

ABCs of multimeter safety

Multimeter safety and you

Don't overlook safety—your life may depend on it

Where safety is a concern, choosing a multimeter is like choosing a motorcycle helmet—if you have a “ten dollar” head, choose a “ten dollar” helmet. If you value your head, get a safe helmet. The hazards of motorcycle riding are obvious, but what's the issue with multimeters? As long as you choose a multimeter with a high enough voltage rating, aren't you safe? Voltage is voltage, isn't it?

Not exactly. Engineers who analyze multimeter safety often discover that failed units were subjected to a much higher voltage than the user thought he was measuring. There are the occasional accidents when the meter, rated for low voltage (1000 V or less), was used to measure medium voltage, such as 4160 V. Just as common, the knock-out blow had nothing to do with misuse—it was a momentary *high-voltage spike or transient* that hit the multimeter input without warning.

Voltage spikes—an unavoidable hazard

As distribution systems and loads become more complex, the possibilities of transient overvoltages increase. Motors, capacitors and power conversion equipment, such as variable speed drives, can be prime generators of spikes. Lightning strikes on outdoor transmission lines also cause extremely hazardous high-energy transients. If you're taking measurements on electrical systems, these transients are “invisible” and largely unavoidable hazards. They occur regularly on low-voltage power circuits, and can reach peak values in the many thousands of volts. In these cases, you're dependent for protection on the safety margin already built into your meter. **The voltage rating alone will not tell you how well that meter was designed to survive high transient impulses.**

Early clues about the safety hazard posed by spikes came from applications involving measurements on the supply bus of electric commuter railroads. The nominal bus voltage was only 600 V, but multi-meters rated at 1000 V lasted only a few minutes when taking measurements while the train was operating. A close look revealed that the train stopping and starting generated

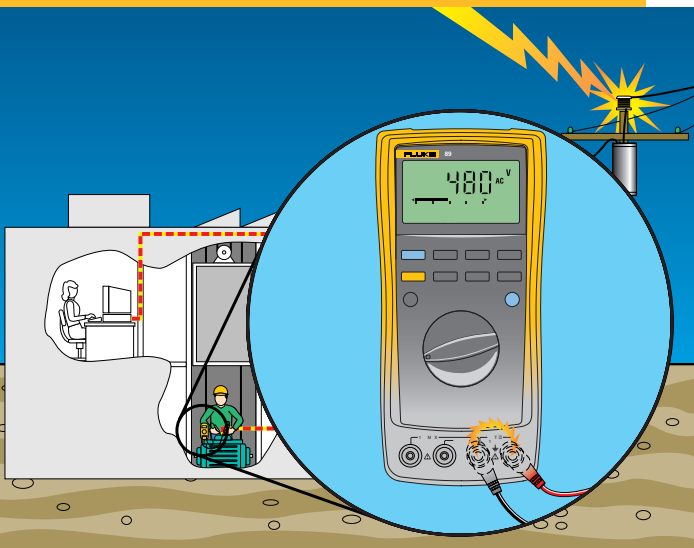
Application Note

10,000 V spikes. These transients had no mercy on early multimeter input circuits. The lessons learned through this investigation led to significant improvements in multimeter input protection circuits.

Test tool safety standards

To protect you against transients, safety must be built into the test equipment. What performance specification should you look for, especially if you know that you could be working on high-energy circuits? The task of defining safety standards for test equipment is addressed by the International Electrotechnical Commission (IEC). This organization develops international safety standards for electrical test equipment.

Meters have been used for years by technicians and electricians yet the fact is that meters designed to the IEC 1010 standard offer a significantly higher level of safety. Let's see how this is accomplished.



Transient protection

The real issue for multimeter circuit protection is not just the maximum steady state voltage range, but a combination of *both steady state and transient overvoltage withstand capability*. Transient protection is vital. When transients ride on high-energy circuits, they tend to be more dangerous because these circuits can deliver large currents. If a transient causes an arc-over, the high current can sustain the arc, producing a plasma breakdown or explosion, which occurs when the surrounding air becomes ionized and conductive. The result is an arc blast, a disastrous event which causes more electrical injuries every year than the better known hazard of electric shock. (See “*Transients—the hidden danger*” on page 4.)

