

ADDRESSING PROTECTION ISSUES FOR SURGE PROTECTIVE DEVICES

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Overview

- SPDs and MOV Failure Modes
- Abnormal Voltages
- Repetitive Pulses
- Transient Energies Above the Maximum Rating
- North American Standards and NEC Requirements
- Protection Options

Introduction

Concerns about Surge Protective Device (SPD) failures in the field and device performance have led to some major changes in the industry in recent years. Most of the safety issues have centered on the various failure modes of the MOV inside the SPDs. Safety standards and products have undergone some very radical changes in the past 3 years. Review of these changes is important to ensure that you are taking advantage of these significant safety improvements.

As of September 29, 2009, suppliers of UL Listed SPD (formerly transient voltage surge suppressors (TVSSs) must comply with the latest revisions of UL 1449 - Standard for Surge Protective Device, 3rd Edition to maintain their UL Listing. Failure of a SPD to comply with the new revisions of UL 1449 will void its UL listing and possibly that of the systems where it is used. Since Article 285 of NEC® 2011 requires that SPD devices be listed and labeled with a short circuit current rating (SCCR), loss of their UL listing will preclude their use. Likewise, UL508A uses the SCCR of the TVSS to develop a SCCR for industrial control panels. The loss of the TVSS's UL listing could preclude its use in industrial control panels. See [1] for more information on the changes in UL 1449.

This note will provide:

- An overview of MOV-based SPD failure modes.
- A review of key tests required by the UL 1449 standard.
- An overview of protection options.

Failure Mode Concerns

Under normal voltage conditions, the MOV shown in Figure 1 is in a very high resistance (non-conductive) state. When a high voltage transient is imposed on the power line, the MOV changes to a low resistance, highly conductive state when the transient voltage exceeds the MCOV of the MOV. The

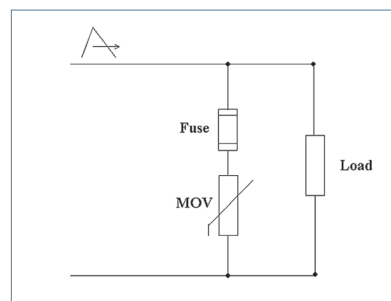


Figure 1: Typical Connection of TVSS

majority of the energy of the transient is then shunted through the MOV and the voltage imposed on the protected equipment is limited to a safe level. After the transient voltage decreases below the MCOV, the MOV returns to its high resistance state. The duration of this conduction can be less than 100 μ S.

The MOV must then dissipate the heat generated during the conductive state. If subsequent conduction states occur too soon after the first transient, the heat energy cannot be dissipated adequately and the MOV temperature can rise to damaging levels.

There are three causes of MOV failures:

- Continuous overvoltage above the MCOV.
- Repetitive pulses
- Transient energies above the maximum rating of the device

Abnormal Overvoltages

Overvoltage operation of an MOV is the fastest way to MOV failure. Under sustained overvoltages an MOV can fail due to a phenomena referred to as thermal runaway. Thermal runaway can occur when the normal 60 Hz power system voltage becomes higher than the MCOV rating of the MOV and initiates flow of continuous 60 Hz current through the MOV. Figure 3 shows the current that results when a 320V-rated MOV was connected to 480V. When the voltage is above the MCOV, the MOV enters its conductive state and current flows through the device until the voltage GOES BELOW THIS VALUE. The magnitude of this current flow depends on the dynamic resistance of the MOV in its conductive state and the impedance of the power system.

