# USING THERMALLY PROTECTED MOVS IN TVSS OR POWER SUPPLY APPLICATIONS

By

Paul W. Traynham, Field Application Engineer,
Littelfuse®, Inc.
1335Gateway Drive, Suite 2003
Melbourne, FL 32904
Phone: (321)733-2050
Fax: (321)733-2022

Pat Bellew, Product Test Engineer,
Littlefuse® Ireland Ltd.
Ecco Road
Dundalk, Ireland
Phone: 353-42-937-0055
Fax: 353-42-933-2336

# USING THERMALLY PROTECTED MOVS IN TVSS OR POWER SUPPLY APPLICATIONS

By

Paul Traynham, Field Application Engineer, Littelfuse®, Inc.
Pat Bellew, Product Test Engineer, Littelfuse®, Inc.

## ABSTRACT

Metal Oxide Varistors (MOVs) are commonly used for transient over-voltage suppression in many applications such as: Transient Voltage Surge Suppressors (TVSS), Uninterruptable Power Supplies (UPS), AC Power Taps, AC Power Meters or other products. Events such as lightning, inductive load switching, or capacitor bank switching, are often the sources of these transients. Additionally, in these applications, the possibility for a sustained abnormal over-voltage, with a limited current condition may exist which necessitates the need to protect the MOVs from an over-dissipation thermal condition.

The UL1449 standard clearly defines abnormal over-voltage, limited current test conditions. The intent of this paper is to outline these conditions, explore the use of MOVs in combination with a TCO (Thermal Cut-Off or Thermal Cut-Out) device, and compare performance with a thermally self-protected MOV technology. Graphs depicting the Epoxy temperature of MOVs without thermal protection will be shown along with a MOV/TCO combination and the internally protected MOV.

## 1. Introduction

Under normal operating conditions, the AC line voltage applied to an MOV is not expected to exceed the MOV's Maximum $AC_{RMS}$ Voltage Rating. Occasionally, over-voltage transients may occur that exceed these limits. These transients are clamped to a suitable voltage level by the MOV provided the transient energy does not exceed the MOV's maximum rating. If, unlike a short duration transient, an MOV is subjected to a sustained abnormal over-voltage, limited current condition (as is required in UL1449), the MOV may go into thermal runaway resulting in overheating, smoke, and potentially fire. For end products to comply with UL1449, some level of protection must be afforded to the MOV to prevent this failure mode. That protection has traditionally been a thermal fuse or Thermal Cut-Off (TCO) device.

## 2. The UL1449 Abnormal Over-voltage Standard

In AC line applications, Neutral and Ground are typically near or at the same potential. In the event of a loss of a Neutral-Ground connection, there exists a risk that a sustained over-voltage may be applied to an MOV that is rated for a much lower continuous voltage. In an unlimited current condition, the MOV will first fail short, but due to the high amount of energy available, it most often ruptures instantaneously. If, however, there are loads tied to the AC line that limit current flow, the MOV can overheat and potentially cause the TVSS device to overheat resulting in smoke, out-gassing and eventually fire. This potential condition is specifically identified and addressed in the UL1449 TVSS Standard. See Table 1. In many cases, it requires that end-product manufacturers include a thermal protection element for an MOV.

| Device Rating | Phase | Test Voltage [a] | Voltage Rating of Conductor Pair that the test voltage is to be applied to |
|---|---|---|---|
| 110-120V | Single | 240 | All |
| 110-120V/220-240V | Split | 240 | 110-120V |
| 120/208V | 3-Wye | 208 | 120V |
| 220-240 | Single | 415 | All |
| 220-240V/380-415V | 3-Wye | 415 | 220-240V |
| 240V | High Leg Delta | 240 | 120V |
| 254-277V | Single | 480 | All |
| 254-277V/440-480V | 3-Wye | 480 | 254-277V |
| 480V | High Leg Delta | 480 | 254-277V |
| 347V | Single | 600 | All |
| 347/600V | 3-wye | 600 | 347V |
| [a] For device ratings not specified in this table, the test voltage shall be the maximum phase voltage (if available) or twice the conductor pair voltage ratings up to 600V max. | | | |

**Table 1: Test Voltage Selection Table**

Table 1. defines the test voltage that should be applied to various TVSS devices depending on the designer's desired device[1] rating. Each test voltage is applied across each conductor pair with a short circuit current of 5A, 2.5A, 0.5A and 0.125A respectively across each of four TVSS devices. Since this test is destructive, four devices are needed to test for each of the four short circuit currents. The four devices must be energized for 7 hours, or until current or temperatures within the TVSS device attain equilibrium, or until the TVSS becomes disconnected from the AC Line.