Overvoltage installation categories

The most important single concept to understand about the standards is the Overvoltage Installation Category. The standard defines Categories I through IV, often abbreviated as CAT I, CAT II, etc. (See Figure 1.) The division of a power distribution system into categories is based on the fact that a dangerous high-energy transient such as a lightning strike will be attenuated or dampened as it travels through the impedance (ac resistance) of the system. A higher CAT number refers to an electrical environment with higher power available and higher energy transients. Thus a multimeter designed to a CAT III standard is resistant to much higher energy transients than one designed to CAT II standards.

Within a category, a higher voltage rating denotes a higher transient withstand rating, e.g., a CAT III-1000 V meter has superior protection compared to a CAT III-600 V rated meter. The real misunderstanding occurs if someone selects a CAT II-1000 V rated meter thinking that it is superior to a CAT III-600 V meter. (See “*When is 600 V more than 1000 V?*” on page 7.)

Understanding categories: Location, location, location

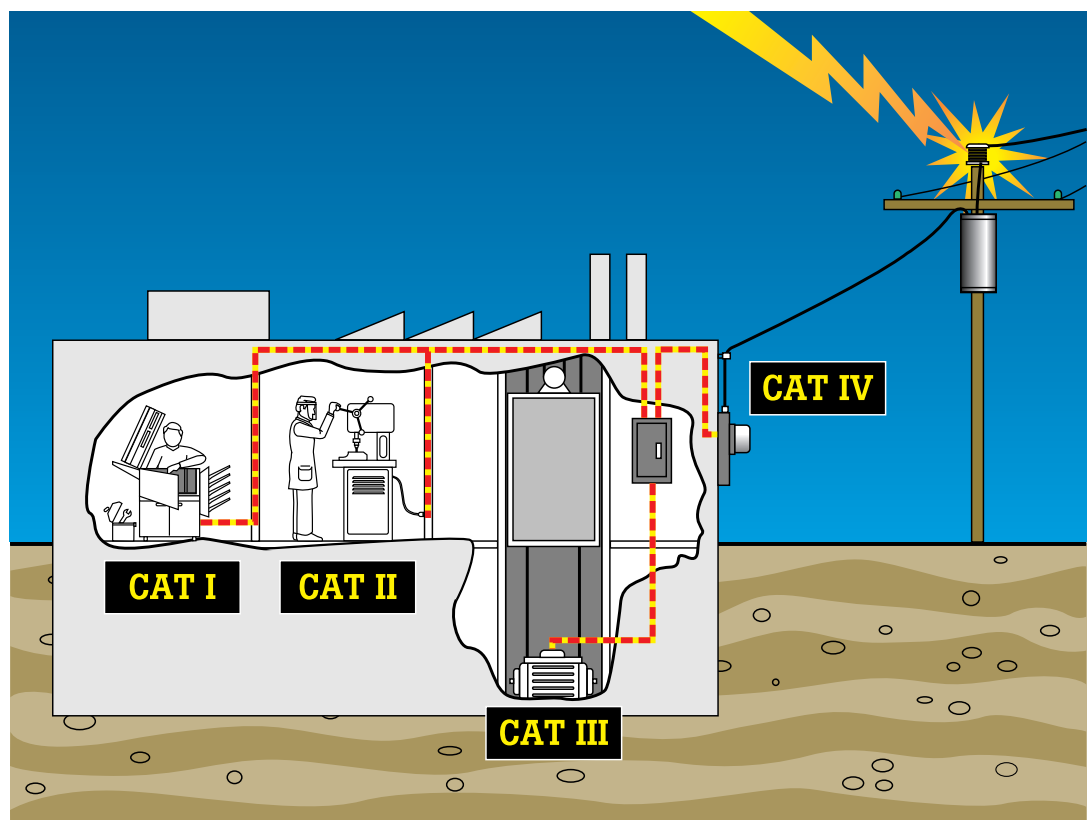


Figure 1. Location, location, location.

