Response to the article, "**The Advantages of Selenium in Surge Supression Circuits**", Stephen N. Olson, Precise Power Inc., 1999.

Selenium has been used in the old TVSS devices for decades. Over the years, most manufacturers realized that the performance features of selenium were outweighed by the cost, increase in size, changes in the types of disturbances observed on the power grid, and additional installation costs and restrictions.

Argument #1 A Non-Sacrificial Technology from ***"The Advantages of Selenium in Surge Suppression Circuits"***

Every MOV carries a rating of "so many" amps. The rating is based on the size of the MOV: 6,500 or 10,000 amps for a 20mm MOV, 30,000 amps for a 32mm MOV, 40,000 or 80,000 amps for a 40mm MOV, and so on. When exposed to an impulse in excess of the surge current rating, the MOV will, in most cases fail. Additionally, a combination of a given number of lower level impulses will, at some point, cause the MOV to fail. MOVs by design, are sacrificial components. Selenium by nature, is non-sacrificial. When used in a "hybrid" system, even if the MOVs have failed, the Selenium continues to provide protection. This is particularly important in the case of a lightning strike which actually consists of 6-12 strokes of diminishing amplitude. Even if the first stroke or first few strokes, takes out the MOVs, the critical load will continue to be protected by the Selenium. Even if the surge current handling capacity of the Selenium is exceeded, the Selenium plates "self heal" and almost instantaneously return to operational status.

SSI Response to Argument #1

The article starts with some general statements about MOVs and implies that they will fail if a surge current exceeds the rating of the MOV. What they do not mention is the modern Surge Protective Devices (SPDs) use current sharing designs that allow fifteen 20 kA rated MOVs in parallel to provide 300 kA Peak Surge Current withstand capability. Most SPDs do not rely on a single MOV per mode (L-N, L-G, N-G, and L-L). Even Current Technology uses this method inside the yellow plastic case of their SEL300 models. The justification for the use of a 100 kA per mode, 200 kA per mode, or 300 kA per mode SPD is not that you are expecting a 100, 200, or 300 kA surge on any of the modes. A few selected exerts from IEEE Standard C62.72-2016, "IEEE Guide for the Application of Surge-Protective Devices for Use on the Load Side of Service Equipment in Low-Voltage (1000 V or Less, 50 Hz or 60 Hz) AC Power Circuits", provides useful information:

Section 7.1 General

"Low-level (low-magnitude) surges are more prevalent than high-magnitude surges.

Where an individual evaluation is not possible, such as is the case of a direct lightning strike, it might be assumed that 50% of the total lightning current enters the ground termination of the lightning protection of the structure considered. The other 50% of the current is then assumed to be distributed among the services entering the facility. This distribution of lightning current is also noted in (IEC 61643-12 [B1]). The effects of increased numbers of SPDs installed within the PDS will also directly affect the distribution of a surge. The repetitive operation of numerous SPDs can significantly affect the voltage stability of the system."

Section 7.4 Rate of occurrence (versus) current level

"IEEE Std C62.41.1 provides a large database with regard to the rate of occurrence of surges. A large number of studies are cited and the reader is referred to that document for further information regarding the rate of occurrence.

The data collected indicate that the peak current levels of most lightning strikes are in the range of 10 kA to 40 kA. The median value of the peak current reported was in the range of 15 kA to 20 kA. Only 6% of the currents were above 60 kA, and less than 2% of the currents were above 100 kA (Key and Martzloff [B2]), (Lewis and Foust [B3]), and Transient Voltage Suppression [B4]). The rate and peak current levels of surge events will also vary depending on the geographical location. In addition, the research data indicate the value of the initial stroke. Lightning is usually a multiple stroke event, and the subsequent strokes often have less energy than the initial stroke. Further, it should be understood that the peak current values detailed above are that of the lightning stroke only and not the peak current value entering the PDS."

