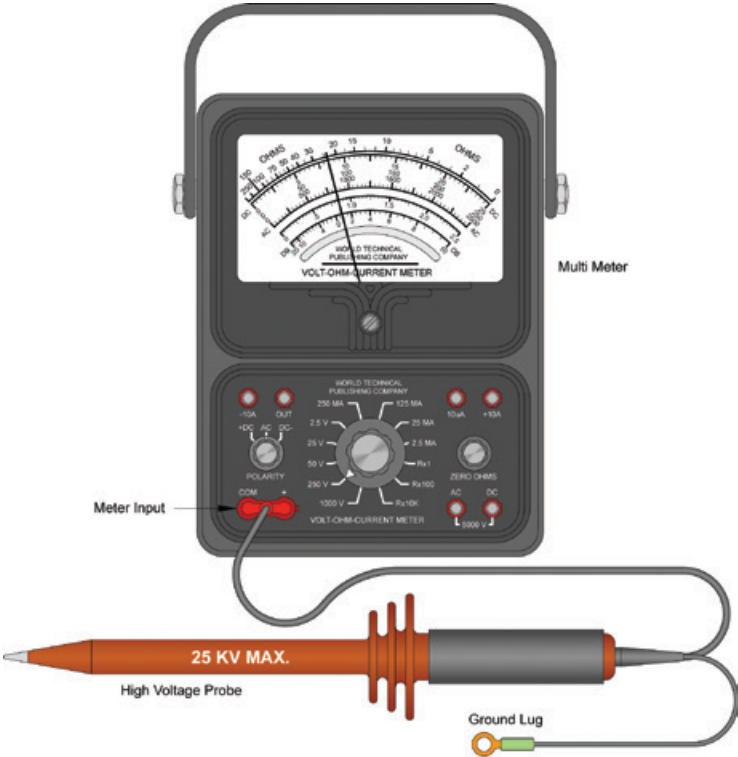


# Electrical Arcs

By Brian S. Elliott

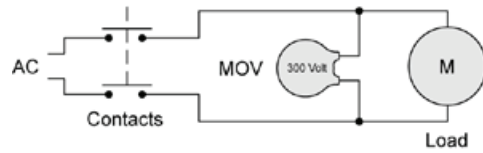


Those of us who have worked with, or around, electrical equipment have witnessed electrical arcs. At the very least, we've seen the sparks produced when a relay or contactor switches off. Similarly, most of us also know that repetitive arcing can be very damaging to contacts over the long term, requiring periodic replacement of relays or their contacts. The principal reason for arcing is the inductive kickback produced by a coil when it is de-energized. When power is disconnected, a coil naturally tries to preserve the current. It does this by increasing the voltage. In some cases, this increase reaches several thousand volts, which easily promotes arcing across contacts and through the coil itself.

During this discharge, localized temperatures often become high enough to promote rapid erosion of the control contacts. Induction motors and solenoid coils represent the most common source of arc energy. This phenomenon is easily observed by watching a motor starter with open contacts. When the motor turns on, the contacts close in a fairly uneventful fashion. However, when the contacts open, there is a bright, momentary arc produced which is visible to the naked eye. This arc represents the inductive energy stored in the motor coil.

Another common source of arcs occurs when energized components are placed too closely to an opposite potential. When properly utilizing commercially available components, a proximity situation rarely occurs. There are, however, several situations which promote arcing. Obviously, using components at higher voltages than they are rated for reduces their effective stand-off voltage, thereby creating an arc. Electrical components should never be used at voltages higher than the manufacturer's recommendations. Over the long term, dirt also becomes a factor. As dirt builds up on electrical components, standoff voltages may decrease until an arc initiates. One of two things happens at this point; either the arc energy blows away the dirt build-up and the component returns to normal operation, or the dirt burns and a carbon path is produced on the insulating surfaces of the component(s), permanently reducing the stand-off voltage. This, in turn, promotes more arcing, which causes more damage and a run-away situation can rapidly form. If the power source is sufficient to maintain a continuous arc, then extreme damage to the contacts and surrounding components can occur in very short order.

