EXAMINATION OF FIRE DAMAGED METAL OXIDE VARISTORS

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A Metal Oxide Varister (MOV) is a non-linear bi-polar resistor. The typical MOV contains three parts, the metal oxide (zinc oxide), the leads, and an epoxy coating. An MOV has a high resistance at low voltages, and a low resistance at high voltages. During a low voltage time period the MOV can be modeled as an open circuit. MOVs are utilized in devices to help protect against damage from high voltage spikes. To protect against voltage spikes MOVs are connected between the load side and ground or load and neutral such that went a spike occurs and the maximum continuous voltage or threshold voltage of the MOV is reached, the MOV closes the circuit and creates a short. Excess voltage is dissipated as heat, and works to protect the load.

There are two types of MOVs, a radial and a strap type. Radial MOVs are commonly seen in 20, 32 or 40 mm sizes. Each of the two MOV types use a ceramic grain boundary with zinc oxide grains. The zinc grains and grain boundary together act as diodes; the number of grain boundaries in series determines the voltage rating of the MOV, while the diameter of the MOV determines its energy rating in joules.

Voltage spikes, commonly known as power surges, degrade MOVs. The life expectancy of an MOV is defined by the manufacturer and includes variables such as current, time, and transient pulses. The main variable for life expectancy is the MOV's energy rating usually measured in Joules. The more frequently a MOV is closed and activated or the more time in which a power surge lasts will affect the life expectancy and subsequent failure of an MOV. These devices are designed to conduct significant power for short durations, not sustained energy. Faults of the utility grid such as loss of the neutral conductor or shorted high voltage lines can cause sustained energy events, sometimes referred to as TOVs (Temporary Over Voltages). Catastrophic failure of an MOV can be decreased by changes in design. These design changes of MOV circuits usually includes connecting more devices in parallel or by using a higher energy rating MOV than required. The design difficulty with connecting devices in parallel is that the MOVs rated the same (in terms of nominal voltage) and even from the same lot will not have the same threshold voltage. As an example, a test of 5 devices (nominal rating 270 volts) from the same lot yielded the following test results with 1 mA AC, 60 Hz, flowing:

287 289 295 297 298 volts.

Testing was conducted with a Vitrek 944i dielectric analyzer in an automatic mode. The difficulties presented by the test data are obvious: the sharp knee and the disparity in voltages will cause the current to almost predominantly be carried by the 287 volt unit if the five were placed in parallel. Ergo, paralleling of units does not necessarily increase the joule rating in a substantive manner.

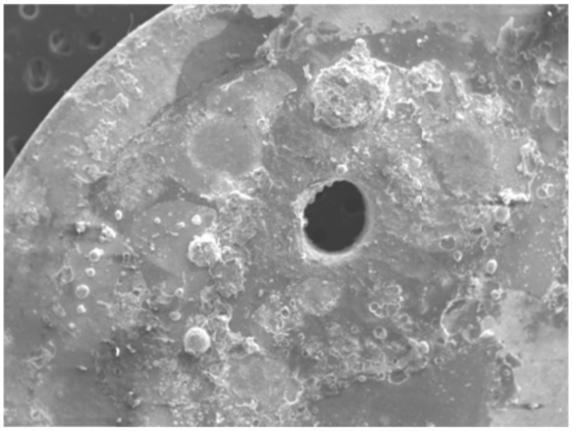
MOVs breakdown during high voltage events which cause localized heating and thermal runaway due to lack of conformity in individual grain boundary junctions which leads to dominant current paths. If the high voltage fault is sustained for a long period of time the epoxy on the MOV can catch fire. In a prior paper by one of the authors, some of the aspects of MOV fire causation were detailed.

In an attempt to lessen the instance of fires caused by MOVs, UL has issued the third edition of UL 1449. The new ‘lingo’ is no longer a Transient Voltage Surge Suppressor (TVSS) but instead a SPD (Surge Protective Device). Schemes at protecting the MOVs call for the thermal fusing of the MOV, as well as having a voltage rating that exceeds the available supply voltage. As an example, an MOV used in an across the line application at 120 volts (nominal) will be required to withstand voltages of about 250 volts, corresponding to an open neutral. A manufacturer may well choose a rating of 270 volts to insure compliance with this criterion. A second method of insuring compliance is by thermal fusing and inline fusing. Both seek to cut off power before the MOV body erupts in fire.

