Fuse Application Relative to Surge Current for Surge Protection Devices

When properly selected, the fuse is the best alternative device to use for indicating that an MOV has been degraded by a single surge event.

KENNETH J. BROWN
Leviton Manufacturing Company, San Diego, CA

Introduction

This article addresses the proper application of fusing for low-voltage (less than 1000 VAC) Surge Protective Devices (SPDs). An SPD is a protective device used for limiting surge voltages experienced on equipment by discharging or diverting surge current.[1] SPDs can be utilized on either the line or load side of the main service disconnect. An SPD used on the line side is referred to as a surge arrester. An SPD used on the load side is referred to as a transient voltage surge suppressor (TVSS).

SPD performance for TVSS is generally validated by testing to an IEEE C62 recommended practice. IEEE C62.45 is the "Guide on Surge Testing for Equipment Connected to Low Voltage AC Power Circuits." SPD performance for Surge Arresters is C62.11, "Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits." SPD safety requirements are validated by test and inspection to Underwriters Laboratory (UL), Standard 1449, Second Edition. As a result of the UL1449 tests, a Surge Voltage Rating (SVR) is assigned to the product. UL determines the SVR rating of a product by obtaining the average measured limiting voltage from 3 test samples following a duty cycle test.[2]

Metal Oxide Varistors

To properly evaluate the durability of an SPD, the unit should have a surge current rating. A surge current rating is defined as the maximum 8/20 µs surge current pulse the SPD device is capable of surviving using a single impulse without degradation in SVR of more than 10%, given a specified surge current level. Surge current is typically rated per protection mode.[3] Many SPD circuits provide several modes of protection, which are defined as the modes for which the SPD has directly-connected protection elements. Such modes of protection are Line-to-Neutral (L-N), Line-to-Ground (L-G), Neutral-to-Ground (N-G), and Line-to-Line (L-L).

The 8/20 µs waveform is approximately a current waveform with an 8 µs rise time and a 20 µs duration. The resultant waveform is a combination open-circuit voltage waveform and short-circuit current waveform. This waveform is defined in IEEE C62.45.

Section 6 of IEEE C62.45 provides test procedures for carrying out surge testing. In section 6a, it is noted that "A surge test is a single event."[4] Once the surge has been applied to the unit under test (UUT), any damage that occurs must be repaired and the probable cause determined before the next surge test is performed. This concept also applies to actual in-service functional conditions where lightning could occur. If an SPD protects service equipment and is damaged or degraded in the process, it should be replaced.

Metal oxide varistors (MOVs) are generally the best available nonlinear devices for protection of low-voltage AC SPDs.[5] MOVs are bipolar components which means they will provide clamping for both positive and negative voltages. MOVs usually have a surge current rating based on the 8/20 µs current impulse. MOV manufacturers also provide an impulse response time, the time lag between the application of a surge and the varistor's "change of state" conduction action. Most MOVs have an impulse response time of less than 50 ns.

It is important to note that although the varistor itself has a response time of less than 0.5 ns, the parasitic inductance and capacitance associated with the package and leads increased the overall response time to less than 50 ns.[5] This response time is reduced again by the parasitic inductance and capacitance associated with most SPD installations due to wiring limitations. However, for the purposes of this article, the MOV response time is adequate for the previously defined surge pulse rise time.

Lightning surges on overhead power lines have long been represented by a voltage surge of 1.2/50 µs and a current surge of 8/20 µs (IEEE C62.1 1984),[6] which is described as the Combination Wave in the up-to-date IEEE document. Figure 1 shows the short-circuit current combination waveform according to IEEE C62.45.

The combination waveform is commonly generated in many laboratories and is used as an appropriate standardized representation of the environment near the service entrance of a building connected to an overhead distribution system.

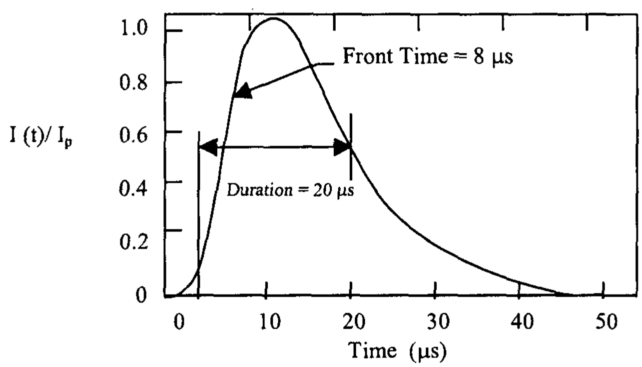


Figure 1. *Combination Wave, Short-circuit Current.*

It should be noted that the response time of an MOV (50 ns maximum) is 160 times faster than the current surge rise time of 8 µs. This ensures that the MOV change of state, or clamping, will occur and divert surge current away from protected equipment well within the time frame of a typical lightning induced surge.