Controlling arc damage from coils and motors is done by suppressing inductive kickback. There are three basic methods which can mitigate inductive kickback: shorting, arc lengthening and switching management. For lower power applications, such as small solenoids and fractional horsepower motors, shorting is the simplest method. Shorting can be accomplished by using a metal oxide varistor (MOV), a neon lamp or a spark gap. An MOV is the most common component used to suppress lesser energies. These devices represent an open circuit below their specified rating and become conductive above that rating. An MOV is connected directly to the terminals of the coil. When the coil is disconnected, its voltage starts to rise, and when it reaches the MOV rating, its output becomes shorted. All arcing is suppressed because the kickback voltage is never large enough to initiate the arc in the first place.



**Figure 1: MOV Suppression**

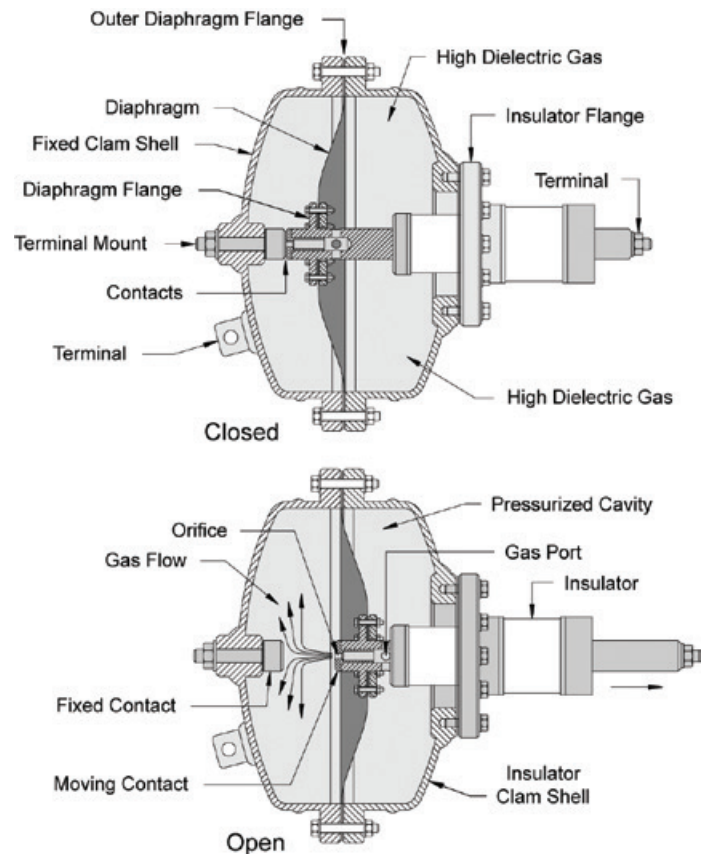
suppression, they are placed in the same location as the MOV in figure 1.

A spark gap can also serve to suppress inductive energies. Once again, the protective element is placed across the terminals of the coil. As the voltage rises, it eventually reaches a point which causes a spark to form across the gap; the idea being that the arc gap will initiate a spark before the control contacts.

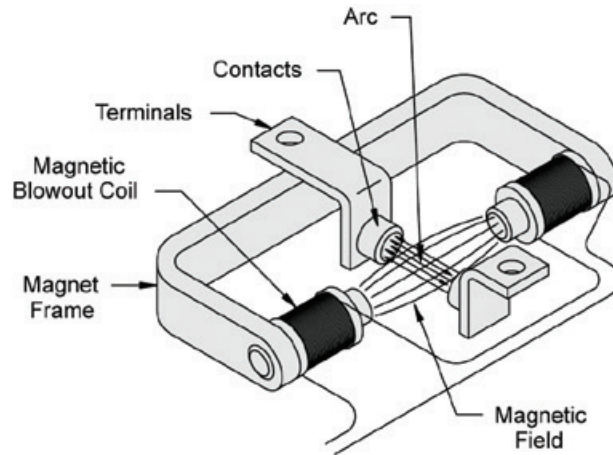
MOVs, neon lamps and arc gaps have practical limitations. For applications involving higher energies, such as multi-horsepower motors or an entire branch circuit, controlling inductive kickback through shorting simply isn't practical. Usually, arc lengthening is used for these applications. In these cases, the arc is lengthened until inductive energies can no longer sustain the reaction.