Section 7.4.1 Lightning characteristics and current level

"There are three types of lightning flashes: negative, positive, and bipolar. It is estimated that 90% of the lightning discharges are negative and that less than 10% are positive (Uman [B5]). Bipolar lightning discharges are rare, and they make up the remaining percentage of the lightning discharges from cloud to earth."

Section 7.4.1.1 Negative lightning flashes

"Research examining the peak current associated with lightning flashes occurred as far back as 1944 (McCann [B6]). Similar to the differences in the rate of rise of the stroke current between initial strokes and subsequent strokes, there are differences in the peak current between initial strokes and subsequent strokes. For negative flashes, 50% of the initial return strokes exceeds 30 kA, and only 5% of the initial peak return stroke currents measured exceeds 80 kA (Uman [B5], Thottappillili [B7], IEEE PES T&D Committee [B8]), and Tominaga et al.[B9]).

In most cases, subsequent strokes have a peak current that is less than the measured value of the initial return stroke current (Uman [B5], Thottappillili [B7], and IEEE PES T&D Committee [B8]). Fifty percent of subsequent return strokes are between 12 kA and 15 kA (Uman [B5] and Thottappillili [B7]). Disagreement exists in the literature about the peak current of subsequent return strokes. Thottappillili indicates that the maximum current of a subsequent return strokes approach 75 kA (Thottappillili [B7]). In other studies, the maximum current of subsequent return strokes is determined to be 30 kA (Uman [B5] and IEEE PES T&D Committee [B8]).

Table 1—Distribution of negative lightning flashes (Uman [B73])

Number of strokes per flash	Frequency of occurrence South Africa (%)	Frequency of occurrence Florida (%)
1	27	26
2	14	15
3	9	12
4	11	17
5	16	6
6	6	5
7	4	4
8	5	8
9	5	1
10 or more	6	6

The time interval between the initial return stroke and subsequent return strokes range from approximately 7 ms to 500 ms (Uman [B5] and Thottappillili [B7]). However, separation times of 46 µs to 110 µs have been recorded in a minority of lightning flashes in data collected from the Kennedy Space Center (Rakov and Uman [B5]). The amount of (average) current that flows in the lightning channel has a maximum value of 500 A with a typical value of 100 A (Thottappillili [B7]).

Several research studies have been published on the number of strokes per lightning flash. Analysis by Uman from studies conducted with 1800 lightning flashes in South Africa and 105 flashes in Florida is depicted in Table 1 (Uman [B5]). Approximately 25% of the negative lightning flashes are single stroke, whereas approximately 75% of the lightning flashes are multiple stroke events. Variations in the number of strokes can be noted between the two geographical areas, but 50% of the lightning flashes in both geographical areas have between two and five strokes.

The mean number of strokes per lightning flash is 4.0 for data obtained from South Africa and 4.1 from data obtained from Florida. A small number of lightning flashes contain 10 or more strokes. The maximum number of strokes recorded in a single lightning flash was 26, which were recorded in New Mexico (Thottappillili [B7]).

From another study published by Schneider Electric [B10], for 31 266 negative stokes recorded during one time period, 82% were less than 30 kA and 98% were less than 60 kA."

From the above it can be seen that surges on the service entering a facility from a lightning strike exceeding 100 kA are extremely rare. For most SPD manufacturers, the reasoning behind the sizing of the kA rating for an SPD is based on the SPDs ability to absorb and dissipate the surge energy from several repeated strikes. A properly sized, and designed MOV-based SPD, with the ability to dissipate the heat generated during the absorption and conversion of the excess surge voltage to heat has a high likelihood of surviving a lightning strike(s). A properly designed SPD uses more than just MOVs. A combination of several components (i.e. surgistors, transorbs, resisters, diodes, capacitors) strategically placed in close proximity on the circuit board, in the right sequence to take advantage of the best characteristics of each component,

and with an encapsulating compound with a high dielectric strength to electrically isolate the components and circuits on the board from each other can provide superior protection without significant deterioration or failure of the MOVs or other components. The encapsulating compound utilized by Surge Suppression LLC allows the placement of the components and circuits on the board to be much closer than would normally be practical due to the compound's high dielectric strength. This means the board itself can be much smaller in physical size, and the enclosure can also be correspondingly smaller. We will see in a minute that size is a critical factor in the application of SPDs.