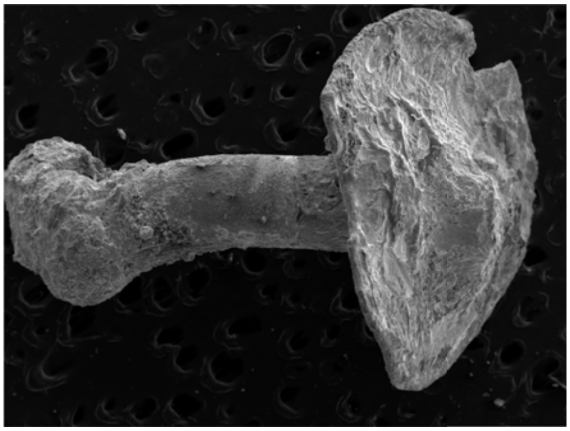
Because of improvements in UL 1449, there will be a corresponding drop in fires caused by MOV failures. But it would be folly to state that MOV fires will be eliminated due to 1449 mandated improvements and compliance. There appears to be a ‘gap’ in the way that 1449 is applied. The writers have seen a number of fires caused by MOV failures within UL listed GFIs. UL 943 requires that GFIs perform after being exposed to surge type waveforms. This requirement is met by the manufacturers when they install an appropriately rated (voltage, energy) MOV in an across the line (line to neutral) configuration. One would reasonably assume that UL would want the MOVs to conform to UL 1449 requirements; such an assumption, however, is wrong. MOVs inside of GFIs are not fused and are not thermally protected. The voltage rating on them has increased such that TOVs (floating neutrals) will not cause the MOVs to erupt in flame.

FIRE INVESTIGATION

The investigation of a fire brought on by a failed MOV can be a straight forward task, or one filled with perils. The ZnO has a high Melting Point (MP) of 1975 deg C. As such, MOVs survive almost every fire. The leads will be detached, and the epoxy will be consumed, but the MOV body will be intact. Testing of several thousand MOVs in TOV situations has shown that the predominant failure of MOVs manifests itself by a ‘hole’ being found in the MOV. Picture 1 shows such the SEM image of such a hole.



Picture 1 – hole through MOV



Picture 2 – Arced Lead of MOV attached to PCB

There is a second mode of failure that can occur, and that is when the lead arcs off the MOV body. Our testing showed about 7 % of MOVs that catastrophically failed after a TOV condition had no visible damage to the MOV, but instead had arced leads. A fire can still occur, but investigation of the fire becomes very difficult. The leads may or may not be found; if the MOV is found, it will be intact in appearance. But without the leads, one cannot state that an MOV failed and caused an overcurrent situation with a resultant fire. Picture 2 shows a lead that failed on an MOV that was soldered to a PCB. The right side of the photo depicts the circuit board pad, while the left side of the lead depicts 'clubbing' associated with arcing.

Our research is associated with the second mode of failure and how fires are investigated; in this scenario, can the recovery of an intact MOV provide data as to whether or not the MOV was experiencing going into a runaway mode, and causing a fire by overcurrent on the lead to the MOV? IE, when an MOV is recovered from a fire, and it does not have a hole present, is there sufficient data available to conclude that the MOV was in a thermal runaway mode, bringing on the fire?

Picture 3 is typical of an MOV that started a fire, but which has no holes in its body. Without the leads being available for examination, is there sufficient data to state that the MOV was or was not in runaway mode? In fact, the only data available is that of breakdown / knee voltage at the usual 1 mA AC level, 60 hertz. To get right to the point, the real issue is the fire – given the high MP of the ZnO, will the fire change the MOV in such fashion that its condition *a priori* can be determined?

Picture 3 – MOV from GFI

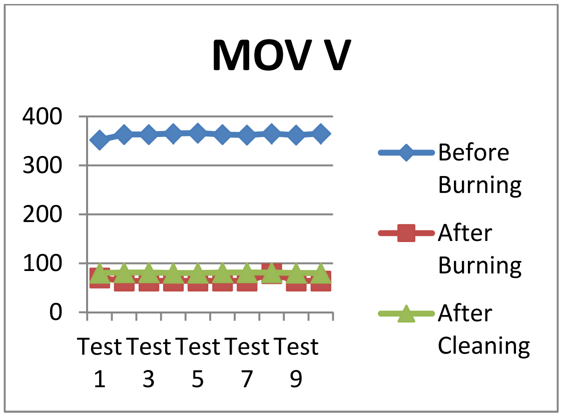
For our experiments, we first measured the breakdown level of a number of MOVs taken from the same lot, all with a nominal 300 volt AC rating. Each of the MOVs was placed in a fire environment and burned for 10 minutes. The nature of the fires varied, with half being made from class A combustibles, and others involving the use of class A combustibles that were accelerated with gasoline. For half of the fires, we removed the MOV at the 10 minute mark by use of pliers. For the remainder of the fires, the fire was extinguished by the application of continuous water, which represents more of a thermal shock to the MOV. Breakdown voltage readings were taken for each MOV, and then each MOV was cleaned ultrasonically, in a solution of MEK for 30 minutes each. A total of 48 MOVs went through the testing.

