

Electronic Systems Protection via Advanced Surge Protective Devices

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Abstract - Market demand and manufacturer innovations have led to improved SPD design and features. New fusing techniques and advancements in Metal Oxide Varistors (MOVs) provide a more comprehensive design, which results in a safer and more reliable SPD that improves overall system integrity. Adding new integral thermal protection in series with individually fused MOVs provides protection against low fault current (high impedance fault), while preserving high surge current protection. When applied using IEEE's recommended cascaded approach for coordinated, facility-wide protection, integrated SPDs offer the best solution for a safe and reliable surge suppression system.

This paper will examine key issues regarding the effective use of SPDs and new designs that provide improved safety, reliability and system integrity.

I. INTRODUCTION

Although SPDs have been in use for many years, it is only recently that they have become an acceptable practice within the electric industry. A Frost & Sullivan report, written by Jane Clemmensen, estimates that the loss in production due to facility downtime is \$26 billion in the U.S. alone. This estimate is based on facility surveys that include numerous power quality problems (e.g., sags, swells, outages, and transients).

Because it is impossible to prevent voltage surges from either entering a building or from occurring inside a building, SPDs must divert (or at least limit) the effects of these voltage surges or spikes. SPDs remove electrical surges or impulses by acting as a low impedance path that turns the transient voltage into a current and shunts along the return path, usually ground. By design, an SPD often acts as a "self-sacrificing" device. In other words, its main purpose is to remove harmful voltage spikes from the electrical system even under potentially SPD-fatal conditions. The key is to ensure that the design is safe enough that in the unlikely event of SPD failure, the SPD will not shutdown a process by tripping the upstream circuit breaker or fuse, damage nearby equipment, or cause physical harm to personnel due to smoke. [1]

II. HOW SAFETY PLAYS A KEY ROLE IN SPD APPLICATION

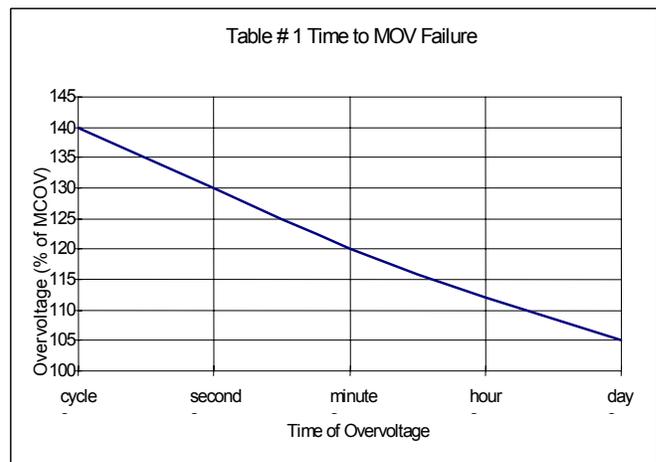
Since the SPDs role is to ensure that the electronic components of the system are not damaged or degraded and operate properly, an SPD must function with a high degree of

safety and reliability. Well designed SPDs are generally maintenance free, dependable and should last the lifetime of the facility.

A. The Cause Of SPD Failures

SPDs that have high surge ratings usually have multiple MOVs connected in parallel (to each other) so that they can share the surge current. However, laboratory tests show that if MOVs are connected in parallel circuits, the MOVs will fail one at a time, rather than all at once. Once one MOV fails short, the remaining MOVs are protected and will not conduct a significant amount of current. Therefore, the current will flow through the single MOV, possibly creating upstream and/or downstream interruptions and disruptive conditions on the system.

Although failures are rare, they can occur when the SPD is incorrectly used (e.g., a WYE-configured SPD installed into a delta system), or when their primary component, the MOV, is subjected to a sustained temporary over-voltage (TOV). A TOV can exceed 200 percent of normal voltage as a result of a utility fault, loss of the neutral on a 3-phase 4-wire system, or an improperly wired device. Though not a surge event, this is the most common cause of SPD failure, accounting for over 90 percent of SPD failures. These occurrences can either gradually degrade the MOV leading to end of life failure or result in quick sudden failure, depending of the level of TOV.



