured current resulting in the calculated resistance. It is a method of characterizing the condition of an insulator.

The most common methods by which insulation may be degraded are environmental (Heat/Cold/Humidity/Contamination). Many of these insulators are subject to heating from soldering during the manufacturing process, and cold or high humidity when not properly stored. In addition, physical damage may occur, causing deformity of the insulation material. Since the thickness of the material can affect insulation resistance, it is common for stretching and compression to change the insulator thickness, which changes the insulation's resistance. Any sharp object, even something as small as metal filings, also may puncture the insulation. Typically, insulation resistance is measured in Millions of Ohms (MΩ). Measuring the insulation resistance during the manufacturing process insures that the insulation has not been degraded.

GROUND BOND TEST

Ground Bond testing is a test that confirms the ground connection from the Device Under Test (DUT) to the earth ground is adequate to carry 2 times the current rating of the DUT.

UL 60950 defines the Ground Bond Test or "Resistance of earthing conductors and their terminations" as follows:

I. If the current rating of the circuit under test is ≤16A, these test conditions apply:
   a. Test Current = 2x current rating of circuit under test (AC or DC)
   b. Test Voltage ≤12V
   c. Test Time = 120 seconds

II. The resistance of the PB conductor shall not exceed 0.1Ω.

III. If the current rating of the circuit under test is >16A, these test conditions apply:
   a. Test Current = 2x current rating of circuit under test (AC or DC)
   b. Voltage drop across DUT ≤ 2.5V
   c. Test Time = Refer to Table below .

Current Rating of Circuit under Test (A)	**Test Time (minutes)**
≤30	2
30 ≤ 60	4
60 ≤ 100	6
100 ≤ 200	8
>200	10

TABLE 3

The diagram below shows a standard Ground Bond test configuration: The device under test must demonstrate that the ground connection (internally) will conduct 2 times its rated current. Then by measuring the voltage and current the ground resistance can be calculated using ohms law:

Ground Resistance =Voltage between Ground contact on input connector ÷ Current conducted through the internal input ground connections.

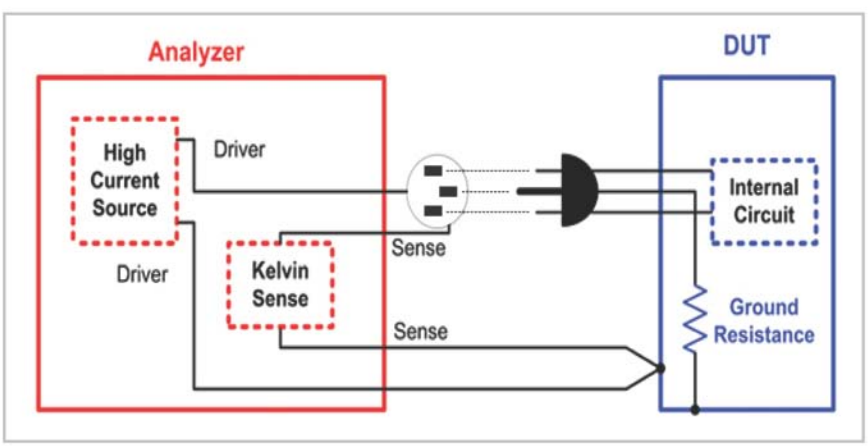

Figure 4

Additional improvements to Safety Test Equipment not defined by the safety standards but based on feedback from manufacturers include:

SIMULTANEOUS TESTING OF GROUND BOND AND HIPOT

When manufacturers are producing high volumes of product, even a few seconds saved can equate to improved process times and higher volumes. Simultaneous testing of Ground Bond and Hipot can cut the actual test times in half, saving the manufacturer process time and money. Many safety test equipment manufacturers have developed high voltage and high current multiplexers to allow for multiple products to be tested from a single safety test device. These are referred to as Scanners and Multiplexers and vary from one or two devices to tens and hundreds of devices.

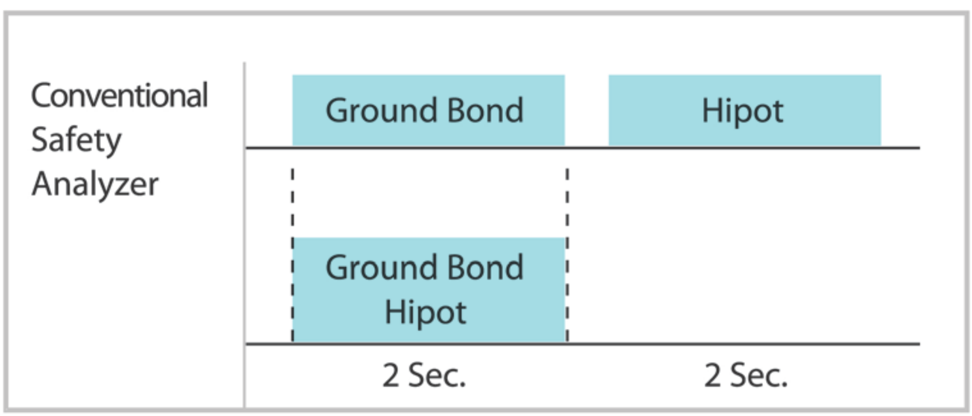

Figure 05

CORONA DISCHARGE/FLASHOVER (ARC) Detection/BREAKDOWN:

All hipot and dielectric test equipment have the ability to detect a breakdown, and some have the ability to detect flashover (ARC), but only a few have the added ability to detect CORONA DISCHARGE. Although safety agencies have not included any requirement to measure the corona discharge in the safety test requirements, by accurately measuring the leakage current dynamically in very small levels, it is possible to determine if the unit is in one of the following conditions:

Corona Discharge: an electrical discharge brought on by the ionization of a fluid surrounding a conductor, which occurs when the potential gradient (the strength of the electric field) exceeds a certain value, but conditions are insufficient to cause complete electrical breakdown or arcing. Corona discharge may be an early symptom of an impending breakdown.

Flashover: an electrical breakdown of a gas that produces an ongoing plasma discharge, resulting from a current flowing through normally nonconductive media such as air. Vasily V. Petrov, a Russian scientist who discovered it in 1802, first described the phenomenon.

Breakdown: a rapid reduction in the resistance of an electrical insulator that can lead to a spark jumping around or through the insulator. This may be a momentary event (as in an electrostatic discharge), or may lead to a continuous arc discharge if protective devices fail to interrupt the current in a high power circuit.

The graph below shows the association of these three conditions:

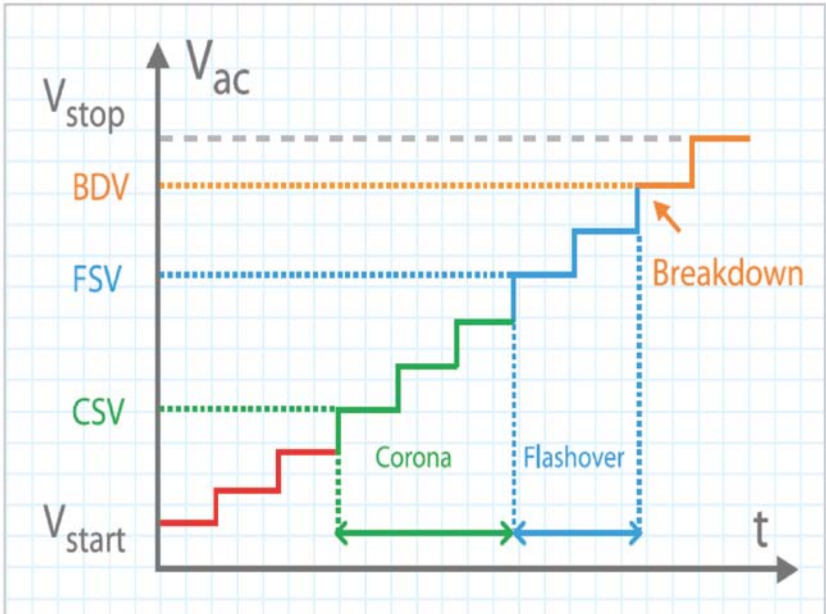

Figure 6

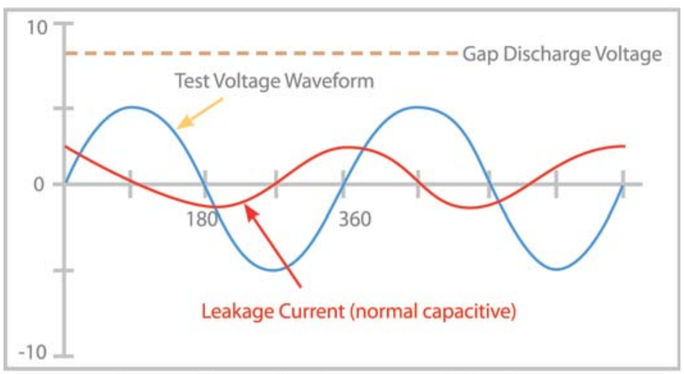

Figure 7 : Normal Leakage Current Waveform

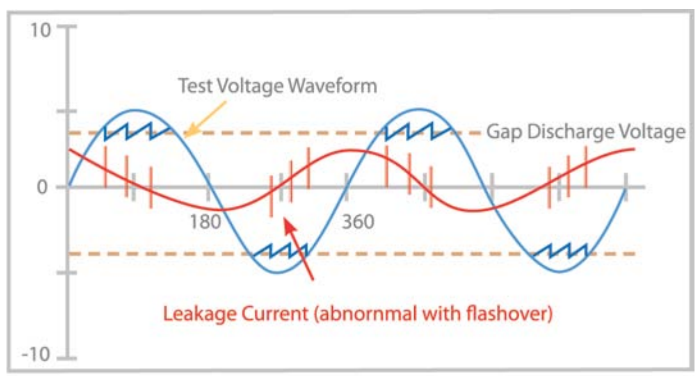

Figure 8 : Leakage Current Waveform when flashover occurred

<u>OPEN SHORT CHECK (OSC)</u>

It is important to know if the device under test is properly connected to insure that the Hipot/Dielectric Test / or Insulation Resistance test has been performed. One test equipment manufacturer has developed a method of insuring the connections to the DUT are normal/open/or shorted referred to as the OPEN SHORT CHECK.