For example, in a standard 120V AC Line application, the requirement is for a $240V_{ACRMS}$ test voltage to be applied across all conductor pairs. There are three pairs; Line-Neutral (L-N), Line-Ground (L-G), and Neutral-Ground (N-G). This test voltage is chosen because very commonly in the U.S., 120V AC power is commonly fed from a center-tapped 240V transformer. If a break occurs at X—X (see Figure 1.), then the load in the bottom phase acts as a current limiter and the line fuse may not clear. Thermally unprotected MOVs are typically rated from 130Vacrms to 150Vacrms and will heat up, out-gas and may catch fire in such circumstances.

[1] In Table 1., "device" is defined as the end TVSS product - example: UPS, TVSS Strip etc.

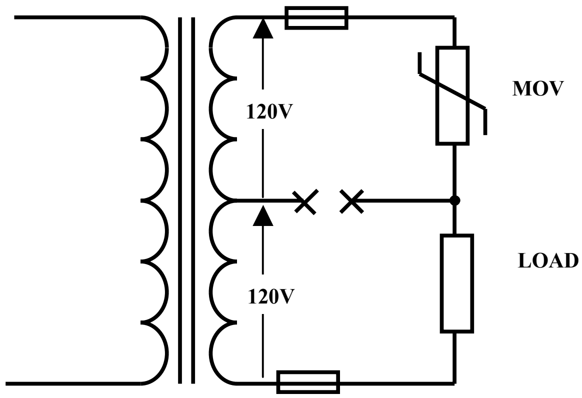


**Figure 1: Possible Fault Condition for a Limited Current Abnormal Overvoltage Event**

## 3. Thermally Protecting MOVs

A simple block diagram of a typical line voltage transient protection scheme used to meet the sustained abnormal over-voltage, limited current test requirements of UL1449 is shown in Figure 2. An MOV or several MOVs in parallel are each placed across each of the three conductive pairs; L-N, L-G, and N-G. This offers the utmost protection for any possible line transient. A standard fuse is placed in series with the line to protect the system from an over-current condition that exceeds a predetermined level. Typically, the current rating of this fuse is higher than the limited current flowing through the circuit during UL1449 testing. This requires the addition of a TCO that is placed in series with each MOV or Parallel combination of MOVs to protect it from a thermal event. Often, the MOVs used are of the radial leaded 14mm or 20mm disk diameter variety.

