EFFECTS OF WIRE LEAD LENGTH ON VOLTAGE PROTECTION RATING

SURGE PROTECTION NOTE 8
BY JEREMY LIELAND, INDUSTRIAL SOLUTIONS ENGINEER

INTRODUCTION

Proper installation of Surge Protective Devices (SPDs) is very important to maximize the performance of these devices. Device performance is normally defined by a set of ratings for the device determined by testing of a nationally recognized test laboratory. One such performance rating that is affected by installation is the Voltage Protection Rating (VPR). VPR gives the user an idea of what voltage levels their equipment will be exposed to in the event there is a surge on the electrical system. This technical paper will examine proper installation practices and the effects of excessive lead length on surge protective devices.

TERMS

- **SPD:** Surge Protective Device
- **VPR:** Voltage Protection Rating

VOLTAGE PROTECTION RATING

The UL 1449 standard 4th edition defines the requirements for testing to determine a device's Voltage Protection Rating. Each device is subjected to three "shots" of a 6kV and 3kA combination waveform (Figure 1). The resulting voltage that is allowed to pass the SPD in the circuit is recorded and an average of the three shots is calculated. This average value is then compared to values table 79.1 in the standard and assigned the appropriate minimum voltage protection rating. For example, if the average of three shots is 539V, the voltage protection rating is 600V. Voltage protection ratings are important as they define the protection level for a very high overvoltage event with its corresponding current. The VPR should be at a value that is something less than five times the rated voltage

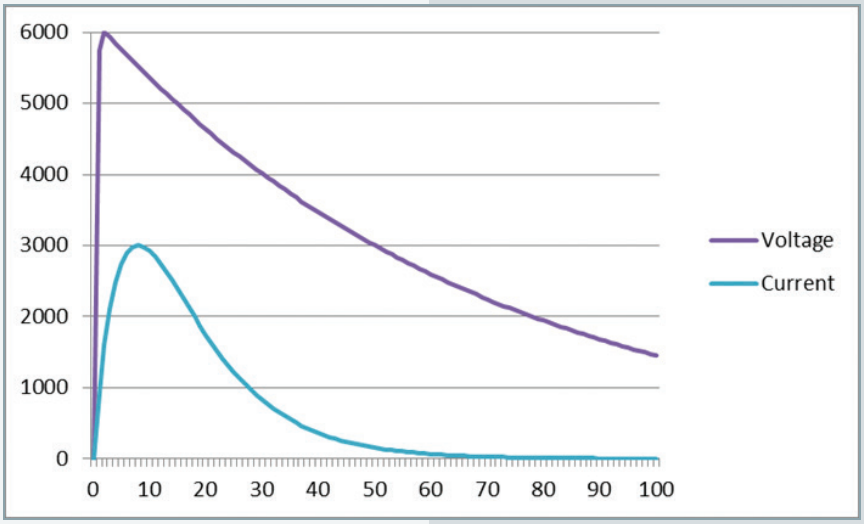

Figure 1: Combination Wave

in order to be effective at protecting downstream electronics from overvoltage. The main reason for a five times limitation is the Information Technology Industry Council's (ITIC) voltage tolerance curve which describes the tolerance region for electronic devices (Figure 2). This curve was originally created for 120V systems, but can be useful to predict power quality effects on industrial power system equipment as well. The beginning point on the curve is 500% voltage for 0.01 cycles. Considering that voltage surges are short time events, typically shorter in duration than 0.01 cycles, it can be inferred that events beyond 500% voltage will cause damage to equipment.

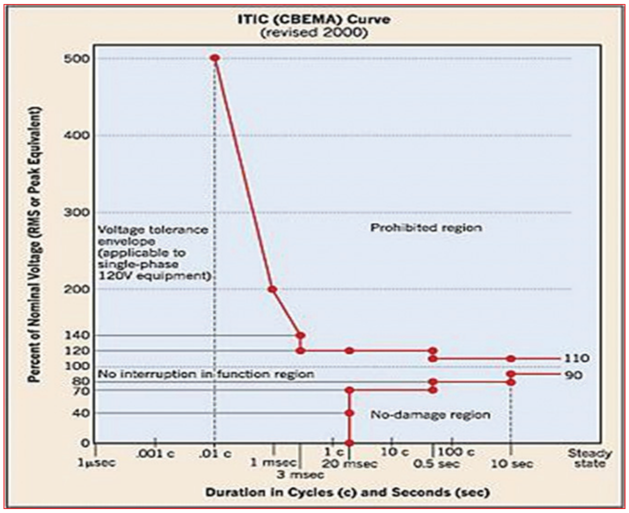

Figure 2: ITIC (CBEMA) curve

WIRE LENGTH EFFECT ON CLAMPING VOLTAGE

Since surges are fast transient events, the response of the circuit is different than that of the nominal AC voltage at 50 or 60Hz. The rapid change in voltage appears to the circuit as a high frequency signal and at higher frequencies AC circuits have more impedance. The equivalent frequency of the UL combination wave voltage is 208.3kHz. The main cause of this frequency response is the inductance of the circuit. Simply adding more wire to a circuit adds more inductance and thus higher impedance to the high frequency surge event. Longer lead lengths of SPDs will increase the clamping voltage and reduce their performance in protecting