There are principally four methods used to lengthen an arc: long-throw contactors, pneumatic suppression, magnetic suppression and arc dividing. Long-throw contactors have the disadvantage of being disproportionately large in comparison to other techniques; therefore, these devices are not commonly used. Pneumatic suppression is typically used for switching situations which deal with extremely large inductive energies. Pneumatic suppression interrupters, as illustrated in **Figure 2**, are most commonly used to switch large elements of the power distribution grid throughout the United States.

**Figure 1** shows how an MOV is used in a circuit to suppress inductive kickback. A neon lamp serves the same basic function as an MOV, with slightly less precision and at lower voltages. In this case, when the voltage climbs high enough to light the lamp, the inductive energy dissipates through the element. When neon lamps are used for transient



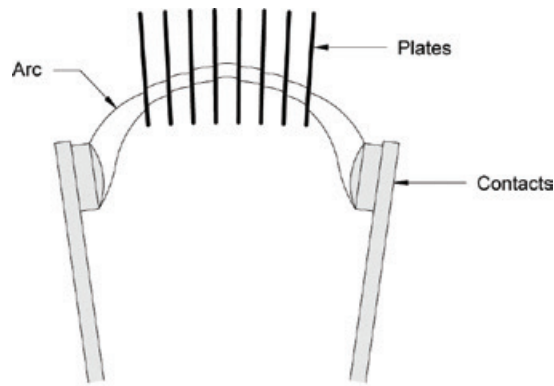
**Figure 2: Pneumatic Suppression Interrupter**



**Figure 3: Magnetic Arc Suppression**

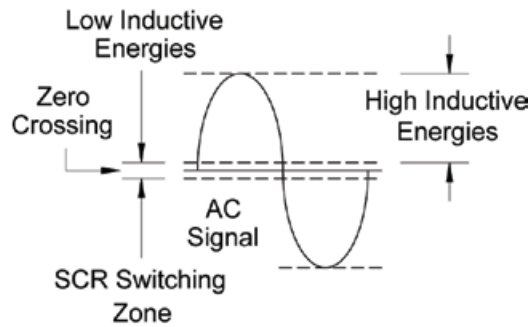
Magnetic suppression and arc dividers are typically utilized when switching multi-horsepower motors. Magnetic suppression is accomplished by forcing the arc to follow the longer field lines of a fixed magnet placed in close proximity to the contacts. The longer path is specifically designed to force an arc length that can't be sustained by the available inductive energies. **Figure 3** shows a schematic representation of magnetic arc suppression.

Arc dividers are typically a set of high-temperature, insulating plates arranged just above the arc formation area. The idea is that the heat generated by the arc forces it to rise into the plate array. This has the effect of dividing the arc into several sections, which immediately extinguishes it. Arc dividers are generally used for higher horsepower applications and long throw interrupters. **Figure 4** shows a schematic representation of an arc divider.



**Figure 4: Arc Divider**

Switch management represents the cutting edge of arc suppression technologies. In these cases, a high speed, solid-state switch element is utilized. Usually a silicon-controlled rectifier (SCR) or high-power transistor set makes up the switch element. If the switch can be turned off at or near the zero crossing of the AC signal, then the coil will have substantially reduced inductive energies and the damaging effects can be principally negated. SCRs are rather popular for these applications because they operate with AC power and turn off when the line current drops below a given level very near the zero crossing. This characteristic of SCRs makes them nearly ideal for switching AC devices with a high inductive component. **Figure 5**, next page, shows an AC cycle and its associated inductive energy zones.



**Figure 5: Inductive Energy Zones**

Since arcs have a tendency to jump toward a neutralizing potential, this makes them a severe safety hazard. It is very important to de-energize and discharge any electrical equipment that is being serviced. This is particularly important with circuits having storage potential, such as

high-voltage capacitors. Devices like this retain a lethal electrical charge well after the power has been disconnected. Many circuits have what is termed a “crowbar”, which is a relay which shorts and discharges any components with storage potential when the power to the equipment is disconnected.

Safety procedures and devices implemented and used on and around high voltage circuits are, to say the least, extremely important. When working with this type of equipment, these procedures and devices mean the difference between a safe working environment and serious injury, or even death. In part two of this article, we’ll discuss safety procedures and equipment commonly applied when working with or designing high voltage electrical equipment. (Sources, Suppression & Safety Considerations)

## Surge Suppressors

To a very large extent, arc suppression is accomplished by controlling high voltage transients. If a sudden voltage spike initiates a spark within a circuit with access to sufficient energies, an extremely damaging arc may result.