Approximate time duration to MOV failure based on the voltage increase in % of the maximum continuous operating voltage (MCOV)

For example, on a 120/208V 3-phase 4-wire system, the Maximum Continuous Operating Voltage (MCOV) is typically 150 VAC. The MOV could likely handle a 50% increase to the nominal system voltage ($1.5 \times 120 = 180$ VAC) for a period of minutes. However, prolonged or frequent over-voltage occurrences will reduce the reliable life expectancy of the MOV.

SPD products that utilize or recommend fuses with excessive surge current ratings do not provide the proper system coordination. They sacrifice low-level fault protection and do not disconnect during low current faults. This can result in catastrophic failure with eventual tripping of the upstream breaker or fuse. The table above (Table #1) depicts how an MOV reacts to over-voltage conditions.

III. PROPER SPD TESTING PROMOTES SAFETY AND RELIABILITY

To ensure that an SPD will operate at peak safety, efficiency and reliability, SPD manufacturers must adhere to numerous standards and perform numerous tests, which should be independently verified. There are two recognized UL 1449 tests that are generally recognized as critical: the *Limited Current Test* and the *AIC rating¹ Test*. An SPD must pass both tests in order to receive the UL 1449 listing. To pass both tests, the device must not produce a flame, have projectiles leave the enclosure, nor shall the internal live parts become exposed during the tests.

The *Limited Current Test* is conducted by applying an abnormal over-voltage (e.g., a line to line voltage) to the SPD via a conductor pair, which are connected to one of the following SPD modes: Phase to Neutral, Phase to Ground and Neutral to Ground. The current is limited to 0.125 Amp, 0.5 Amp, 2.5 Amps and 5 Amps by means of the power source impedance. [2]

The *AIC rating Test* is conducted in the same manner as the *Limited Current Test*, except that the impedance must allow for a current of at least 5000 Amps. The end user must note the difference when comparing the SPD AIC rating with the AIC ratings of other components in the system (e.g., circuit breakers, contactors, relays, etc.). SPD AIC rating is tested at an abnormal over-voltage, and other components are usually tested at nominal system voltage. For example, on a 120/208-Volt SPD, the test will apply a "line to line" voltage of 208 VAC on a "phase to neutral" SPD terminals rated only 120 VAC. [3]

These are important tests because they relate directly to equipment and personnel safety. However, there are other tests that are currently in use within the industry.

The NEMA LS-1 specification, published in 1992, designed test parameters around the existing SPDs commonly promoted surge rating of 100kA per phase. The specification required "no

more than 10% clamping voltage degradation after Ultimate Surge". The test is relatively simple and fast to perform. This allowed the *Ultimate Surge Test* to gain support and popularity because it was an attainable standard. [4]

However, the clamping voltage, or let-through voltage, during *Ultimate Surge* is up to 10 times higher than the nominal system voltage. Therefore, even if it were possible to receive a 200 kA surge at the SPD, the let-through voltage would damage or destroy the electronic components in the system downstream. Though a number of manufacturers promote higher surge current ratings and rely on the Ultimate Surge Test, the purpose and relevance of this test becomes questionable for two reasons. First, the end user's equipment is not protected during such surges as the LTV is too high, and second, test labs are not able to generate peak surge currents much greater than 200 kA.

The *Ultimate Surge Test* may support claims of longer product life; however, testing for product longevity is not as important as testing for and ensuring system and user safety. The remainder of the paper will describe the importance of thermal protection and advances in fuse technology, which increase the reliability of the devices and improve system safety.

A. The Importance of SPD Thermal Protection

The MOV degradation happens very gradually. The increase in leakage current (due to TOV) through the failing MOV progresses at the same rate as the MOVs degradation. This heats up the MOV and the adjacent thermal disconnect, causing the disconnect to trip. Otherwise, when an SPD fails, the MOV short-circuits and must be immediately disconnected from the system.

SPD manufacturers recommend using a circuit breaker or over-current fuse (external or internal) in front of an SPD. For properly designed SPD disconnection, individual MOV fusing is required. The characteristics of the materials for over-current fuses generally don't allow for a simple design. The same over-current fuse can not conduct very high surge current and perform very low fault current disconnection. The SPD surge current rating is improved by having several individual fuses (one per MOV) because the MOVs (and fuses) share the current well during the surge event.