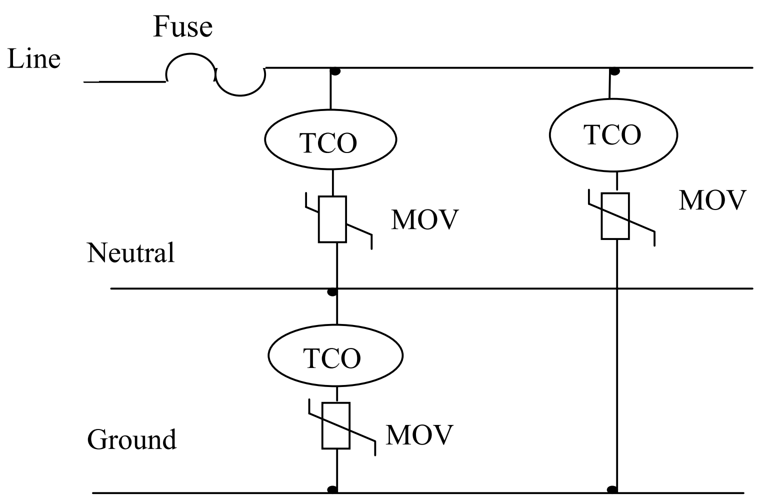


**Figure 2. Typical Off-Line Protection Scheme**

TCOs are available in a variety of different opening temperatures. The position and orientation of the TCO is important if it is to be effective in thermally protecting an MOV. When subjected to a sustained over-voltage, MOVs will short at a random point on the disk and will rapidly begin to self-heat if a limited current is maintained. TCOs are activated by a combination of conducted, convected and radiated heat from the MOV, although the majority of the heat is transferred via conduction. The position of the TCO in relation to the heat source at this shorting point has a considerable effect on the speed of operation of the TCO. The most effective heat coupling has been observed to be via conduction through the varistor terminal lead to the insulated terminal of a metal jacket TCO. Thermal convection and radiation processes are effective when the heat source is immediately beside or below the TCO. Although conduction is the most effective means of heat transfer, the MOV and TCO are not in full contact in most cases. The position of the terminal leads of the TCO makes it difficult for the TCO to be located closely enough to the MOV for effective heat transfer. The result is less than efficient conduction from case to case. An example of a typical arrangement of MOVs and TCOs is shown in Figure 3. Note the TCO does not touch the case of the MOV.

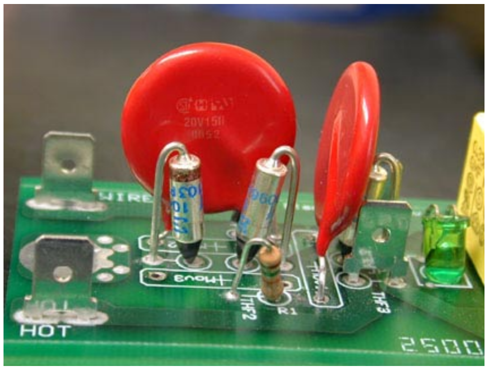


**Figure 3: Typical Arrangement of TCOs with MOVs.**
(One of the MOVs has been removed for clarity.)

The response time of this arrangement can be disproportionately increased if the TCO is not placed in close enough proximity to the MOV and/or the punch-through point on the MOV occurs remotely from the TCO's insulated terminal. In such cases, considerable charring of the MOV can occur and fire is a real possibility. Shrink-wrap or other bonding materials can aid coupling, but in adverse circumstances they are a source of combustible material and may actually make things worse.

While this scheme is generally effective in removing the MOV from the circuit during abnormal over-voltage testing such that the MOV does not reach critical temperatures, the downside to this method is that TCOs can be difficult to handle during the assembly process. Because of the low opening temperatures, TCOs must be soldered carefully. When hand soldering, the iron cannot remain in contact with the lead of the TCO for prolonged periods. Another option is to use clips or pliers as a heat-sink.. TCOs with useful opening temperatures for the MOVs typically cannot be wave soldered, as the device will clear in the solder bath. In general, the use of TCOs in these types of applications becomes largely a hand assembly process.

A new technology has been developed that will aid the designer in meeting UL1449 requirements including the sustained abnormal over-voltage limited current testing, while eliminating most of the problems associated with other methods. This technology is a fully integrated, thermally self-protected MOV - TMOV$^{TM}$ Varistor Series. This new device uses a patent pending thermal element internal to the MOV so that it is in direct contact with the metal oxide disk, allowing for optimum heat transfer. Because of the proximity of the thermal element to the MOV body, a higher opening temperature element can be used. This allows the thermally self-protected MOV to be wave soldered simplifying the assembly process.

Figure 4 illustrates the basic construction of the new device. It is a leaded component with one of its two leads thermally fused. The fusing is achieved by having a break in the copper lead and replacing it with a solder link. Under over-voltage limited current conditions the solder reflows and opens the circuit thus preventing the risk of fire. As can be seen in the drawing, one end of the solder link has a circular insulator under it. This is to insure a good insulation gap after the fusing action. The other end of the link is attached to the silver electrode.