Overvoltage category	In brief	Examples
CAT IV	Three-phase at utility connection, any outdoor conductors	<ul style="list-style-type: none"> Refers to the “origin of installation,” i.e., where low-voltage connection is made to utility power Electricity meters, primary overcurrent protection equipment Outside and service entrance, service drop from pole to building, run between meter and panel Overhead line to detached building, underground line to well pump
CAT III	Three-phase distribution, including single-phase commercial lighting	<ul style="list-style-type: none"> Equipment in fixed installations, such as switchgear and polyphase motors Bus and feeder in industrial plants Feeders and short branch circuits, distribution panel devices Lighting systems in larger buildings Appliance outlets with short connections to service entrance
CAT II	Single-phase receptacle connected loads	<ul style="list-style-type: none"> Appliance, portable tools, and other household and similar loads Outlet and long branch circuits Outlets at more than 10 meters (30 feet) from CAT III source Outlets at more that 20 meters (60 feet) from CAT IV source
CAT I	Electronic	<ul style="list-style-type: none"> Protected electronic equipment Equipment connected to (source) circuits in which measures are taken to limit transient overvoltages to an appropriately low level Any high-voltage, low-energy source derived from a high-winding resistance transformer, such as the high-voltage section of a copier

Table 1. Overvoltage installation categories. IEC 1010 applies to *low-voltage* (< 1000 V) test equipment.

It's not just the voltage level

In Figure 1, a technician working on office equipment in a CAT I location could actually encounter dc voltages much *higher* than the power line ac voltages measured by the motor electrician in the CAT III location. Yet transients in CAT I electronic circuitry, whatever the voltage, are clearly a lesser threat, because the energy available to an arc is quite limited. This does *not* mean that there is no electrical hazard present in CAT I or CAT II equipment. The primary hazard is electric shock, not transients and arc blast. Shocks, which will be discussed later, can be every bit as lethal as arc blast.

To cite another example, an overhead line run from a house to a detached workshed might be only 120 V or 240 V, but it's still technically CAT IV. Why? Any outdoor conductor is subject to very high energy lightning-related transients. Even conductors buried underground are CAT IV, because although they will not be directly struck by lightning, a lightning strike nearby can *induce* a transient because of the presence of high electro-magnetic fields.

When it comes to Overvoltage Installation Categories, the rules of real estate apply: it's location, location, location...

(For more discussion of Installation Categories, see page 6, "Applying categories to your work.")

Independent testing

Independent testing is the key to safety compliance

Look for a symbol and listing number of an independent testing lab such as UL, CSA, TÜV or other recognized testing organization. Beware of wording such as "Designed to meet specification ..." Designer's plans are never a substitute for an actual independent test.

How can you tell if you're getting a genuine CAT III or CAT II meter? Unfortunately it's not always that easy. It is possible for a manufacturer to self-certify that its meter is CAT II or CAT III *without any independent verification*. The IEC develops and proposes standards, but it is not responsible for *enforcing* the standards.

Look for the symbol and listing number of an independent testing lab such as UL, CSA, TÜV or other recognized approval agency. That symbol can only be used if the product successfully completed testing to the agency's standard, which is based on national/international standards. UL 3111, for example, is based on IEC 1010. In an imperfect world, that is the closest you can come to ensuring that the multimeter you choose was actually tested for safety.



LISTED



What does the CE symbol indicate?



A product is marked CE (Conformité Européenne) to indicate its conformance to certain essential requirements concerning health, safety, environment and consumer protection established by the European Commission and mandated through the use of "directives." There are directives affecting many product types, and products from outside the European Union can not be imported and sold there if they do not comply with applicable directives. Compliance with the directive can be achieved by proving conformance to a relevant technical standard, such as IEC 1010 for low-voltage products. Manufacturers are permitted to *self-certify* that they have met the standards, issue their own Declaration of Conformity, and mark the product "CE." *The CE mark is not, therefore, a guarantee of independent testing.*

Tool Tip

Non-contact voltage detectors are a quick, inexpensive way to check for the presence of live voltage on ac circuits, switches and outlets before working on them.



1. Verify the voltage detector function is working properly.
2. Make sure the detector is rated for the level of voltage being measured and is sensitive enough for your application.
3. Make sure you're grounded (through your hand, to the floor), to complete the capacitive voltage connection.

Use either a voltage detector "wand" or a digital multimeter (DMM) with non-contact measurement built in.



This meter has a built-in non-contact voltage tester.

Protection against two major electrical hazards

Transients—the hidden danger

Let's take a look at a worst-case scenario in which a technician is performing measurements on a live three-phase motor control circuit, using a meter without the necessary safety precautions.