Recently, the application of commercially available surge suppressors has become the accepted method for controlling these transients. In most cases, a large capacity surge suppressor is applied at the primary power connection while lesser units are applied throughout the equipment or distribution system as necessary.

In addition to limiting the initiation of arcs, surge suppressors are nearly mandatory for any equipment that uses microprocessor-based components such as PLCs, digital displays and smart products.

Until recently, the performance of surge suppressors has varied among manufacturers and even from component to component. This held true even though they all carry the same ratings and were, presumably, tested using the same procedures.

This anomaly has been due principally to UL's 1449 standard which specifies testing procedures for these devices. Previous versions of this standard left more than a few "loopholes" in testing procedures, which allowed manufacturers a little too much latitude in certifying their products.

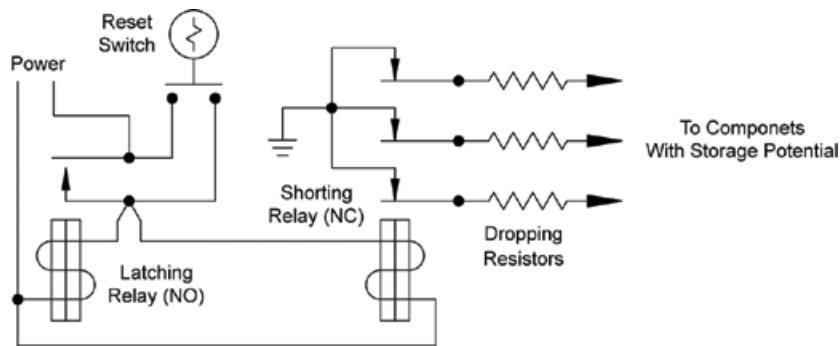
Over the past two years, UL 1449 has been repeatedly updated to better quantify the testing and make the procedures less ambiguous. The current version provides concise testing and procedural guidelines, leaving very little to interpretation. This should ultimately have the effect of producing a more uniform industry standard.

## Crowbar Circuits

Electrically speaking, a "crowbar" is a circuit specifically designed to automatically discharge potentially hazardous voltages from a piece of equipment when it is turned off, if the power is disconnected or if it experiences a fault.

A great deal of electrical equipment uses internal components that have storage potential. Even after the power is disconnected, many electrical components retain lethal electrical energies. The best example of these components is capacitors. Large capacitors retain a great deal of energy for long periods of time – days, weeks and, in some instances, even months. If an unaware technician comes in contact with these components, he may sustain serious injuries or even be killed.

The basic crowbar is a fairly simple circuit and, in the interest of safety, should be kept that way. **Figure 6** shows a typical crowbar circuit.



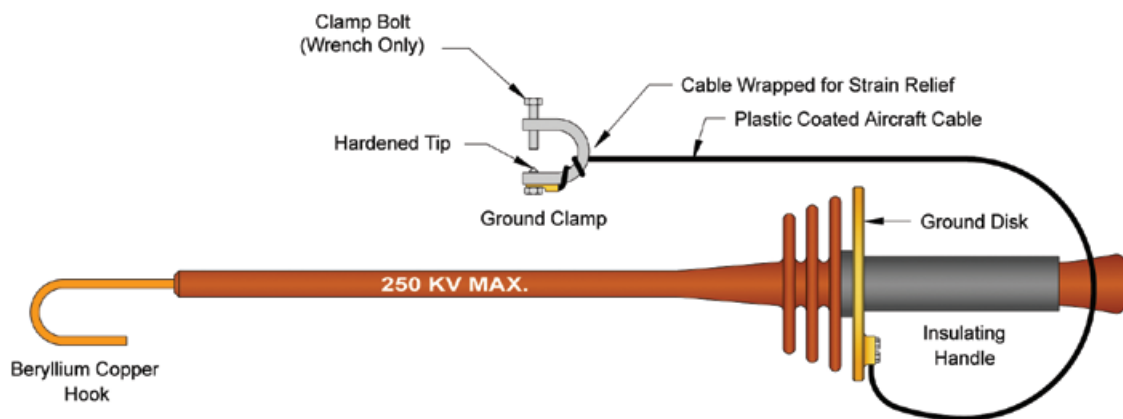
**Figure 6: Crowbar Circuit Schematic**

It consists of a holding relay that controls one or more shorting relays; in this case, a single, normally closed, three-pole unit. The shorting relays are configured to discharge any stored energies within the main circuit. In some cases the stored energies may be high enough to require some sort of dump load, as shown in the illustration. These dump loads are typically in the form of a high wattage resistor. Crowbar circuits are commonly designed to automatically reset, but they may also carry a manual reset key.