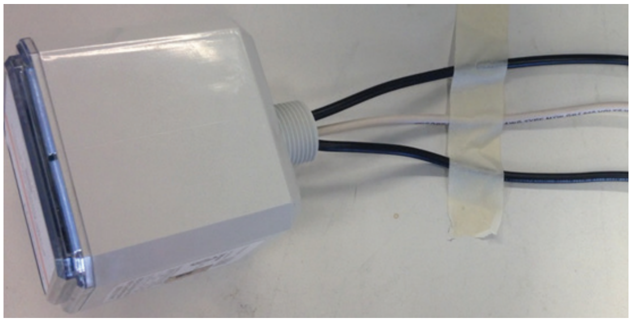

Figure 3: Wire Leads Separated by ~25mm

downstream loads. Standard UL VPR testing is performed with 6 inches of lead length. For most applications, this wire lead length is not practical for field installation. Testing was performed to determine wire lead length effects in three different installation conditions. The first test simulates poor installation in which the leads are separated by approximately 25mm (See Figure 1). Table 1 shows testing results of this test from two different samples with various lengths of wire lead.

Conductor Length	Sample 1 L-N Test Result VPR=600	Sample 1 L-L Test Result VPR=1000	Sample 2 L-N Test Result VPR=700	Sample 2 L-N Test Result VPR=1000
36"	1200	1800	1200	1500
33"	1000	1500	1200	1500
30"	1200	1500	1000	1500
27"	900	1500	1000	1200
24"	900	1500	900	1200
21"	900	1200	800	1200
18"	800	1200	800	1200
15"	800	1200	800	1000
12"	700	1000	700	1000
9"	700	1000	700	1000
6"	600	900	600	900
3"	600	900	600	900

Table 1: VPR for different lead lengths, straight wire, separated by ~25mm.

In examining the results, we can see that the devices performance rapidly deteriorates for cable lengths greater than 6". Sample 1 performs to UL spec only up to 6" for the L-N mode and 12" for the L-L mode. Sample 2 performs to UL spec up to 12" for L-N and up to 15" for the L-L mode. In addition, increased wire lengths beyond 36 inches will further increase the VPR of the SPD system.

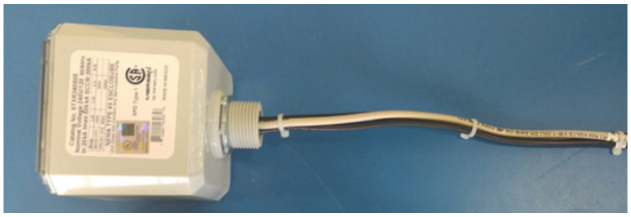

Figure 4: straight tie wrapped cable

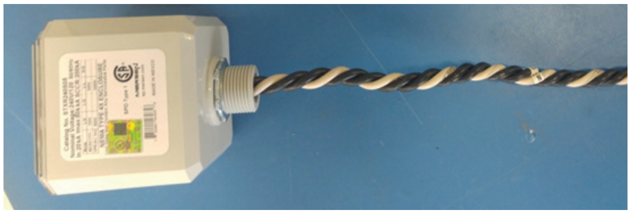

Figure 5: Twisted Cable

Conductor Length	Sample 1 L-N Test Result VPR=600	Sample 1 L-L Test Result VPR=1000	Sample 2 L-N Test Result VPR=700	Sample 2 L-N Test Result VPR=1000
36"	800	1200	800	1200
33"	700	1200	800	1200
30"	700	1200	800	1200
27"	700	1200	800	1200
24"	700	1000	800	1200
21"	700	1000	700	1000
18"	600	1000	700	1000
15"	600	1000	700	1000
12"	600	900	700	1000
9"	600	900	700	1000
6"	500	900	600	900
3"	500	900	600	900

Table 2: VPR for different lead lengths, straight wire, tie-wrapped

Conductor Length	Sample 1 L-N Test Result VPR=600	Sample 1 L-L Test Result VPR=1000	Sample 2 L-N Test Result VPR=700	Sample 2 L-N Test Result VPR=1000
36"	700	1000	800	1200
33"	700	1000	800	1200
30"	700	1000	800	1200
27"	700	1000	800	1200
24"	600	1000	800	1200
21"	600	1000	700	1000
18"	600	900	700	1000
15"	600	900	700	1000
12"	600	900	700	1000
9"	500	900	700	1000
6"	500	900	600	900
3"	500	900	600	900

Table 3: Twisted wire VPR results

For the second test, the leads were tie-wrapped together (Figure 4). Tie-wrapping the conductors allow some cancellation of the electric field to occur which will reduce the circuit inductance. The results of the second test are given in table 2.