Argument #2 – Longevity *from **"The Advantages of Selenium in Surge Suppression Circuits"***

One of the primary measurements of performance for TVSS units is the number of impulses the unit can withstand without failure. The standards used for comparison are ANSI/IEEE C62.41, category "C.3" which uses a 20,000 volt, 10,000 amp impulse and ANSI/IEEE C62.45 which defines the parameters for the testing, such as time interval between impulses, to determine the number of impulses the device can successfully withstand. ANSI/IEEE C62.41 defines the waveform and other characteristics. Manufacturers publish the number of impulses their units can withstand without failure per these two standards. Using these standards, a Selenium based "hybrid" system increases the number of 10,000 amp impulses a given unit can withstand by 200% - 244%. As a minimum, in the field, a Selenium based system will last twice as long as a MOV only system. Please review table "A" above for an exact comparison between MOV only and "hybrid" Selenium based units.

Table A

MOV vs. Selenium "Hybrid"

Surge Current Rating	Model # Selenium Based Unit	Number of Impulses/ Mode	Model #, MOV OnlyUnit	Number of Impulses/ Mode	Percent Diff.
300,000 amps	SEL 300	>15,000	TG 300	>7,500	200%
250,000 Amps	SEL 250	>14,000	TG 250	>7,000	200%
200,000 Amps	SEL 200	>13,000	TG 200	>6,500	200%
150,000 Amps	SEL 150	>12,000	TG 150	>5,500	218%
100,000 Amps	SEL 100	>11,000	TG 100	>4,500	244%

SSI Response to Argument #2

The article states, "One of the primary measurements of performance for TVSS units is the number of impulses the unit can withstand without failure. The standards used for comparison are ANSI?IEEE C62.41, category "C.3" which uses a 20,000 volt, 10,000 amp impulse and ANSI/IEEE C62.45 which defines the parameters for the testing, such as time interval between impulses, to determine the number of impulses the device can successfully withstand." The problem with this is the current IEEE Standard C62.41.2-2002 does not have a category "C.3" test.

Table 3.Standard 1.2/50 µs.8/20 µs Combination Wave
Expected voltages and current surges in Location Categories[a] A and B[b]
Single-phase modes[c] : L-N, L-G, and [L&N]-G
Polyphase modes: L-L, L-N, L-G, and [L.s]-G
(See Table 5 for N-G modes

Location Category[a]	Peak values[d]		Effective impedance (Ω)[e]
	Voltage (kV)	Current (kA)	
A	6	0.5	12 [f]
B	6	3	2

[a]See 4.5 for definition and discussion of location categories.
[b]See Table 4 for Combination Wave application to a low exposure in Location Category C.
[c]See IEEE Std C62.45-2002 for discussion of coupling modes.
[d]The values shown for each location category have been set by consensus to provide guidance and uniformity in test procedures. Other levels may be negotiated between the parties involved, including the particulars of a situation where the transitions between categories can be specifically assessed.
[e]The effective impedance of the surge source (emulated by a test generator) is defined as the ratio of the peak voltage to the peak current. It has the dimension of a resistance, but is not a pure resistance (see 6.3.2).
[f]Nominally, a 12 Ω effective impedance. To allow using a surge generator with 2 Ω impedance, a 10 Ω noninductive
resistor may be added, recognizing that the waveform might be slightly changed.

