Introduction
As of February 9, 2007, suppliers of UL Listed transient voltage surge suppressors (TVSSs) must comply with the latest revisions of UL 1449 - Standard for Transient Voltage Surge Suppressors, 2nd Edition, to maintain their UL Listing. Changes to the abnormal overvoltage tests are intended to ensure that devices are adequately protected against thermal runaway caused by the overcurrents created by overvoltage conditions.

Failure of a TVSS 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® 2005 requires that TVSS 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. This note will provide:

■ An overview of MOV-based TVSS failure modes.
■ A review of the latest tests required by the UL 1449 standards.
■ An overview of protection options.

Terms
TVSS: Transient voltage surge suppressor
MOV: Metal oxide varistor
MCOV: Maximum continuous operating voltage
Clamp Voltage: The peak MOV terminal voltage measured with an applied 8/20μS pulse of rated impulse current
SCCR: Short circuit current rating
Follow Current: The current from the connected power source that flows through the TVSS after the passage of discharge current

Failure Modes of MOV’s and Short Circuit Hazards
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 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 100μS.

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:

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

Figure 1: Typical Connection of TVSS
Transient Energies Above the Maximum Rating
MOV’s have a maximum single pulse peak current rating. Typically, this rating is determined with the 8/20μS 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 common but can occur when a TVSS 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 60Hz arc fault current can cause catastrophic damage without adequate protection.

Abnormal Overvoltages
Under sustained overvoltages an MOV can fail due to a phenomena referred to as thermal runaway. Thermal runaway can occur when

the normal 60Hz power system voltage becomes higher than the MCOV rating of the MOV and initiates flow of continuous 60Hz 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 next zero crossing of the voltage. The magnitude of this current flow depends on the dynamic resistance of the MOV in its conductive state.

The continuous heating generated by this current will exceed the energy capacity of the MOV and eventually cause the device to rupture (see Figure 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.

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

Repetitive Pulses
MOV’s also have multiple pulse ratings. Every time an MOV conducts transient energy, its life is slightly reduced (see Figure 5 for a typical surge rating curve). For a given surge length, the expected number of pulses the MOV can safely absorb during its lifetime is displayed. 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%. One surge near it's capacity of 10kA may degrade the MOV’s life just as much as as 20 surges at .2kA.
To ensure protection against the widest range of fault currents, the Abnormal Overvoltage Tests of Section 37 now requires additional current levels.”

**Addressing Overcurrent Issues for Transient Voltage Surge Suppressors**

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 60Hz voltage wave, the MOV will go into thermal runaway as described previously. Failure (case rupture) will occur when the heat generated by the 60Hz current through the MOV exceeds the MOV's energy capacity.

**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, Transient Voltage Surge Suppressors: TVSS, 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 TVSS be marked with short circuit current ratings (SCCR) to ensure that the TVSS 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**

TVSS 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 5 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 overcurrent 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. 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. 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.

After further investigations, UL issued a revision to UL 1449 in February of 2005, adding new test current levels, again in response to field failures. To address concerns of intermediate short circuit current levels, the Full Phase Voltage—Short Circuit Current Abnormal Overvoltage Test of Section 37.3 now requires 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 now requires tests at 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 have been given until February 9, 2007 to comply with these new requirements since it is anticipated that products and/or protection schemes will need to be re-designed.
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 μS — 100kHz 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 μS 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 μS 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.

Overview of UL 1449 Test Requirements

UL 1449 identifies several test requirements for safety and performance. The tests for confirming safe operation of permanently connected TVSS products are discussed below.

Overvoltage Test. This test verifies that the TVSS will withstand an overvoltage of 110% of rated supply voltage for 7 hours. The TVSS 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.

Abnormal Overvoltage Tests. The latest revision to UL 1449 has added intermediate test currents to this test sequence to fill holes in the test protocol. This test verifies that the TVSS can withstand specified overvoltages 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 TVSS’s voltage rating.

Full phase voltage - short circuit current abnormal overvoltage test. 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

continued on page 5
the TVSS is safely disconnected from the AC supply. For example, 480V is applied across devices rated 277V. This test is performed with available fault currents of 100A, 500A, 1000A and a value chosen from Table 61.2 by the manufacturer (see table, right). In this test, the device will likely go into thermal run-away as described on page 2 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 TVSS’s are now 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 Current Test. This test verifies that the TVSS will withstand impulse surges of 6kV and 10kA without any evidence of fire, operation of protective devices or creation of openings that expose energized parts. Each TVSS is subjected to one positive impulse and one negative impulse for the connections identified for the Measured Limiting Voltage Test. After the impulse tests, the device must stay connected to a AC circuit at rated voltage.