In examining these results, we can see that for Sample 1, the device performs at or better than the rated VPR up to 18" for the L-N mode and up to 24" in the L-L mode. SPD installations with leads greater than these lengths would not be as effective at protecting equipment downstream. In contrast, shorter wire leads reduce the effective VPR, which provides better protection. As indicated in green at the table above, the lengths indicated would perform better than the UL test.

BENDS IN WIRING

The examples in tables 1 and 2 show results for straight wire. When wires are run with sharp bends, the inductance will increase and thus increase the VPR. Sharp bends imitate a wire loop, which is more inductive than a straight run. Should bends be required, they should not exceed recommended bend radii to keep added inductance to a minimum.

REDUCING INDUCTANCE IN WIRE LEADS

Inductance in wire leads can be reduced by adding a tight twist to the leads (Figure 5). This twist will allow magnetic fields created by the current flow to cancel and reduce the effective inductance. Table 3 shows the third set of tests performed with twisted cable.

With the wire leads twisted, the standard VPR rating is held up to 24 inches in the L-N mode and all the way to 36 inches in the L-L mode for sample 1. For sample 2, the standard VPR rating is held up to 21" for both modes. This allows for longer cable runs with little ill effects to the VPR rating of equipment. Note that each device performs one class better than the UL rating for normal 6 inch cable runs. Again, this is true for straight wire only. Bends in the cable would reduce some of the positive gains.

TWISTED WIRE VERSUS LOW IMPEDANCE CABLE.

Some SPD manufacturers offer low impedance cable to allow devices to be installed at distances further away from the protected circuits. These specialized cables help reduce the change in VPR versus straight run cable. Testing was performed to compare the performance of standard twisted wire versus published data for one manufacturer's low impedance cable. The graph below in Figure 6 shows the change in voltage by distance for standard straight cable, low impedance cable and twisted wire. From the graph, it can be seen there is little difference between twisted cable and low impedance cable up to 5 feet in length. At 20 feet, the difference between the two is just under 400 volts. Clearly, the change in voltage for both low impedance cable and twisted wire are much less than standard straight cable at longer distances. However, the amount of change at distances greater than 4 feet can be enough to adversely affect the protection of the equipment and allow over-voltages greater than 5x the system voltage. For example, consider that low impedance cable at 10 feet adds 500V to the protection rating. If the system is 208/120Y or 240/120 split phase, then the desired limitation is 120 * 5 * sqrt(2) = 850V. This means that the VPR of the device in the L-N mode cannot exceed 350V to get effective protection. Most 120V SPDs on the market today have VPR of around 600-700V. This means that regardless of the type of cable, lengths for that voltage level should not exceed 4 feet. At 480/277Y, the limitation will need to be around 1950V. Given that most devices have a VPR of 1200V, the additional cable needs to add less than 750V. For that case, about 10.5 feet of twisted wire would be the maximum run. Low impedance cable could be considered for longer runs.

Note that these added cable impedances are only from the SPD lead wires themselves. Care should be taken in approaching the maximum lead length as there are some other factors that can affect the results. One of these is the impedance of cable and bus from the service. This will increase the limiting voltage. Another factor is that the tests noted in this paper only consider the UL combination waveform at 6kV/3kA and an effective frequency of 208.3kHz. Other types of fast transients in networks have been observed with rise times of less than 10ns and ringing waves with effective frequency of up to 1 megahertz. The higher the frequency, the more impedance to the impulse. Practical limits less than the maximum cable run should be used to allow for those considerations.

A couple of other things should be considered before using low impedance cable. These are the cost of the cable, and skill of the installer. Since low impedance cable is a specialized cable, it bears a higher cost. Also, low impedance cable typically is more difficult to install than standard wire that is twisted.