Here's what could happen:

1. A lightning strike causes a transient on the power line, which in turn strikes an arc between the input terminals *inside the meter*. The circuits and components to prevent this event have just failed or were missing. Perhaps it was not a CAT III rated meter. The result is a *direct short* between the two measurement terminals through the meter and the test leads.
2. A high-fault current—possibly several thousands of amperes—flows in the short circuit just created. This happens in thousandths of a second.

When the arc forms inside the meter, a very high-pressure shock wave can cause a loud *bang*—very much like a gunshot or the backfire from a car. At the same instant, the tech sees bright blue arc flashes at the test lead tips—the fault currents superheat the probe tips, which start to burn away, drawing an arc from the contact point to the probe.

3. The natural reaction is to pull back, in order to break contact with the hot circuit. But as the tech's hands are pulled back, an arc is drawn from the motor terminal to each probe. If these two arcs join to form a single arc, there is now *another direct phase-to-phase short, this time directly between the motor terminals*.

4. This arc can have a temperature approaching 6000 °C (10000 °F), which is higher than the temperature of an oxyacetylene cutting torch! As the arc grows, fed by available short circuit current, it superheats the surrounding air. Both a shock blast and a plasma fireball are created. If the technician is lucky, the shock blast blows him away and removes him from the proximity of the arc; though injured, his life is saved. In the worst case, the victim is subjected to fatal burn injuries from the fierce heat of the arc or plasma blast.

In addition to using a multi-meter rated for the appropriate Overvoltage Installation Category, anyone working on live power circuits should be protected with flame resistant clothing, should wear safety glasses or, better yet, a safety face shield, and should use insulated gloves.