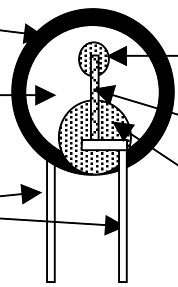


**Figure 4: Basic Construction of TMOV*TM* Varistor**

This method of construction allows the new device to perform to standard MOV ratings with regards to peak current, peak energy, voltage clamp levels, etc. while providing the safety of thermally protected device.

### 5. Comparing Methods of Thermally Protecting MOVs

The internally, thermally protected MOV overcomes most the disadvantages of the MOV/TCO combination method. Because the thermal fuse element is inside the epoxy coating, it is in intimate contact with the ceramic disk. And, because the thermal element is at the center of the disk, it is close to the heat source.

In order to compare the clearing times of both methods, several standard MOVs (Littelfuse 20mm, 130Vacrms, UltraMOV™ Varistors) in combination with TCOs of various opening temperatures, Tf, were tested and compared with several thermally self protected MOVs (Littelfuse 20mm, 130Vacrms, TMOV*TM* Varistor). Both methods were subjected to a sustained abnormal over-voltage of 240V at 5A. As can be seen in Table 2a and as expected, the TCOs with higher Tf's take longer to clear. The 73ºC TCO proved difficult to hand solder without clearing the device despite the use of an appropriate heat-sink. Table 2b shows the clearing times for the internally protected MOV. Clearly, the times are shorter than for any of the MOV/TCO combinations tested.

**Table 2a: MOV/TCO**

| TCO Tf (ºC) | Clearing time (Seconds) | |
|---|---|---|
| | Mean | Range |
| 73 | 30 | 11 - 52 |
| 94 | 34 | 20 - 46 |
| 121 | 36 | 16 - 56 |

**Table 2b: Thermally Self-Protected MOV**

| | Clearing time (Seconds) | |
|---|---|---|
| | Mean | Range |
| TMOV | 13 | 2 - 25 |

**Table 2: Observed Clearing Times for 5A Limited Current Test**

Figure 5 shows the effects of applying a UL1449 abnormal over-voltage test ($240V_{RMS}$, 5A) on three devices or combination of devices - 1) MOV alone (20mm, 130Vacrms) 2) MOV/TCO combination (20mm, 130Vacrms MOV and TCO with Tf = 94°C), and 3) thermally self-protected MOV (20mm, 130Vacrms).