(In this case, the circuit shown contains a manual reset.) Intended to add another level of safety to the equipment, the manual reset assures that the equipment cannot be reenergized without a specific action from a technician.

## The Grounding Hook

For a variety of reasons, most extremely high voltage equipment can't realistically utilize crowbar circuits. In these cases the technician must be sure that all components with storage potential are manually discharged and remain in that state during the service work. This is the realm of the grounding hook, as shown in **Figure 7**.



**Figure 7: Grounding Hook or "Jesus Stick"**

These units consist of a copper bar bent with a long-leg hook. The shaft is insulated and the opposite end has two handles with a high voltage hand guard. A plastic-coated piece of aircraft cable is connected to a copper plate and bar. The opposite end of the cable is connected to a bolt-on ground clamp. The bolt-on clamp assures that the ground connection can't be casually or accidentally disconnected.

Even though a grounding hook is a shorting device, it typically carries a maximum voltage rating. As with any high voltage equipment, never exceed the maximum voltage rating of the unit; doing so may cause serious injury or death. In use, grounding hooks are often permanently mounted in the area where they are to be used. After the equipment is disconnected from the power source, the sticks are hooked onto the appropriate terminals to assure that the circuit is completely discharged and remains in that state.

## Live Testing

Despite how much technicians try to avoid it, sometimes it is simply necessary to troubleshoot an energized circuit and/or conduct live testing. In these situations, crowbar circuits and grounding hooks do nothing to protect the technician.

During live testing, arc hazards are at their peak; personnel should exercise great care in these environments. To a large extent, arc suppression during live testing is done by identifying high potential areas and avoiding anything that will deteriorate the stand-off effectiveness of the equipment. If the technician inadvertently inserts a conductive tool between two high potential terminals, it may initiate an arc that can produce serious injury or even death.

Poor grounding exacerbates this condition and only serves to heighten arc hazards. In a situation where an arc forms within a properly grounded cabinet, the hazard is safely contained and does little more than startle the technician. However, if the cabinet isn't grounded, an inadvertent arc may form through the person standing in front of the box, which can instantly kill them.

Dirt build-up can significantly reduce the stand-off voltage of any electrical component. As stand-off voltage is reduced, arc hazards increase. It is very important to keep high voltage equipment clean. If a piece of equipment is particularly dirty, it should be cleaned or replaced before any live work is conducted. Properly cleaning a piece of hazardous electrical equipment can mean the difference between an uneventful afternoon and one you'll remember for the rest of your life.

## High Voltage Meters and Probes

Troubleshooting high voltage equipment is typically done with specially designed high voltage meters or ordinary multimeters equipped with specialized high voltage probes, as shown in **Figure 8**, next page. This particular probe is rated at 25 KV and has a 100 to 1 attenuation factor. The meter is set to the 250 volt range and the probe is connected to the input terminals. The technician simply multiplies any reading by 100 to determine the circuit voltage.