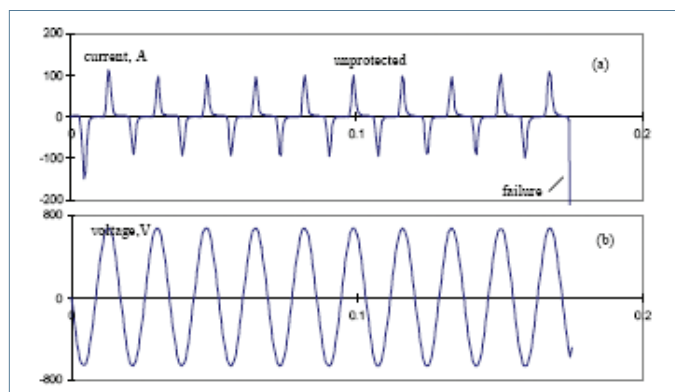


Figure 2: Currents resulting from abnormal overvoltage test. Notice that current flow begins when the voltage goes above the MCOV in each half cycle.

The continuous heating generated by this current will exceed the energy capacity of the MOV and eventually cause the device to

rupture (see Figure 3 & 4 for an example). When the MOV is connected across the line terminals of electrical equipment and not adequately protected, its failure can lead to serious arcing faults in the equipment. Consequently, protection against a broad range of currents is necessary to safeguard against this mode of failure.



Figure 3: TVSS damage due to abnormal overvoltage test.



Figure 4: Case rupture of MOV during abnormal overvoltage test.

Abnormal overvoltages can be caused by loss of neutral or misapplication of the device (e.g. a SPD rated 120V installed on 480V application).

Repetitive Pulses

MOVs also have multiple pulse ratings. Every time an MOV conducts transient energy, its life is slightly reduced. For a given surge length, the expected number of pulses the MOV can safely absorb during its lifetime is displayed. One surge near its capacity of 10kA may degrade the MOV's life just as much as 20 surges at .2kA. The pulse lifetime ratings are based on the definition of rated life, which is the point at which the nominal voltage of the MOV has decreased by 10%.

Surges can breakdown some of the junctions between the zinc oxide grains in the MOV. The greater the energy absorbed during a transient, the greater the number of junctions damaged. The result is a reduction of the MCOV and capability of the MOV energy absorbing capability. This change in structure does not affect the ability of the MOV to clamp surges. Conversely, the voltage required for MOV conduction is reduced.

If the MCOV is reduced to the point that the MOV conducts during part of the normal 60 Hz voltage wave, the MOV will go into thermal runaway as described previously. Failure (case rupture) will occur when the heat generated by the 60 Hz current through the MOV exceeds the MOV's energy capacity.

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Transient Energies Above the Maximum Rating

MOV's have a maximum single pulse peak current rating. Typically, this rating is determined with the 8/20 μ S waveshape defined in IEEE C62.45-2002. (See page 4 for a discussion of the standard test waveform defined in IEEE C62.45-2002). This rating identifies the maximum transient energy that can be absorbed by the MOV without damage to the device. This type of failure is not likely but can occur when a SPD with a single pulse peak current rating is improperly selected for an application. Exposed to pulse energy beyond its rating, the MOV can fail catastrophically on a subsequent pulse. When connected across the terminals of equipment connected to the power system, a resultant 60 Hz arc fault current can cause catastrophic damage without adequate protection.

North American Standards and NEC Requirements

Several changes have been made to North American codes and standards in recent years to address safety concerns about surge suppression products.

National Electric Code

Article 285, Surge Protective Devices (SPD), was added to the 2002 edition of the National Electric Code to cover the safe application of surge suppression products permanently installed on premise wiring systems.

Section 285.5 requires that such products be listed devices. Section 285.6 requires that the SPD be marked with short circuit current ratings (SCCR) to ensure that the SPD is not installed in a location where the available fault current is greater than the capability of the surge suppressor's protection system. SCCR's are necessary to ensure compliance with NEC 110.10.

UL 1449 Standard for Transient Voltage Surge Suppressors

SPD devices listed to the UL 1449 standard are acceptable for application on wiring systems per NEC 285.5. They must successfully pass the tests detailed on page 4 without creating conditions that would increase the risk of fire or shock. Changes to this standard in recent years have had major implications in the selection of protection schemes.