Table 4.Scenario I tests for SPDs intended for Location Category C[a]

	Standard tests		Optional test
Exposure	1.2/50 µs Voltage generator Minimum open-circuit voltage to be applied to SPD	8/20 µs Current generator Current to be driven through the SPD[b]	100 kHz Ring Wave for front-of-wave response evaluation
Low	6 kV	3 kA[c]	6 kV
High	10 kV	10 kA	6 kV

[a]The scope of these tests is limited to SPDs, in contrast with all the other recommended tests that may be applied to equipment other than SPDs.
[b]Values shown for the current are applicable for each phase of the SPD. In contrast with a test applied to equipment for the purpose of assessing its response to the surge environment, a test applied to characterize the performance of an SPD requires that the specified current be driven through the SPD. For the low exposure, this can be accomplished with a typical Combination Wave generator. For the high exposure, two separate generators, in two successive tests, must be used to apply the specified values.
[c]For low exposure tests, if a Combination Wave generator is used instead of two separate generators, the generator charging voltage has to be adjusted to obtain the stated current amplitude.

The current standard has a Category C High with a minimum open-circuit voltage of 10 kV and a current to be driven through the SPD of 10 kA. This is a current driven test that requires the specific current level, and whatever voltage level above 10 kV is required to reach and maintain that 10 kA current level. This is a much different, and more stressful test than the previous version of the standard which had a Category C-3 level, 20 kV, 10 kA, voltage driven combination wave impulse that required the 20 kV and up to 10 kA. Depending on the Equipment Under Test (EUT) the current varied substantially, but rarely ever reached the full 10 kA.

IEEE Standard C62.45-2002 does not list the number of impulses, or the time interval between impulses to determine the number of impulses the device can successfully withstand.

In Annex B (iniformative) Complementary notes, (This is not part of the requirements of the standard and is for information only)

Section B.30 Multiple surge

“In service, the protectors within the ***EUT*** will be subjected to one or, at most, a few ***surge events*** at a time (including a net of several surges associated with a lightning flash, including subsequent strokes). Typically, a long recovery period of minutes, hours, or even days will follow before they are required to withstand the next surge event. However, during thorough surge testing, it might be necessary to apply a sequence of tens or even hundreds of pulses or surge events. Surging at all network ***phase angles*** versus the ac line and in both polarities on a progressive stress basis might result in a large number of successive test waves.

In ***production tests***, it is important to limit the number of surges applied to devices intended for shipment in order to avoid possible degradation of the product.

It is possible that a component would be stressed during a single surge and continue to perform “normally” for some time. However, the life of this component might be shortened so that it might fail much earlier than it would have without the surge. The device parameters might be altered by the surge, but the device would remain temporarily functional, perhaps even within its specifications. A thermal runaway might be initiated if the device was left powered for a sufficient time after completion of the series of pulse applications. Therefore, some life testing should follow surge testing.”

Section B.37 Qualification test

"It will generally be up to the equipment specifier and manufacturer to agree on which tests will be performed. Tests performed to qualify a new equipment design or a major modification to an existing one will ordinarily be more complete than tests carried out on a routine basis on production products."

Section B.34 Repetition rate

"A maximum allowable surge repetition rate cannot be determined without the evaluation of the ***EUT*** protection design. For this reason, it is strongly recommended that the maximum allowable repetition rate for pulse trains of varying length be incorporated into the test plan. In the absence of other requirements, it is suggested that the wait times of Table B.2 be incorporated in the test protocol.

Table B.2—Suggested wait times

Location category	Waveform type	Power parameters	Numbers of applied surges	Wait time (seconds)
A	0.5 µs–100 kHz Ring Wave	6kV OCV[a] 200 A SCI[b]	10 to 1000	6 to 20
B	0.5 µs–100 kHz Ring Wave	6kV OCV I 500 A SC	10 to 1000	10 to 30
C	Combination Wave	6kV OCV 3kASCI	10 to 1000	30 to 120

[a]OCV—Open-circuit voltage
[b]SCI—Short-circuit current

Note that all equipment do not need to follow the wait times of Table B.2, which are suggested mainly for testing new equipment designs. The fact that a particular piece of equipment should be surged more slowly than the table suggests in no way implies that it provides less surge protection in the field. The slower rate is relevant during surge test, where repetitive testing should not be performed at a rate that would produce cumulative heating of the SPD. There might be repetition rate requirements for surges to be withstood in actual service, such as multiple discharges, and these should be determined at the outset if they exist. The repetition capabilities of the surge test generator should also be considered.