Measured Limiting Voltage Test. This test verifies that the TVSS will perform according to its marked suppressed voltage rating without any evidence of fire, operation of protective devices or creation of openings that expose energize parts. Tests are run with L-G, L-N, L-L and N-G connections, and each TVSS is first tested with impulse surges of 6kV and 0.5kA, then subjected to 20 consecutive pulses of 6kV and 3.0kA for all connections. Ten of the pulses are positive and ten are negative and are less than 60 seconds apart. After the TVSS is allowed to cool to room temperature, the first test with impulse surges of 6kV and 0.5kA are re-run. The measured limited voltage cannot deviate by more than 10% of the initial test and cannot exceed the manufacturer’s marked suppressed voltage rating by 10 % (see figure 7 for a typical suppressed voltage trace).

Temperature Test. This test verifies that two-port connected TVSS’s can operate at maximum rated voltage, current and frequency without adversely affecting product materials or exceeding temperature limits set forth in the standard.

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

Withstand Test. TVSSs that are able to be connected to AC power circuits and having current supplied through them to loads must be subjected to this test. This test verifies that the specified branch circuit overcurrent protection device is capable of opening short circuits downstream of the TVSS without damage to the TVSS. The test circuit is calibrated to the short circuit current marked on the TVSS (see table, below).

| Available Fault Currents ratings from Table 61.2 of UL 1449 |
|----------------------|---|---|---|
| 5kA | 25kA | 85kA |
| 10kA | 30kA | 100kA |
| 14kA | 42kA | 125kA |
| 18kA | 50kA | 150kA |
| 22kA | 65kA | 200kA |

Overcurrent Protection Options

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 1’t heating from surge currents. Instead they are used to clear high-level 60Hz follow currents that could result from an MOV failure.

Note:
The requirements for the Measured Limited Voltage Test will have changes in the recently approved 3rd Edition. These changes will become effective on September 29, 2009. For more information on the upcoming changes contact Technical Services Department.
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 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 60Hz ampere rating. For example, the VSP40 is rated to pass the energy of a 8/20 μs 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 60Hz 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 the latest revision of UL 1449’s Limited Current Abnormal Overvoltage Tests before damage occurs to the MOV.

**MOV Thermal Protection**

Current flow through an MOV due to 60Hz overvoltages, as discussed on page 2, 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 typically includes 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 Ferraz Shawmut’s Thermally Protected MOV (TPMOV). 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...
Addressing Overcurrent Issues for Transient Voltage Surge Suppressors

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.

Warning: Although the TPMOV has passed all tests of UL 1449 standards and has a SCCR of 100kA without fuse protection, the user needs to consider if there is a risk of the device being misapplied on voltage systems greater than its rating. When misapplied, the MOV in the TPMOV may fail prior to be disconnected. Use of a VSP fuse in series is an additional safeguard that should be considered in this case. Consult Ferraz Shawmut's Technical Services for additional details.

Figure 10: VSP Fuse Protection and TPMOV.
Ferraz Shawmut's TVSS Products
Ferraz Shawmut’s complete family of surge suppression devices includes the TPMOV (Thermally Protected MOV), Surge-Trap™ transient voltage surge suppressor, VSP surge-rated fuses and Surge Switch.

Thermally Protected MOV (TPMOV)
Developed to address the failure characteristics of MOVs, the Ferraz Shawmut Thermally Protected MOV 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 8/20 μs max surge rating, a footprint consistent with 25mm – 40mm MOVs, visual and remote indication, and a small package.

Surge-Trap™ Transient Voltage Surge Suppressor
Surge-Trap uses the patented TPMOV that meets the new requirements of UL 1449 and does not require additional overcurrent protection for its 200kA interrupting rating. It features visual and remote indicators that provide status of the protection circuit and is offered with a DIN-rail mount option.

Surge Rated Fuses - VSP
Ferraz Shawmut surge suppression fuses are specially designed to address the protection of TVSS systems. The VSP fuses are designed to withstand 8x20 μs surge pulses without opening, allowing the TVSS 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.

TVSS Surge Switch
Ferraz Shawmut’s Surge Switch is an extremely compact, high-performance, annually 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 8x20 μs waveform seen in transient-voltage surge protection device applications.

Additional Resources
- Product Application Note: Thermally Protected MOV
- Advisor: For Product Information on Surge Products
- PCIM Article Reprint: Thermally Protected MOVs Resist Overvoltage Failures