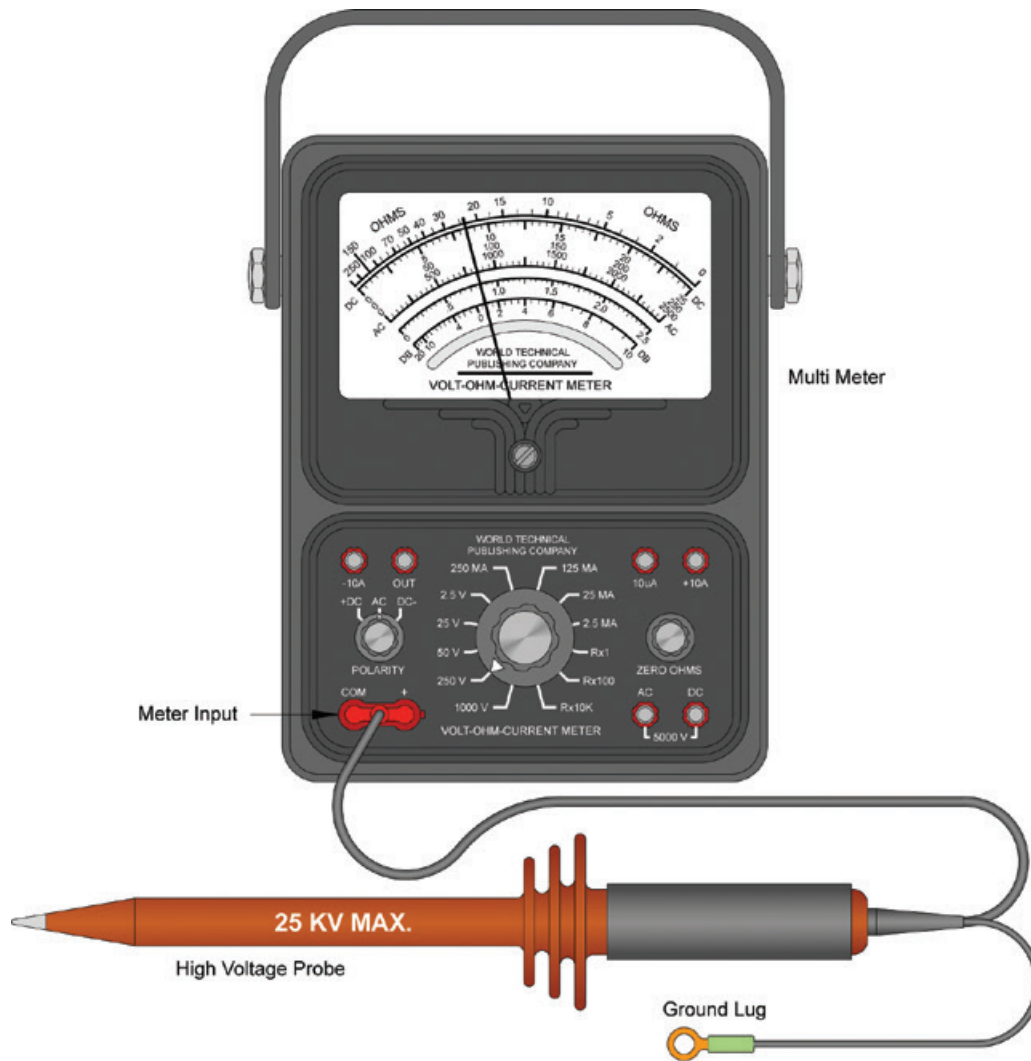
Following a few basic safety procedures makes using these probes very safe. On the other hand, ignoring these procedures can cause serious bodily harm and even death. Remember, when working around this type of circuitry, there is no middle ground.

When using any high voltage instrumentation, always read and understand the manufacturer's recommendations concerning the specific equipment.

When using high voltage probes, always connect the grounding lug to a suitable earth ground. This connection serves an important safety function as it adds a second level of protection for the technician.

Similarly, never use a high voltage probe at voltages higher than its maximum rating. During operation, one hand should be in your pocket and the other should be used to grip the handle. Never touch the probe in front of the hand guard, even when the probe is not in use. Obviously, touching the forward part of the probe during use





**Figure 8: Multi Meter w/ High Voltage Probe**

greatly increases the technician's chance of electrocution. Touching the forward part when not in use will deposit oils and dirt from the skin. Over time, contaminants like these can build up and affect the stand-off voltage of the probe.

Have your high voltage probes re-qualified by the factory on a regular basis. Never use a high voltage probe of unknown origin. If the history of the probe is not clear, it should either be sent back to the manufacturer for re-qualification or destroyed. Inspect your high voltage probe before each use. In any high voltage case, work being conducted on this type of circuit should always be carried out by personnel who have been properly trained for the specific equipment and safety issues that apply to the environment. Additionally, a spotter technician, trained in CPR, should always be present when personnel are working with potentially hazardous electrical equipment. With the right equipment, proper training and judicious application of safety procedures, a technician can safely work with and around equipment that would otherwise be considered lethal.

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