In the case of the EUT being a computer system, a very high repetition rate at low energy level might be necessary to check for software ***susceptibility,*** whereas a "one-shot" surge would be needed to check for hardware ***vulnerability***."

It is clear from the above that the "C.3" 20,000 volt, 10,000 amp impulse is not part of the recommendations, and with the wide variations in the number of applied surges (that top out at 1000) and the time between surges (30-120 for the 6 kV, 3 kA Combination Wave impulse), there are no hard standards for any life cycle to failure tests in the standard. It is up to the manufacturer to determine how the test should be conducted, and each manufacturer is free to choose a different set of parameters. This test was originated as a marketing gimmick to give one manufacturer a unique characteristic on their spec sheet that no one else was using. If they could convince the engineer that this was valid and necessary, the engineer put it in the bid spec and that manufacturer would automatically be sole-sourced on the bid. The marketing plan worked and, to remain competitive, several other manufacturers came up with their own type of life cycle testing using a variety of voltage and current combinations with unknown times between surge impulses. Since there are no established specific standards or controls, only general suggestions, this test should be viewed as what it is, a marketing gimmick. To end this discussion on life cycle testing, the Nominal Discharge Current Test portion of the UL Standard 1449, Fourth Edition, "Standard for Safety Surge Protective Devices", Section 40.7, "Nominal discharge current – For Type 1 and Type 2 SPDs and Type 1,2 Component Assemblies," replaces the life cycle testing as a durability test.

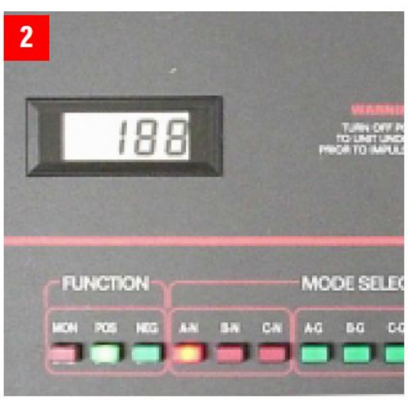
*Argument #3 Clamping Voltage from **"The Advantages of Selenium in Surge Suppression Circuits"***

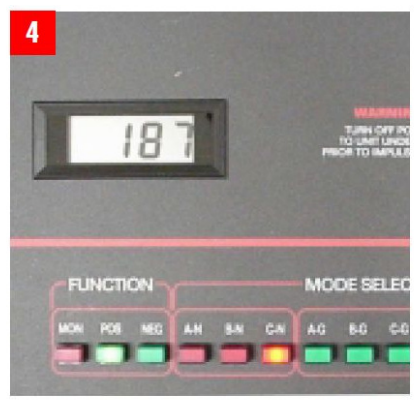
Photograph 1 (below) shows test probes connected to the three phases of a "hybrid" TVSS unit containing Selenium. This unit is a 120/208 volt, three phase, wye system. Note that phase "B" has had the fuse connecting the Selenium removed, while the fuses for phases "A" and "C" are intact. When a 1600 volt impulse from a surge generator is placed on phase "A", the clamping voltage is measured at 188 volts. Likewise, on phase "C" the clamping voltage is measured at 187 volts. However, phase "B", the phase with only MOVs a clamping voltage of 267 volts. The actual clamping voltages are shown in photographs 2, 3, & 4 (page 2). When you consider that you do not want to begin to clamp an impulse at less than 120% above nominal, (144

An ILSCO® Company

16041 Flight Path Drive
Brooksville, FL 34604
Phone 888-987-8877
www.surgesuppression.com

volts), and that a typical 120 volt rated TVSS' unit utilizes 150 volt MOVs, a clamping voltage of 187 volts is extraordinary. The difference in clamping voltage between the technologies is 80 volts, or an improvement of 316%, over an MOV only system.