However, for low fault current disconnection, over-current fuse(s) must be used in combination with a thermal disconnect. The thermal disconnect is capable of handling very high surges without opening and performing low fault current disconnection, but the thermal disconnect is not fast enough in the case of high fault current condition. Therefore, the combination of thermal disconnector(s) with the over-current fuse(s) on individual MOV(s) is the best solution.

¹ - "AIC rating" (Available Interrupt Current), "IR" (Interrupt Rating), "Maximum Fault Current Rating"; these three terms have the same connotation.

IV. NEW ADVANCES IN SAFETY AND RELIABILITY - THERMAL DYNAMIC FUSING

An advanced SPD on the market today contains multiple MOVs, each of which are accompanied by a thermal fuse spring (TFS), a fuse trace (FT) or a fuse trace with soldered hole (FTWSH) connected in series. The TFS, FT and FTWSH should withstand a surge current equal to the surge current rating of the MOV with which they are associated. Refer to figure 1 below.

These enhancements are based on empirical test data, which prove that the combination of thermal disconnection and over-current protection provides the highest level of component disconnection safety relating to fault occurrences.

Thermal Fuse Spring and Fuse Trace

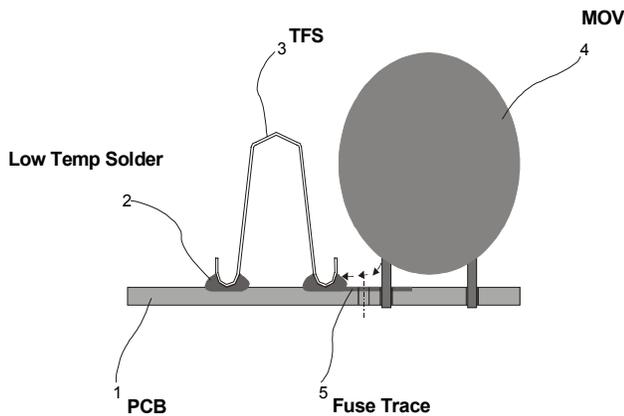


Figure 1. Printed circuit board layout of TFS system

A. Thermal Fuse Spring (TFS) Technology

An overheated MOV produces sufficient heat to prompt a thermal disconnection. For small fault currents, or if the occurrence is over a longer period of time, the TFS will disconnect the series MOV.

Some SPDs use a FT and an MOV in series with a 100A circuit breaker. Those SPDs may pass standard safety tests, but may fail in real world application. For example: if the fault current is less than 100A, the SPD might catch fire, but the circuit breaker will not trip. SPDs that are designed with a TFS will allow disconnection of the shorted MOV at the overheating stage.

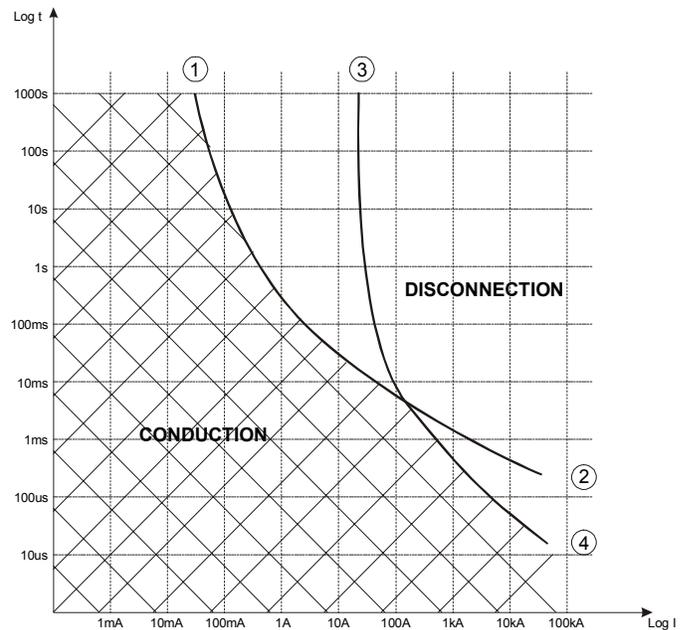
However, in instances of incorrect installation, or when a highly abnormal over-voltage condition occurs, a FT will help in the disconnecting process. At very high fault current levels, the FT will open faster than the TFS. In these instances, the FT improves the AIC rating of the SPD.