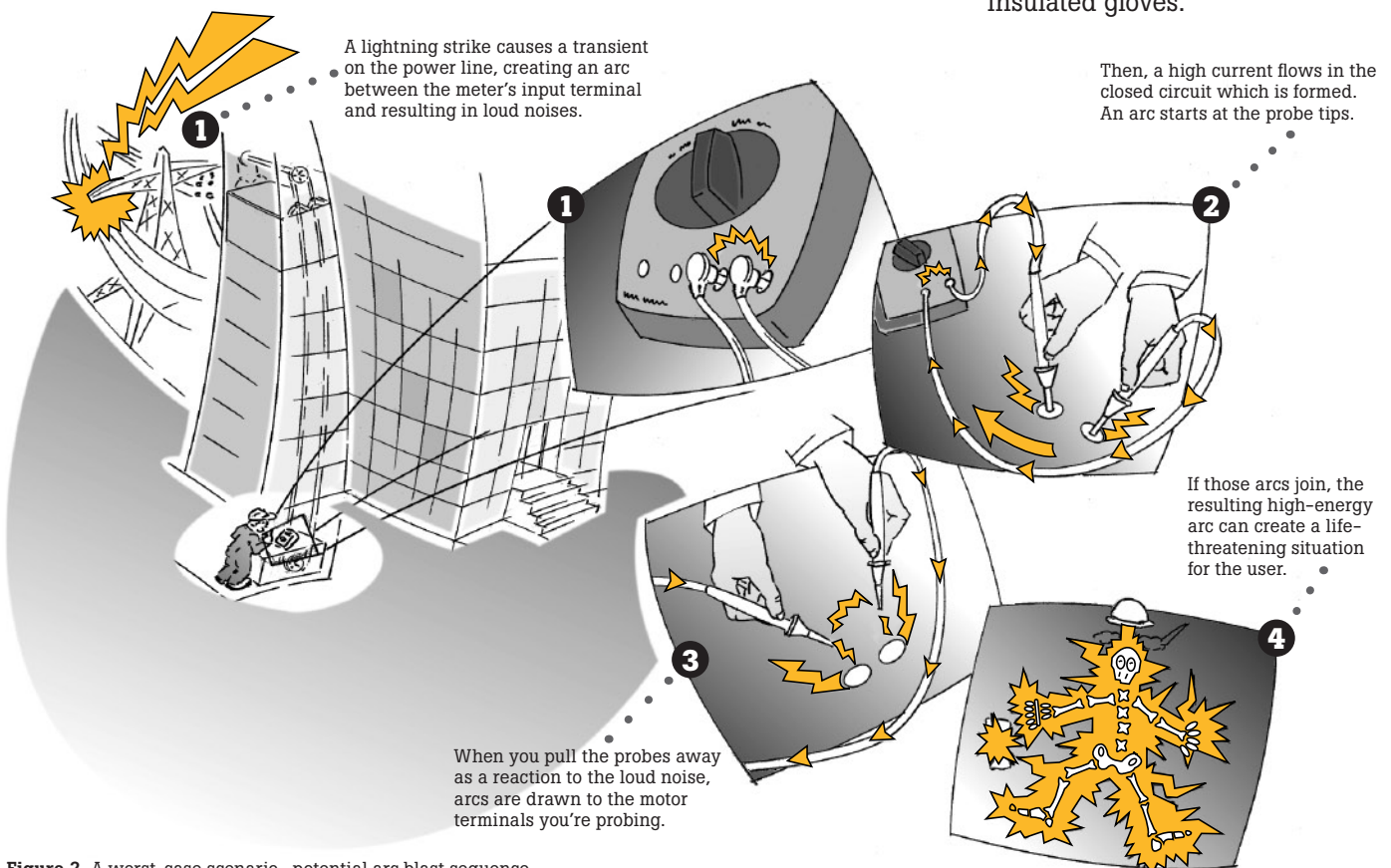


Figure 2. A worst-case scenario—potential arc blast sequence.

Arc blast and electric shock

Use the right *high-energy* fuses

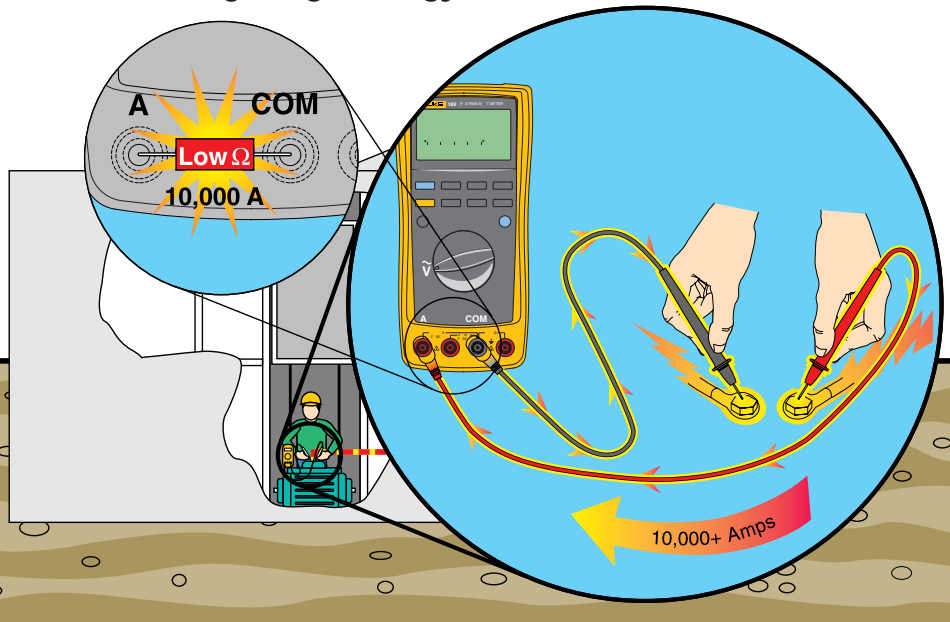


Figure 3. Misuse of DMM in Ammeter Mode.

Transients aren't the only source of possible short circuits and arc blast hazard. One of the most common *misuses* of handheld multimeters can cause a similar chain of events.

Let's say a user is making current measurements on signal circuits. The procedure is to select the amps function, insert the leads in the mA or amps input terminals, open the circuit and take a series measurement. In a series circuit, current is always the same. The input impedance of the amps circuit must be low enough so that it doesn't affect the series circuit's current. For instance, the input impedance on the 10 A terminal of a Fluke meter is .01 Ω. Compare this with the input impedance on the voltage terminals of 10 MΩ (10,000,000 Ω).

If the test leads are *left in the amps terminals and then accidentally connected across a voltage source*, the low input impedance becomes a *short circuit!* It doesn't matter if the selector dial is turned to volts; the leads are still physically connected to a low-impedance circuit.* That's why the amps terminals *must be protected by fuses*. Those fuses are the only thing standing between an inconvenience—blown fuses—and a potential disaster.