SSI Response to Argument #3

When the article discusses Clamping Voltage, it uses a Current Technology selenium unit with the selenium disconnected from Phase B. This only represents the results of the testing with their own MOV design. **Surge Suppression LLC SPDs achieve a low let-through voltage using proprietary and patented technology that allows us to protect the down-line equipment without the cost or negative features of selenium**

technology.

*Argument #4 Swell Withstandability from **"The Advantages of Selenium in Surge Suppression Circuits"***

MOVs can fail by one of two methods,overexposure or heat. As previously mentioned, the addition of Selenium greatly improves the ability of MOVs to handle a single large overexposure, as well as the number of lower level overexposures. Failure due to overheating is caused by a "swell" condition. A "swell" is a multi-cycle overvoltage. This condition causes the MOV to repeatedly "fire", building up heat in the MOV until the overheating causes the MOV to fail. Making the likelihood of this scenario to occur more common are the recent changes UL made to their 1449 standard. In the past, TVSS manufacturers potted their MOVs. This potting material also served as a heat sink which drew the heat away from the MOVs. The new UL 1449 standard called for an overvoltage test. TVSS manufacturers found that in almost every case, their potting material melted, and in some cases actually flowed out of their TVSS units, causing them to fail testing. To alleviate the problem, TVSS manufacturers took to packing their MOVs in sand. Every change has an engineering trade-off. While the sand allows TVSS units to pass the UL 1449 testing, sand serves as an excellent insulating material. When an MOV in a TVSS unit of currentt design experiences a "swell" condition, the sand keeps the MOV from dissipating the heat and causes the MOV to fail faster than in the older designs with potting material. Please review table "B" taken from the guide specification for a Selenium based "hybrid" product. With a line impedance of .7 ohms, a Selenium based unit can withstand a "swell" condition measuring 200% over nominal voltage for over >3,600 cycles (one minute). You will never see a 200% overvoltage for more than a few seconds in the field. Compare this performance against 5-10 cycles, which is the approximate number of cycles an MOV only product can withstand in the same situation.

Table B

Excessive MCOV Withstand

% Overvolatge	160%	170%	180%	190%	195%	200%
Line impedance of power system=0.1 ohms						
# of cycles	>3600	200	40	8	5	4
Line impedance of power system=0.3 ohms						
# of cycles	>3600	>3600	700	125	80	30
Line impedance of power system=0.7 ohms						
# of cycles	>3600	>3600	>3600	>3600	>3600	>3600

SSI Response to Argument #4

The discussion around "swell" conditions of a multi-cycle, sustained overvoltage was something all SPD manufacturers had to deal on a regular basis in the past. Up until about 20 years ago, voltage fluctuation and sustained overvoltage were the primary reason for warranty replacement for SPDs, if it was allowed under the warranty. Voltage control on the Utility Power Distribution System was more lax than it is today, and outside disturbances were more common. A standard clamping, voltage responsive SPD will "turn on" and begin to clamp the surge voltage when the voltage level passes a specific Maximum Continuous Operating Voltage MCOV) point. For a 120 Vrms Line to Neutral mode the MCOV used to be 130 Vrms. Around 20 years ago, the TVSS manufacturers and surge component manufacturers got together and decided that a change in the MCOV levels for TVSS could prevent almost all the voltage fluctuation failures they were experiencing. They also felt that improvements in TVSS design had lessened the impact the higher MCOV would have on the let-through voltage getting down-line to the protected equipment. When the standard MCOV levels were raised, the overvoltage and voltage fluctuation failures of TVSS devices dropped dramatically. Using the same 120 Vrms Line to Neutral as an example, the MCOV was raised from 130 Vrms to 150 Vrms. As utilities got better at controlling and regulating their voltage and protecting their lines on the grid, the number of remaining overvoltage and voltage fluctuation failures decreased to the point where today it is one of the least common reasons for SPD warranty replacement. **With the near elimination of the voltage fluctuation and sustained overvoltage problem in all but a few locations and facilities, the cost of the selenium technology is hard to justify. Keep in mind that, contrary to what the article states about MOV only product warranties, Surge Suppression LLC Advantage series have a 25-Year replacement warranty, and the SpecPRO series has a 15-year warranty for 7 mode and a 10-year warranty for 4 mode SPDs that covers any electrical anomaly, including lightning. That includes voltage fluctuation and sustained overvoltage.**