The second edition of UL 1449, initially issued in 1996, added the Abnormal Overvoltage Tests to address field failures caused by temporary overvoltage (TOV) conditions with low follow currents. To pass the Limited Current Abnormal Overvoltage Test, a TVSS needed to meet the standard's requirements for test currents of 5A, 2.5A, 0.5A and 0.125A. Overcurrent protective devices (OCPD) typically selected to protect MOV's from case rupture and sized to pass larger surge currents without opening, were not able to open for small follow currents caused by thermal runaway.

After further investigations, UL issued a revision to UL 1449 in February of 2005, adding new test current levels. To address concerns of intermediate short circuit current levels, the Full Phase Voltage—Short Circuit Current Abnormal Overvoltage Test of Section 37.3 was changed to require tests to be performed with fault currents of 100A, 500A, 1000A and the selected SCCR of the device. In addition, the Limited Current Abnormal Overvoltage test of Section 37.4 changed test currents to 10A, 5A, 2.5A and 0.5A. Compliance to the standard's requirements at all test current levels is required to maintain the UL Listing of existing TVSS designs. Manufacturers of TVSS's were given until February 9, 2007 to comply with these requirements since it was anticipated that products and/or protection schemes needed to be re-designed.

The third edition of UL 1449 went into effect on September 9th, 2009. This edition replaced the term TVSS with SPD, combined secondary surge arrestors with SPD's and created type designations based on point of use. The Voltage Protection Rating replaced the suppressed voltage rating (SVR) using a higher surge test current and a different methodology. A Nominal Discharge Current (I_n) was also added. See [1] for more details on these changes.

Overview of UL 1449 Test Requirements

Current Testing. These tests verify that the SPDs can withstand continuous overvoltages with a wide range of potential fault currents without creating conditions that would increase the risk of fire or electric shock. Creation of holes in the enclosure or emission of flame, molten metal, glowing or flaming particles is not allowed. Test voltages are based on the SPD's voltage rating.

Short circuit current rating test- For Type 1 and Type 2 SPDs. Test voltages are identified for each allowable device rating. This test applies full-phase voltage across the device for up to seven hours or until the SPD is safely disconnected from the AC supply. For example, 480V is applied across devices rated 277V. This test is performed with an available fault current value chosen from Table 39.2 by the manufacturer (see Table 1). In this test, the device will likely go into thermal runaway as described earlier and will need to be safely disconnected from the circuit to pass this test.

Available Fault Current Ratings from Table 61.2 of UL 1449

5kA	25kA	85kA
10kA	30kA	100kA
14kA	42kA	125kA
18kA	50kA	150kA
22kA	65kA	200kA

Table 1: Test Currents.

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Intermediate current test. Test voltages are the same as the Short Circuit Current Rating tests. For example, 480V is applied across devices rated 277V. This test is performed with available fault currents of 100A, 500A, 1000A. In this test, the device will also likely go into thermal runaway and will need to be safely disconnected from the circuit to pass this test.

Limited current abnormal overvoltage test. This test is similar to the full phase voltage test above, except that a variable resistor in the test set-up is adjusted to limit the short circuit test current. For permanently connected devices, four SPDs are tested with short circuit currents of 10A, 5A, 2.5A and 0.5A respectively. The devices are energized for up to seven hours, until the temperature of the TVSS attains equilibrium or until the TVSS is safely disconnected from the AC supply.

Surge Testing. These tests verify that the TVSS will properly operate in the presence of impulse surges of 6kV without any evidence of fire, operation of protective devices or creation of openings that expose energized parts.

VPR - Voltage Protection Rating. Unidirectional test waveforms (see next section) are used to determine this rating. Devices are subjected to three 6 kV/ 3 kA impulse surges. The Voltage Protection Rating is a value chosen from Table 63.1 in UL 1449 and must be higher than any of the three measured limiting voltages.