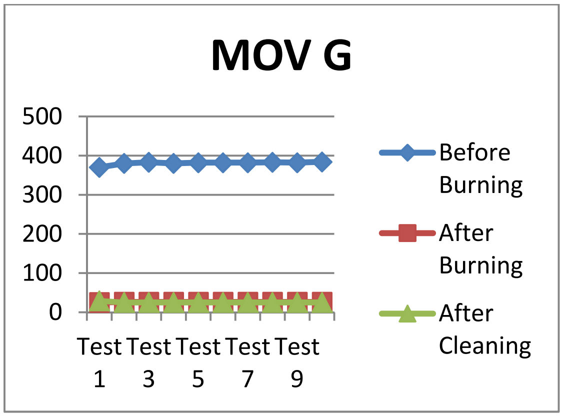
In regards to the breakdown voltages, a total of 10 measurements were made on each MOV for a given condition (Pre fire, post fire, post clean). As in earlier testing, we used a Vitrek 944i set at 1 mA AC, 60 hertz.

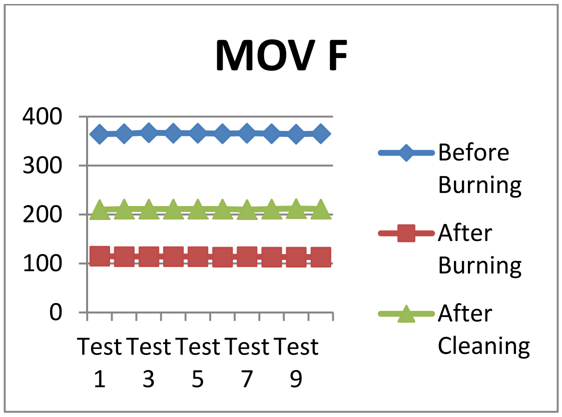
ACTUAL RESULTS

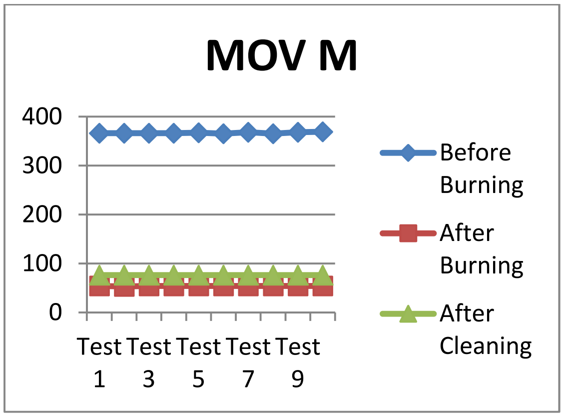
The actual results were in some ways what was predicted and in some ways unexpected. Our predictions were that there would be a shift (downward) in the breakdown voltage, and that cleaning the MOV after the fire would allow for an accurate voltage measurement, somewhat predictable based on the fire. We were right on the first belief, but incorrect on the second prediction.

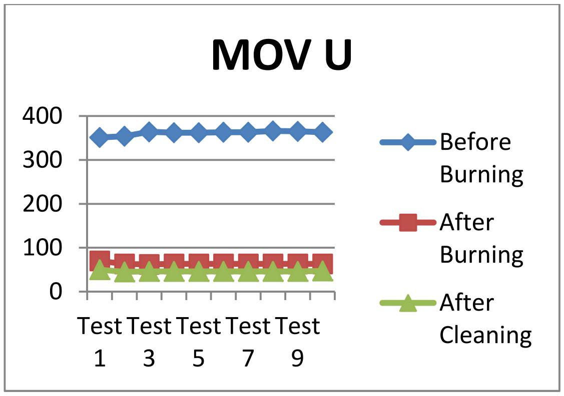
The value of our work (we hoped) was that for a fire investigation, recovery of an MOV without a hole would allow for some assessment of its a *priori* condition. As an example, an MOV that was rated at 275 volts nominal breakdown, and which exhibited a 260 volt breakdown after a fire, was probably not in a runaway condition. An MOV rated at 275 volts before a fire, and which measured 90 volts after a fire, would be considered a candidate for having caused a fire.