B. Fuse Trace (FT) and Fuse Trace with Soldered Hole (FTWSH) Technology

Silver fuse traces have been used for years, but this design protects only up to a certain level of surge current unless the cross-sectional area is large. The new design of Fuse Traces utilize copper in their circuitry, which provides better surge (kA) ratings but also less cross-sectional area, allowing for disconnection on low fault currents.

In very rare situations, such as during a high fault current (above 1000 Amp), the TFS might not disconnect the MOV quickly enough. In that situation, a special fuse trace with soldered hole (FTWSH) will provide additional help. The hole is filled with solder, which improves the disconnection time during a fault condition. Tests showed that if a FT and FTWSH have the same surge current rating, the FTWSH will disconnect at a 50% lower fault current than the FT. These two designs used in tandem provide disconnection capability for both high and low fault currents.

C. Coordination of MOV/TFS and FT



- ①-② Thermal Fuse Spring & Metal Oxid Varistor Combination
- ③-④ Fuse - Trace as Overcurrent disconnection

Graph 1. The graphic depicts 'current vs. time' curves (i/t curves). The first curve, between points 1 and 2, is the MOV/TFS i/t curve. The second curve, between points 3 and 4, is the FT i/t-curve. The TFS is capable of disconnecting the MOV in the low fault condition range (between point 1 and curves intersection). The FT is capable of disconnecting the MOV in the high fault condition range (between curves intersection and point 4).

V. CONCLUSION

The likelihood of, sensitivity to and potential damage caused by power quality problems, including voltage sags, swells, outages and transients becomes greater with the marketplace's increased reliance on electronics. Surge Protection Devices (SPDs) are becoming increasingly more important in residential, commercial and industrial power quality applications. Their main purpose is to remove harmful voltage spikes from the electrical system even under potentially SPD-fatal conditions. The key is to ensure that the design is safe enough that in the unlikely event of SPD failure, the SPD will not shutdown a process by tripping the upstream circuit breaker or fuse, damage nearby equipment, or cause physical harm to personnel due to smoke, fire or flying debris.

To ensure that an SPD will operate at peak safety, efficiency and reliability, SPD manufacturers must adhere to numerous tests, which should be independently verified. Tests that relate directly to equipment and personnel safety, rather than product longevity, are considered the most relevant and appropriate. A properly designed SPD will last the lifetime of the facility and require little or no maintenance.

SPDs that contain multiple MOVs, each of which are accompanied by a thermal fuse spring (TFS), a fuse trace (FT) or a fuse trace with soldered hole (FTWSH) connected in series offer improved safety and reliability. The TFS, FT and FTWSH should withstand a surge current equal to the surge current rating of the Metal Oxide Varistor (MOV) with which they are associated. An overheated MOV produces sufficient heat to prompt a thermal disconnection. For small fault currents, or if the occurrence is over a longer period of time, the TFS will disconnect first.

However, in instances of incorrect installation, or when a highly abnormal over-voltage condition occurs, a FT will help in the disconnecting process. New FT design utilize copper in their circuitry, which provides better surge ratings but also less cross-sectional area, allowing for disconnection on low fault currents. At very high fault current levels, the FT will open faster than the TFS. In these instances, the FT improves the AIC rating of the SPD.

Additionally, tests show that if a FT and FTWSH have the same surge current rating, the FTWSH will disconnect at a 50% lower fault current than the FT. These two designs used in tandem provide disconnection capability for both high and low fault currents.

These enhancements are based on test data, which prove that the combination of thermal disconnection and over-current protection provides the highest level of component disconnection safety relating to fault occurrences. When applied using IEEE's recommended cascaded approach for coordinated, facility-wide protection, the new design for SPDs offer the best solution for a safe and reliable surge suppression system.

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- [3] UL1449 AIC Rating, 2nd Edition, Section 39. Northbrook, IL, Aug. 15, 1996, pp. 71.
- [4] NEMA Standards Publication No. 1 LS-1: Low Voltage Surge Protective Devices, Section 3-9, Maximum Surge Current. Washington, DC, May, 1992.