Use only a multimeter with amps inputs protected by high-energy fuses. Never replace a blown fuse with the wrong fuse. *Use only the high-energy fuses specified by the manufacturer.* These fuses are rated at a voltage and with a short circuit interrupting capacity designed for your safety.

Overload protection

Fuses protect against *overcurrent*. The high input impedance of the volts/ohms terminals ensures that an overcurrent condition is unlikely, so fuses aren't necessary. *Overvoltage* protection, on the other hand, *is* required. It is provided by a protection circuit that clamps high voltages to an acceptable level. In addition, a thermal protection circuit detects an overvoltage condition, protects the meter until the condition is removed, and then automatically returns to normal operation. The most common benefit is to protect the multimeter from overloads when it is in ohms mode. In this way, overload protection with automatic recovery is provided for all measurement functions as long as the leads are in the voltage input terminals.

*Some multimeters, such as the Fluke 180 Series, have an Input Alert which gives a warning beep if the meter is in this configuration.

Electric shock

While most people are aware of the danger from electric shock, few realize how little current and how low a voltage are required for a fatal shock. Current flows as low as 30 mA can be fatal (1 mA=1/1000 A). Let's look at the effects of current flow through a "typical" 68 kilogram (150 pound) male:

- At about 10 mA, muscular paralysis of the arms occurs, so that he cannot release his grip.
- At about 30 mA, respiratory paralysis occurs. His breathing stops and the results are often fatal.
- At about 75 to 250 mA, for exposure exceeding five seconds, ventricular fibrillation occurs, causing incoordination of the heart muscles; the heart can no longer function. Higher currents cause fibrillation at less than five seconds. The results are often fatal.

Now let's calculate the threshold for a "hazardous" voltage. The approximate body resistance *under the skin* from hand to hand across the body is 1000 Ω. A voltage of *only 30 V* across 1000 Ω will cause a current flow of 30 mA. Fortunately, the skin's resistance is much higher. It is the resistance of the skin, especially the outer layer of dead cells, that protects the body. Under wet conditions, or if there is a cut, skin resistance drops radically. At about 600 V, the resistance of the skin ceases to exist. It is punctured by the high voltage.

For multimeter manufacturers and users, the objective is to prevent accidental contact with live circuits at all costs.

Look for:

- Meters and test leads with double insulation.
- Meters with recessed input jacks and test leads with shrouded input connectors.
- Test leads with finger guards and a non-slip surface.
- Meter and test leads made of high-quality, durable, non-conductive materials.

Work safely

*Safety is everyone's responsibility but ultimately it's in **your** hands.*

No tool by itself can guarantee your safety. It's the combination of the right tools and safe work practices that gives you maximum protection. Here are a few tips to help you in your work.

- Work on de-energized circuits whenever possible. Use proper lock-out/tag-out procedures. If these procedures are not in place or not enforced, *assume that the circuit is live.*
- On live circuits, use protective gear:
 - Use insulated tools.
 - Wear safety glasses or a face shield.
 - Wear insulated gloves; remove watches or other jewelry.
 - Stand on an insulated mat.
 - Wear flame resistant clothing, not ordinary work clothes.
- When making measurements on live circuits:
 - Hook on the ground clip first, then make contact with the hot lead. Remove the hot lead first, the ground lead last.
 - Hang or rest the meter if possible. Try to avoid holding it in your hands, to minimize personal exposure to the effects of transients.
 - Use the three-point test method, especially when checking to see if a circuit is dead. First, test a known *live* circuit. Second, test the target circuit. Third, test the live circuit *again*. This verifies that your meter worked properly before and after the measurement.
 - Use the old electricians' trick of keeping one hand in your pocket. This lessens the chance of a closed circuit across your chest and through your heart.



Always wear appropriate personal protective equipment (PPE), including flame-resistant clothing, leather over rubber gloves, safety glasses, and an arc-rated face shield or hood, both with hard hat and hearing protection.