I_n - Nominal Discharge Current Protection Rating - For Type 1 and Type 2 SPDs. After the VPR is determined, 15 surge tests are performed at 6kV and the I_n current selected by the manufacturer. Type 1 SPDs must be either 10kA or 20kA. Type 2 SPDs can be 3kA, 5 kA, 10 kA or 20 kA. Test surges are applied in 3 groups of 5 surges. There is 30 minutes rest between each group. Following these tests, the SPDs are subjected to the VPR tests. Results must be within 10% of the original tests.

Operational Voltage Test. This test verifies that the SPD will withstand an overvoltage of 115% of rated supply voltage for 30 minutes. The SPD must pass this test without creating conditions that would increase the risk of fire or electric shock. Creation of holes in the enclosure or emission of flame, molten metal, glowing or flaming particles is not allowed.

Dielectric Voltage-Withstand Test. This test verifies that the SPD can withstand a 60 Hz voltage of 1000V plus two times rating for one minute for various application points.

Waveforms for Testing TVSS Devices

IEEE C62.45-2002, IEEE Recommended Practice of Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits identifies two waveforms that are commonly used for testing the performance of TVSS devices.

Oscillatory. The ringing 0.5 μ S —100k Hz waveform shown in Figure 6 is used to simulate the oscillations created when a surge, impinging on a low-voltage indoor conductor system, excites the natural resonant frequencies. Because of the expected impedance between the source and the indoor locations such as an outlet, source impedances of test generators are selected to limit current and energies to lower levels than the unidirectional waveforms.

Unidirectional. The 1.2/50 μ S voltage waveform shown in Figure 7 is used to simulate the voltage delivered by surges at outdoor and service entrance locations. A test voltage of 6kV is typically selected for indoor locations whereas 10kV and higher are used for outdoor locations. Source impedances are selected to deliver larger currents (and energy) - see the 8/20 μ S waveform also shown in Figure 7. These test circuits are also used for TVSS's intended for such indoor locations as feeders and short branch circuits.

In both these test configurations, the voltage waveform is the open-circuit voltage of the test generator and the current waveform is the current obtained by shorting the output of the test generator.

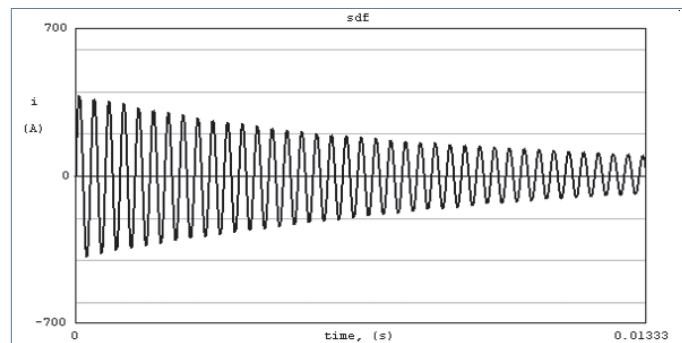


Figure 6: 0.5 μ S-100k Hz. Oscillatory Test Waveform. The voltage has a rise time for its first peak of 0.5 μ S (from .1 to 0.9 times the first peak value). It then decays while "ringing" at 100k Hz. Each Peak is approximately 60% of the previous peak.

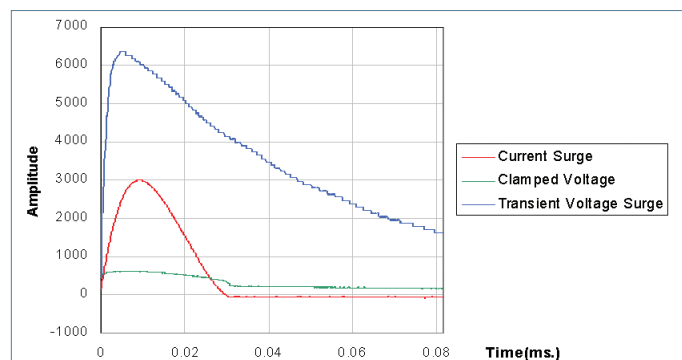


Figure 7: Unidirectional Test Waveforms. The rise time of 1.2 μ S for the voltage wave is defined as 1.67 times the time it takes for the voltage to rise from 0.3 to 0.9 of its peak. The rise time of 8 μ S for the current wave is defined as 1.25 times the time it takes for the current to rise from 0.1 to 0.9 of its peak. The decay time of 50 μ S and 20 μ S refer to the time it takes for the wave to decay to 50% of its peak.