Based on the fact that any equipment with conductors separated by an insulator will result in some type of capacitance, and applying a high frequency and measuring the impedance, then it can be determined if the connection is open (very high capacitance) or shorted (very low capacitance) or normal (acceptable capacitance range). The figures below illustrate this principle:

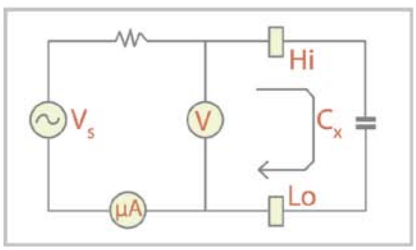

Figure 9: Normal Connection

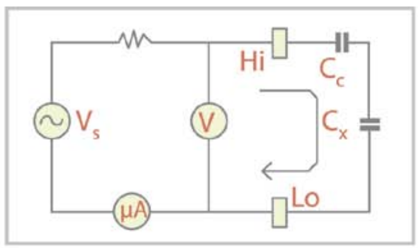

Figure 10: Connection Open

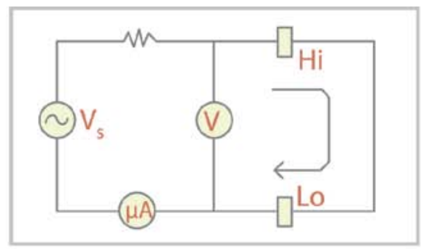

Figure 11: Connection Short

GROUND FAULT INTERRUPT (GFI) & OPERATOR PROTECTION

Hipot and Dielectric Withstand test equipment can present an electrical shock hazard to the test operator. Test equipment manufacturers have included a GROUND FAULT INTERRUPT (GFI) circuit to help prevent the operator from being electrically shocked. A ground fault exists whenever currents i1 and i2 are not equal, as shown in figure 12.

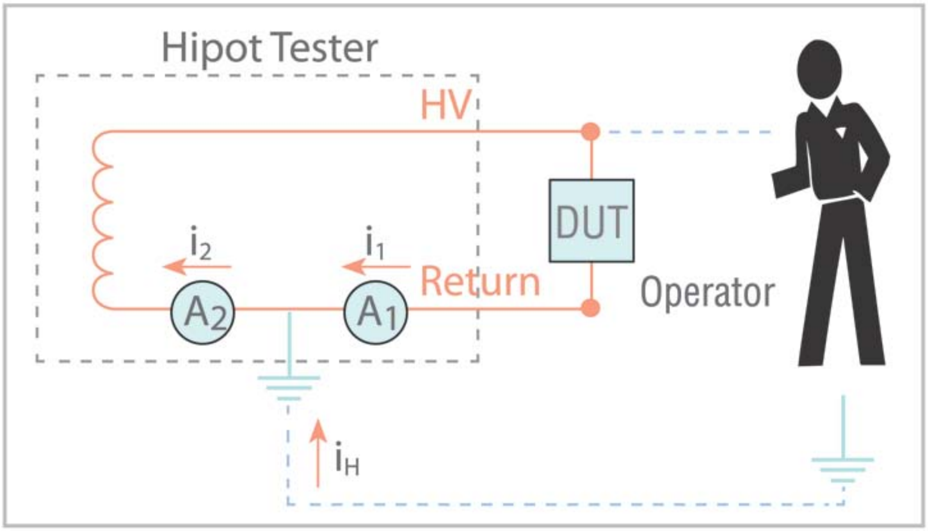

Figure 12

Because of the many safety agency standards, your test equipment manufacturer can always be a good source of information and support when you have questions about safety test requirements and issues. For quick support, the applications engineers, and sales and service support people from your test equipment manufacturer, are readily available to help you.

-End-

Disclaimer: This article is a general overview of electrical safety testing. It is not a complete document for defining all the requirements of electrical safety testing.

About Larry Sharp: *Larry Sharp is the Sr.Applications Engineer at Chroma Systems Solutions. He began his career with Burroughs Computer Systems as a Power Supply Engineer, spent 19 years with a major Power Supply manufacturer as their Technical Services Manager and most recently came on board with Chroma Systems Solutions as their Applications Engineer. Larry is a graduate of DeVry Institute.*

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