Test Results

This background information provides a context for discussion of the surge relationship to the fuse. A fuse is an over-current protective device containing a calibrated current-carrying element that melts and opens a circuit under specified over-current conditions.[7] The element is a calibrated conductor. When a sustained overload occurs, the element will generate heat at a faster rate than can be absorbed by the element itself. If the overload continues, the element will reach its melting point and open. This entire process takes time, and the time of operation is dependent upon the applied current. The time it takes to open a fuse is usually expressed in a time vs. current curve.

The time vs. current curve of a fuse does not directly relate to the surge impulse characteristics of our typical 8/20 µs current surge because the current curve does not typically include the high-current fuse response time. The time constant of a fuse is a function of its resistance and inductance. A typical 60 Hz, 125 VAC to 600 VAC fuse time constant for test currents of 10 kA or more is 10 ms. This is a good approximation of the time it would take for a fuse to open in a lightning-induced surge condition.

The process for opening a fuse involves 3 heat-energy levels, each with an associated I^2t rating. The I^2t rating is a measure of the heat energy (current squared per second) level required to achieve each step in the opening process. The first step in the process is the melting or pre-arc I^2t level. The second step in the process is the arcing I^2t level, which is the level where the internal arcing process has initiated. The third step is the clearing I^2t level, which is the heat energy level required to open the fuse. The higher the I^2t level, the more 8/20 µs surge current a fuse will pass while remaining intact.

An MOV will respond in less than 50 ns, and the average surge impulse induced by lightning will have an 8-µs rise time and a 20-µs duration. The fuse is relatively slow with a time constant of 10 ms. This is 500 times slower than the average pulse width of a combination wave surge impulse. Given these conditions, if the fuse opens, it will open after the surge energy has been successfully diverted to ground by the MOV.

Recent testing performed at an independent laboratory tends to validate this hypothesis. Table 1 identifies SPDs by sample number and their associated clamping voltages given the surge current level specified in the third column.

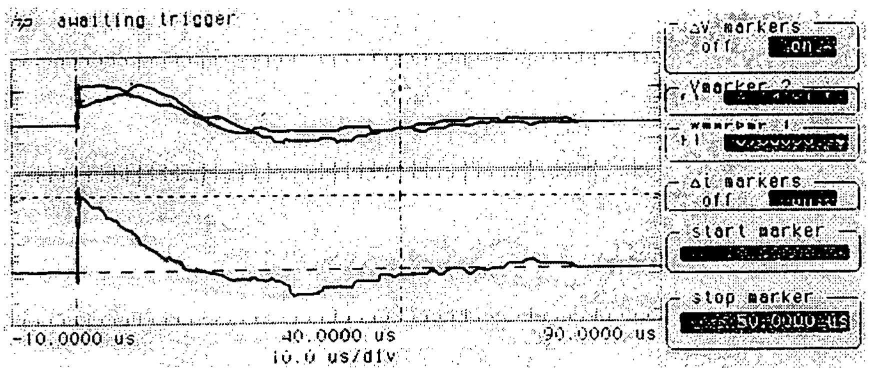
For each of the following tests, a similar type, size, construction, and ampere rated fuse was used. Figure 2 shows that the first sample (SPD#1) was tested at 20 kA and the clamping voltage was measured at 2743 volts. The second sample (SPD#2) was tested at 20 kA with a similar fuse, and the clamping voltage was measured at 2306 volts. The clamping voltage observed in the second test was lower than in the first test even though the fuse opened during the second clamping test (Figure 3). Since the fuse was open following the 20 kA surge test, and the clamping performance was better than the previous test where the fuse remained intact, it is concluded that the fuse opened at the tail end of the combination wave impulse.

The tests described above support the contention that a surge protection device can perform two useful functions:

- The SPD can perform its required function of diverting damaging surge current to neutral and/or ground.