Conclusion

Remember earlier when we mentioned that size was a critical factor in the application of SPD? Consider the physical size of the Current Technology SL3, 300 kA/mode, 600 kA/phase, 7 mode SPD at 32 inches high by 22 inches wide by 11.95 inches deep, and weighs 88 lbs. The comparable Surge Suppression LLC unit, the SpecPRO, 300 kA/mode, 600 kA/phase, 7 mode SPD is 14 inches high by 12 inches wide by 6 inches deep and weighs 30 lbs. The Advantage series 300 kA/mode is 900 kA/phase, 10 mode and is exactly the same size and weight as the 7 mode SpecPRO model. The N.E.C. Article 285.12 requires the SPD to be installed with the leads for the phases, neutral and ground to be as short and straight as possible to provide the optimum protection for the down-line equipment. Given the scarcity of wall space in most electrical rooms, it is

16041 Flight Path Drive
Brooksville, FL 34604
Phone 888-987-8877
www.surgesuppression.com

almost impossible to find sufficient space directly adjacent to the switchgear for the Current Technology SL3 series SPDs. It is not uncommon to find them installed on an opposite wall with 20 or 30 feet of cable and conduit from the switchgear to the SPD. The Surge Suppression LLC SPDs are small enough, and light enough to be mounted on the side, or even inside, most switchgear without impeding personnel movement around the switchgear in the electrical room. The question you have to ask is: "Am I willing to accept a unit with a higher price tag, that costs more to install, will likely not fit in the available space next to the switchgear, that has a shorter warranty, and has higher let-through voltage down-line, providing less protection?

Bibliography

[B1] IEC 61643-12, Low-Voltage Surge-protective Devices—Part 12: Surge-protective Devices Connected to Low-Voltage Power Distribution Systems—Selection and Application Principles.

[B2] Key, T. S. and Martzloff, F. D., "A consensus on powering and grounding sensitive electronic equipment," IEEE/IAS Annual Conference, pp. 1-7, Sept. 1986.

[B3] Lewis, W. W. and Foust, C. M., "Lightning investigation on transmission lines," AIEE Transitions, vol. 64, pp. 107-115, 1945.

[B4] Transient Voltage Suppression. Harris Corp., Melbourne, FL, 1998.

[B5] Uman, M. A., "Natural and artificially-initiated lightning and lightning test standards," Proceedings of the IEEE, vol. 76, no. 12, pp. 1548-1564, 1988.

[B6] McCann, G. D., "The measurement of lightning currents in direct strokes," AIEE Transitions, vol. 63, pp. 1157-1164, 1944.

[B7] Thottappillili, R., "Electromagnetic pulse environment of cloud-to-ground lightning for EMC studies," IEEE Transactions on Electromagnetic Compatibility, vol. 44, no. 1, pp. 203-213, 2002.

[B8] IEEE PES T&D Committee, "Parameters of lightning strokes: A review," IEEE Transactions on Power Delivery, vol. 20, no. 1, pp. 346-358, 2005.

[B9] Tominaga, T., Kuwabara, N., Kato, J., Ramli, A., Halim, A., and Ahmad, H., "Characteristics of Lightning Surges Induced in Telecommunication Center in Tropical Area," IEEE Transactions on Electromagnetic Compatibility, vol. 45, no. 1, pp. 82-91, 2003.

[B10] Surge Protection: Measured Lightning Stroke Data, Schneider Electric Data Bulletin #1300DB1101, October 2011, http://static.schneider-electric.us/docs/Electrical%20Distribution/Surge%20Protective%20Devices/1300DB1101.pdf