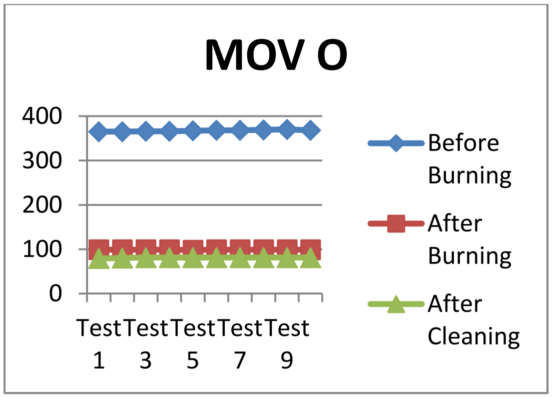


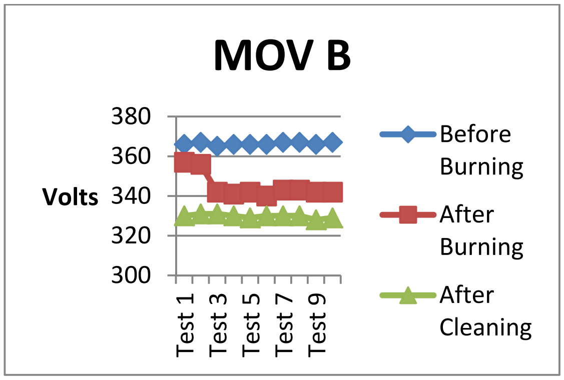


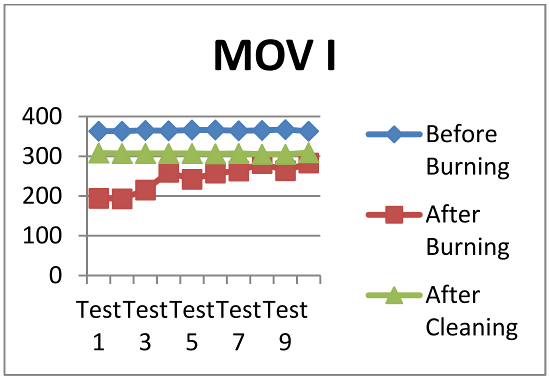












What can be stated is that for all 48 MOVs, there was a downward shift in the breakdown voltage. In no case did the voltage rise. This data alone is helpful, in that a post fire breakdown voltage on an MOV that is above the line voltage can immediately be dismissed in terms of having the MOV causing the fire.

The finding that was the most puzzling was the change in breakdown voltage between *pre* and *post* clean states. There was not a monotonic change. For some MOVs, cleaning caused the breakdown voltage to increase (as would be expected), and at times the breakdown voltage dropped after cleaning. The enclosed graphs show that MOVs V, F and M all had rises in breakdown voltages after cleaning, while MOVs U and O saw voltages drop after cleaning. The MOV G functioned almost the same before and after cleaning.

Statistical analysis did not show any trends or associations, much less correlations, between MOVs that were cooled quickly (water quenching) and from removal from the fire environment.

Discussion

The first point of discussion would be the seemingly 'lack of rigor' to our test methodology. Historically, a scientific test has been one that is repeatable, and which allows for a different investigator to perform the same tests and obtain similar data. We don't disagree with a philosophy that has been used for hundreds of years.

The comment that we make is that in a given fire, we will know little to nothing about the thermal perturbations that an MOV may see during the fire. We also know little about the starting breakdown voltage. As a way of an example, an MOV may have shifted downward in its breakdown rating. We also know little about the cooling effects and thermal transients during extinguishment. All in all, we know very little about a given device except for a nominal rating when it left the factory. *Post priori*, we know only two data points on an MOV that does not have a hole present – breakdown voltages before and after cleaning, and these were not seen to change in a monotonic fashion.

We did note that several of the MOVs varied in their breakdown voltage post fire, but before cleaning. The MOVs I and B demonstrate the value in the taking of multiple readings. Both MOVs demonstrate that cleaning is effective in at least taking the MOV to a point where it can be tested in a repeatable fashion. The MOVs also demonstrate that contamination post fire will prevent obtaining reliable readings.

SUMMATION

It is our opinion that post fire MOV evaluation has some use utility in a fire investigation, but that the utility is limited. If the MOV has a hole present, one needs to look for the cause (floating neutral, energized ground), as well as determine what types of fusing or other protection were present. If an arced lead for an MOV is found, this is an indicator of an MOV that is in runaway.

When the MOV body is intact, and the leads are not recovered, breakdown voltages both pre and post clean should be obtained. Thereafter, one can conclude that the MOV was not causative (the breakdown voltage exceeds available line voltage) or the role is indeterminate – the MOV may or may not have gone into runaway and caused overcurrent on the leads.