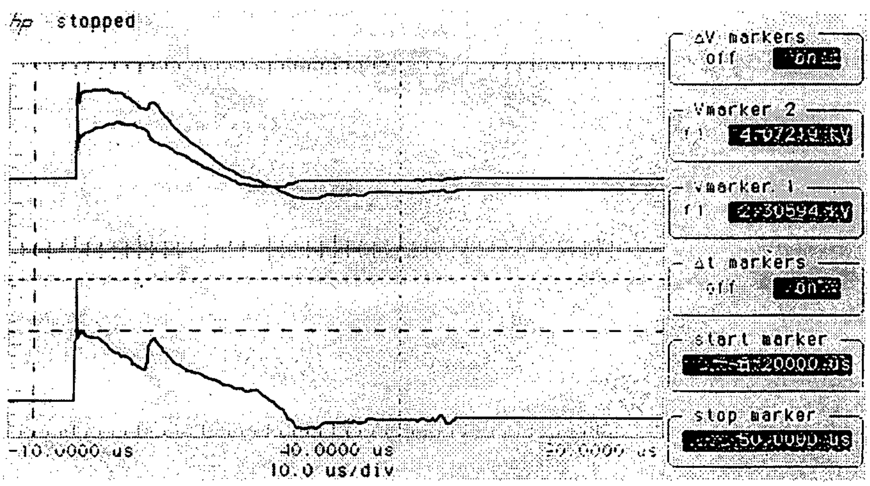
20 kA, 8 x 20 µs Surges (0.25-ohm source impedance pulser)									
		Surge Level	Pulser Voltage		Actual Current (kA)	Clamping Voltage	Photo	Test	
	Unit	(kA)	(kV)	Mode	Fig. #	Fig. #	Fig #	Result	Comments
SPD #1	1	20	7.2	L2-N	16.7-73	2743-74	184	Pass	Fuse intact
SPD #2	1	20	7.2	L2-N	16.7-75	2306-76		Pass	Fuse open

Table 1. *Test Results and Figure Reference Table for SPDs Surged at the Levels from 20 kA.*



Note: Lower curve shows line clamping voltage referenced to neutral.

Figure 2. *Measured Clamping Voltage. Surge Injection: 20 kA, L2-N, Fuse Intact.*



Note: Lower curve shows line clamping voltage referenced to neutral.

Figure 3. *Measured Clamping Voltage. Surge Injection: 20 kA, L2-N, Fuse Open.*

- A properly fused SPD will result in an open-fuse condition to indicate that a large surge occurred. If the surge is large enough to open a fuse that was previously tested to survive a 20 kA, 8/20 µs surge pulse, then it is probable that MOVs or other surge-diverting components have been degraded and should be replaced.

Conclusion

It is often stated within the SPD industry that an SPD fuse must stay intact through the duration of a surge current test to accurately represent the sustainable surge current. From the results of testing, coupled with a thorough understanding of associated waveform timing, it was found that a surge can be successfully diverted while the fuse element is in the opening process. Further, opening the fuse will provide the added benefit of notification of SPD degradation. An SPD can be designed to notify a user of inadequate operation by turning off a diagnostic LED or activating an audible alarm when a fuse is open. Many SPD manufacturers presently use an LED or alarm to indicate whether a fuse has opened within the SPD. The correct combination of fuse and diagnostic LED will let the user know that an excessive surge was experienced and the SPD should be replaced.

When selecting a fuse for SPD applications, great care must be exercised in choosing a fuse with the proper I^2t for the specific application. If the fuse is undervalued (I^2t too low), it may open prior to diverting the energy associated with the surge condition. If the fuse is overvalued (I^2t too large), it will remain intact following a large surge, and could misrepresent the condition of an SPD. If the fuse remains intact, the diagnostic indicator will be illuminated, giving the user an indication that the SPD is functioning properly when, in fact, the MOVs or other surge-diverting components could be degraded. In summary, when properly selected, the fuse is the best alternative device to use for indicating that an MOV has been degraded by a single surge event.

References

1. IEEE C.62-1996 Draft, "Standard Test Specifications for Surge Protection Devices for Low Voltage AC Power Circuits," p.6
2. Underwriters Laboratories, Inc., "Standard for Transient Voltage Surge Suppressors," UL 1449 Second Edition, August 96, pp. 55-60.
3. NEMA Standards Publication, "LS2 Draft, Performance Standard for Load-Side Permanently-Connected Low Voltage Surge Protective Devices," May 1997, p.8.
4. IEEE 62.45-1992; "Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits (ANSI)," pp. 15-34.
5. Standler, R. B., "Protection of Electronic Circuits from Overvoltages," Dec. 1989, pp. 133-145.
6. IEEE 62.1-1984; "Standard for Gapped Silicon-Carbide Surge Arresters for AC Power Circuits," Nov. 1989, pp. 13,14.
7. Gould Shawmut, "Gould Advisor," No. 102, 1997, p. AP-3.

Additional Sources

Institute of Electrical and Electronics Engineers, Inc. C62 "Surge Protection," IEEE C62.41-1991 "Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits" (ANSI) pp. 35-47.

KENNETH BROWN *is the Engineering Manager at Leviton Manufacturing Company. Kenneth's educational background includes an undergraduate degree in Electronics Engineering from the Ohio Institute of Technology and an MBA from West Coast University. He is married to Carol Brown and has two children, Heidi and Christine. (619) 671-5264.*