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Protection Options

MOV Thermal Protection

Current flow through an MOV due to 60 Hz overvoltages, as discussed earlier, causes heating of the MOV. Thermal protectors are designed to sense the temperature rise of the MOV and disconnect it from the circuit before catastrophic failure occurs. Complete electrical protection for SPD's might include short circuit protection and thermal sensing. The thermal protector must have a thermal response that coordinates closely with the response of the MOV.

Figure 9 compares the performance of an unprotected MOV with Mersen's TPMOV™ (Thermally Protected MOV). The varistor rating (MCOV) of both MOVs was 320V. Both were tested at a 150% overvoltage of 480V (see middle trace). The supply circuit had an available short-circuit current of 41.2 kA and X/R = 6.6.

The top trace in Figure 9 shows the current wave for the unprotected MOV. The MOV starts conducting during the part of the AC cycle where the supply voltage exceeds the MCOV voltage of the MOV. The amplitude of the current pulses depends on the dynamic resistance of the MOV. The temperature of the MOV increases leading to failure of the MOV after 0.176 seconds.

The bottom trace shows the response of the Mersen TPMOV™. In this case, the TPMOV operates after 0.045 seconds and isolates the MOV without damage. Note that the current pulses are higher than those of the device at the top. This is due to slight differences in dynamic resistances between MOVs in the conductive state.

For lower available short circuit current (i.e., higher system impedances) the amplitude of the current pulses would be lower and take longer to damage the MOV. The opening time of the TPMOV™ would be greater, but would still disconnect from the power system prior to MOV failure.

Fuse Protection

Fuses used in series with MOVs, as shown in Figure 8, are not used to protect MOV's from damage due to excessive I^2t heating from surge currents. Instead they are used to clear high-level 60 Hz follow currents that could result from an MOV failure.

Fuses have been successfully used to protect equipment from the catastrophic failure of MOVs, when MOVs are connected across the line terminals of equipment with large available fault currents and fail in a short circuit mode. To achieve optimum transient protection, the fuse must be selected to allow the MOV's rated surge current to pass without opening. In the case of MOV failure, the fuse must safely interrupt the potentially large

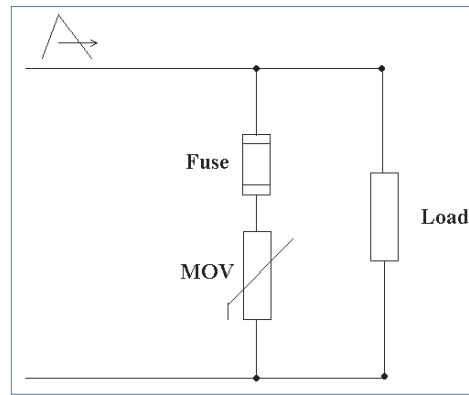


Figure 8: Fuse Protection of MOV.

Note: The requirements for the Measured Limited Voltage Test changed in the UL 1449 3rd Edition. These changes became effective on September 29, 2009. For more information on the specific changes contact our Technical Services Department.