Applying categories to your work

Shortcuts to understanding categories

Here are some quick ways to apply the concept of categories to your every day work:

- The general rule-of-thumb is that the closer you are to the power source, the higher the category number, and the greater the potential danger from transients.
- It also follows that the greater the *short-circuit current* available at a particular point, the higher the CAT number.
- Another way of saying the same thing is the greater the *source impedance*, the *lower* the CAT number. Source impedance is simply the total impedance, including the impedance of the wiring, between the point where you are measuring and the power source. This impedance is what dampens transients.
- Finally, if you have any experience with the application of transient voltage surge suppression (TVSS) devices, you understand that a TVSS device installed at a panel must have higher energy-handling capacity than one installed right at the computer. In CAT terminology, the panelboard TVSS is a CAT III application, and the computer is a receptacle-connected load and therefore, a CAT II installation.

As you can see, the concept of categories is not new and exotic. It is simply an extension of the same common-sense concepts that people who work with electricity professionally apply every day.

Multiple categories

There's one scenario that sometimes confuses people trying to apply categories to real world applications. In a single piece of equipment, there is often more than one category. For example, in office equipment, from the 120 V/240 V side of the power supply back to the receptacle is CAT II. The electronic circuitry, on the other hand, is CAT I. In building control systems, such as lighting control panels, or industrial control equipment such as programmable controllers, it is common to find electronic circuits (CAT I) and power circuits (CAT III) existing in close proximity.

What do you do in these situations? As in all real-world situations, use common sense. In this case, that means using the meter with the higher category rating. In fact, it's not realistic to expect people to be going through the category-defining process all the time. What is realistic, and highly recommended, is to *select a multimeter rated to the highest category in which it could possibly be used*. In other words, err on the side of safety.

How to evaluate a multimeter's safety rating

Understanding voltage withstand ratings

IEC 1010 test procedures take into account three main criteria: steady-state voltage, peak impulse transient voltage and source impedance. These three criteria together will tell you a multimeter's *true voltage withstand value*.

When is 600 V more than 1000 V?

Table 2 can help us understand an instrument's true voltage withstand rating:

1. *Within* a category, a higher "working voltage" (steady-state voltage) is associated with a higher transient, as would be expected. For example, a CAT III-600 V meter is tested with 6000 V transients while a CAT III-1000 V meter is tested with 8000 V transients. So far, so good.
2. What is not as obvious is the difference between the 6000 V transient for CAT III-600 V and the 6000 V transient for CAT II-1000 V. They are *not* the same. This is where the source impedance comes in. Ohm's Law ($Amps = Volts / Ohms$) tells us that the 2 Ω test source for CAT III has *six times the current* of the 12 Ω test source for CAT II.

The CAT III-600 V meter clearly offers superior transient protection compared to the CAT II-1000 V meter, even though its so-called "voltage rating" could be perceived as being lower. *It is the combination of the steady-state voltage (called the working voltage), and the category that determines the total voltage withstand rating of the test instrument, including the all-important transient voltage withstand rating.*

Measurement Category	Working Voltage (dc or ac-rms to ground)	Peak Impulse Transient (20 repetitions)	Test Source (= V/A)
CAT I	600 V	2500 V	30 Ohm source
CAT I	1000 V	4000 V	30 Ohm source
CAT II	600 V	4000 V	12 Ohm source
CAT II	1000 V	6000 V	12 Ohm source
CAT III	600 V	6000 V	2 Ohm source
CAT III	1000 V	8000 V	2 Ohm source
CAT IV	600 V	8000 V	2 Ohm source

Table 2: Transient test values for measurement categories. (50 V/150 V/300 V values not included.)

A note on CAT IV: Test values and design standards for Category IV voltage testing are addressed in IEC 1010 second edition.

Creepage and clearance

In addition to being tested to an actual overvoltage transient value, multimeters are required by IEC 1010 to have minimum "creepage" and "clearance" distances between internal components and circuit nodes. Creepage measures distance across a surface. Clearance measures distances through the air. The higher the category and working voltage level, the greater the internal spacing requirements. One of the main differences between the old IEC 348 and IEC 1010 is the increased spacing requirements in the latter.

The bottom line

If you are faced with the task of replacing your multimeter, do one simple task before you start shopping: Analyze the worst-case scenario of your job and determine what category your use or application fits into.

First choose a meter rated for the highest *category* you could be working in. Then, look for a multimeter with a voltage rating for that category matching your needs. While you're at it, don't forget the test leads.



Look for category and voltage ratings of test leads and multimeters.

IEC 1010 applies to test leads too: they should be certified to a category and voltage as high or higher than the meter. When it comes to your personal protection, don't let test leads be the weak link.

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