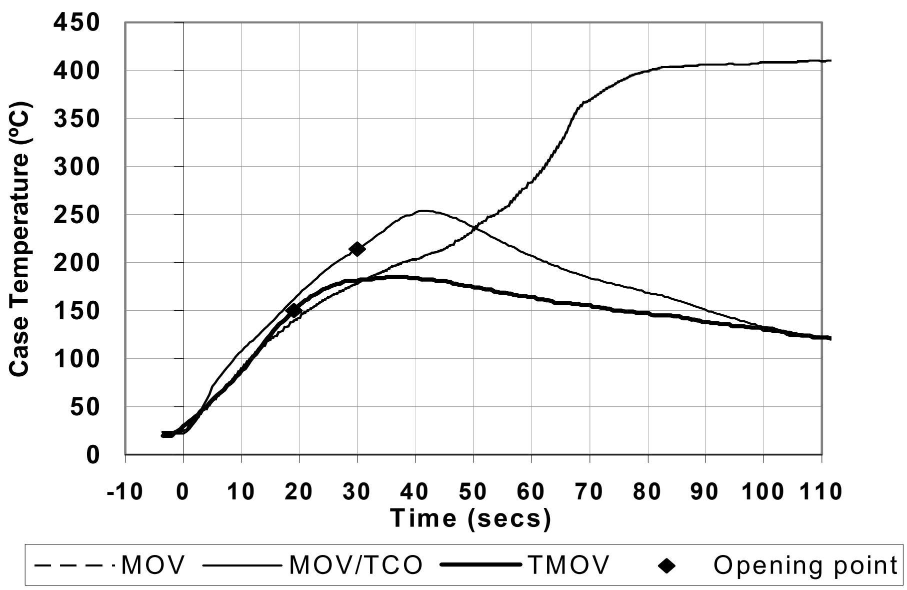


**Figure 5. Surface Temperature vs. Time for Several Protection Schemes**

Epoxy surface temperature vs. time was captured for each method. As can be seen, the case temperature of a standard MOV rated for $130V_{RMS}$ will continue to rise (to the point of combustion) if no thermal protection is used. The MOV/TCO combo performs better reaching temperatures of 220°C before the TCO clears. The internally protected MOV has a faster response time, clearing at temperatures of around 150°C in less than 20 seconds. Note that the temperature continues to rise once the thermal fuses have cleared. Heat generated within the zinc oxide disk is at a higher temperature than the outer epoxy coating. Heat continues to flow outward to the epoxy for some time before finally cooling down.

Figures 6a – 6c illustrate the effects of the temperature rise on each MOV. As can be seen, the new technology eliminates much of the charring when compared with a standard MOV or MOV/TCO combination.

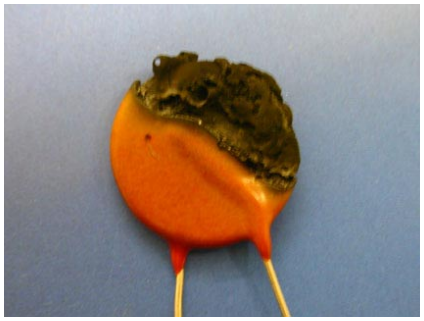

**Figure 6a: Standard MOV**

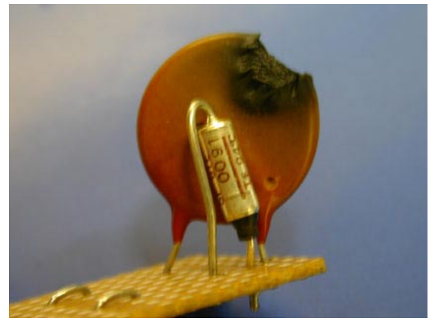

**Figure 6b: MOV/TCO Combo**

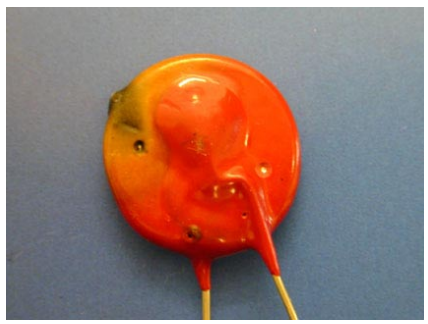

**Figure 6c: Thermally Self-Protected MOV**

## 6. Conclusion

The UL1449 standard includes a requirement that was created to protect the end product and users from a loss of neutral situation where an abnormal over-voltage/limited current condition could be applied to Metal Oxide Varistors. This event would cause an MOV to have a sustained voltage applied in excess of its maximum working voltage, which in turn would cause the MOV to enter a thermal runaway condition.

Several methods exist to prevent the MOV from reaching combustible temperatures - the most common of which is to use TCOs. While TCOs perform adequately in limiting MOVs from reaching very high temperatures, there are limitations. Out-gassing and some charring are evident when the test is applied. Additionally, the assembly process is difficult to automate, as wave soldering is typically not an option.

Overall, the new integrated MOV-thermal fuse technology reduces part count, saves space and is UL1449 recognized not only to the normal UL1449 MOV requirements, but also to the abnormal over-voltage testing discussed in Table 1. It performs better than other methods when subjected to a limited current over-voltage condition, by clearing more quickly, at a lower temperature and with minimal to no out-gassing or charring. It has all the performance capability of a standard MOV, including peak pulse current capability, energy rating and clamping voltage. The new device can also be wave soldered which saves on assembly costs and simplifies the assembly process by eliminating most of the hand assembly required with other methods.

**Bibliography:**

1. Transient Voltage Surge Suppressors - UL1449, June 25, 1998.
2. Littelfuse Datasheet, *Thermally Protected Metal Oxide Varistor (TMOV$^{TM}$ Varistor),* March 2001.
3. Littelfuse Datasheet, *High Surge Current Radial Lead Metal Oxide Varistor (UltraMOV$^{TM}$ Varistor Series),* March 2001.