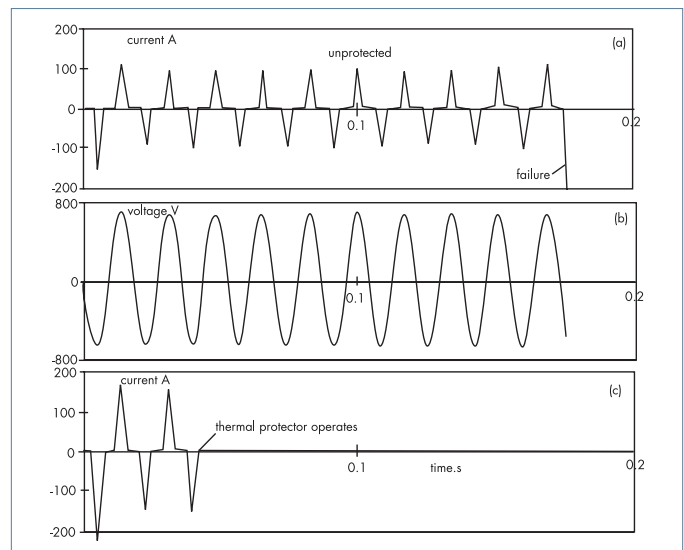


Figure 9: Self-protected TPMOV® technology.

follow current that will result from the low-resistance state of the MOV failure. To protect against case rupture from the heating of the follow current, the fuses used for these applications need to be very current limiting.

The VSP MOV fuse shown in Figure 8 has a surge current rating and not a 60 Hz ampere rating. For example, the VSP40 is rated to pass the energy of a 8/20 μ s wave with a peak current value of 40kA without opening, allowing the MOV to properly clamp the surge voltage as intended. If the MOV were to fail however, the VSP40 would offer excellent current-limiting performance against the 60 Hz follow current. Furthermore, the VSP's ampere interrupting rating (AIR) of 200,000A ensures that it could perform this function for all AC applications.

Fuses selected to pass large surge currents and yet prevent the catastrophic failures of MOV's from large fault currents are unlikely to clear the lower level currents specified in UL 1449's Limited Current Abnormal Overvoltage Tests and Intermediate Current Tests before damage occurs to the MOV.

Recommended Products

Mersen's complete family of surge protection devices includes the TPMOV® (Thermally Protected MOV) technology, Surge-Trap® surge protection devices, VSP surge-rated fuses and the Surge Switch.

TPMOV® Technology

Developed to address the failure characteristics of MOVs, Mersen's TPMOV® (Thermally Protected MOV) technology, meets the new requirements of UL 1449. It is a completely fail-safe device composed of a voltage clamping device and a disconnecting apparatus. It is UL 1449 Recognized, and features a 40kA 8/20µS max surge rating, a footprint consistent with 25mm – 40mm MOVs, visual and remote indication, and a small package.



Surge-Trap® SPDs

Mersen, an industry pioneer in surge protection technology, has developed a world-class suite of surge protection devices for your entire facility. Surge-Trap SPDs are designed to UL1449 3rd Edition standards and feature Mersen's industry leading patented TPMOV® technology inside. Providing advanced overvoltage protection to meet today's toughest requirements, you can rely on Mersen's Surge-Trap SPDs for proven and safe facility-wide protection.



Surge-Rated Fuses - VSP

Mersen surge suppression fuses are specially designed to address the protection of SPD systems. The VSP fuses are designed to withstand 8x20µS surge pulses without opening, allowing the SPD system to react to the surge. All surge suppression fuses have a 8x20 µS surge rating, not a continuous current rating. Under AC short circuit conditions these surge suppression fuses are very current limiting.



Surge Switch

Mersen's Surge Switch is an extremely compact, high-performance, manually operated, non-fused switch with a unique contact design that actually clamps contacts tighter during a surge. It is specifically designed to withstand the high surge current of 200kA with the 8x20µS waveform seen in transient-voltage surge protection device applications.



Additional Resources

- Component Protection Note 3: Addressing Overcurrent Issues for Transient Voltage Surge Suppressors
- Component Protection Note 4: Important Changes to UL 1449 Safety Standards for Surge Suppression

“Complete electrical protection for SPDs typically includes short circuit protection and thermal sensing.”

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