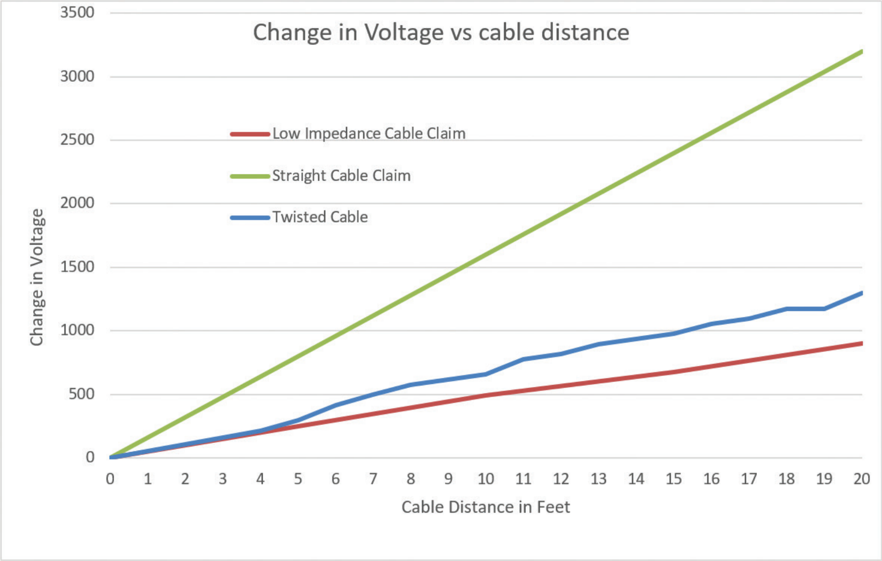

Figure 6: Change in Voltage vs Distance

BUS MOUNTED SURGE PROTECTIVE DEVICES

One alternative to twisted wire or low impedance cable is an internally mounted or bus mounted SPD. These devices are typically installed by the panelboard manufacturer and are connected directly to the panelboard bus. Internal SPDs have the advantage of adding very little to no additional impedance to the circuit. One disadvantage of these types of units is that selection is limited to what the panelboard manufacturer offers. If the user desires a more robust device, many times that is not an option. Serviceability is also more challenging for internally connected devices as the entire panelboard must be de-energized to replace any components.

SPD LOCATION IN THE CIRCUIT

As hinted at above, the location of the SPD in the circuit can affect the performance of the device. The normal power distribution wiring can have a similar impedance and increased voltage effect as additional lead length of the SPD.
For equipment which is entirely indoors, SPDs should be placed as close to the service entrance as possible. Cascaded protection can be used to reduce surges caused by internal surges. See Figure 7 below. Refer to Mersen Tech Topic TT-SPN7 for information on cascaded protection.

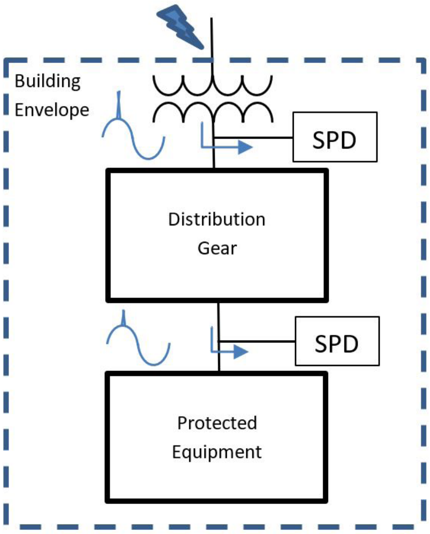

Figure 7: Equipment inside building envelope

For equipment located outside the building envelope such as exterior lighting, rooftop HVAC units, etc. surge voltages can be induced in the equipment power lines outside the building. That equipment can see higher voltages than if it was inside the building. In these cases, the best practice would be to place SPD on-board the equipment or as close as possible to ensure the power line from the SPD to protected equipment does not add too much impedance to render the SPD less effective. If possible, SPD at both the branch panel feeding the external circuits and the equipment should be used for the most effective protection. See Figure 8 below for an example.

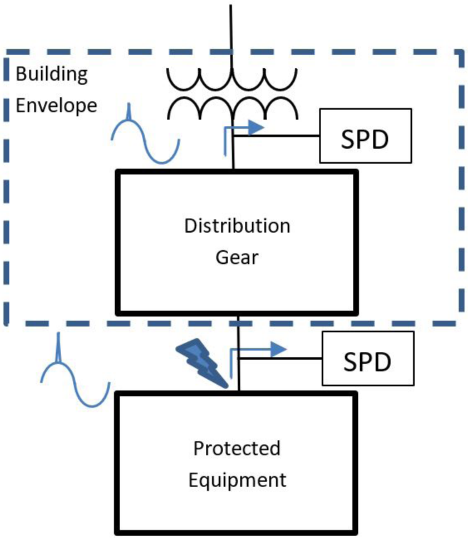

Figure 8: Equipment outside building

RECOMMENDATIONS

All SPDs should be installed as close to the service entrance or protected equipment as possible. Cable and conduit runs should be as straight as possible to avoid adding inductive impedance to the circuit. If bends are required, they should not exceed normal bend radii and should not be looped. At a minimum, the leads should be tie-wrapped together to allow the device to perform at its UL certified protection rating. Where runs exceed 6”, the cable should be twisted to negate the effects of cable inductance on performance. Table 4 below shows absolute maximum runs for each cable type, not considering additional voltage drop from power lines, bus or higher frequency surges. In general, leads of cable over 6 feet in length are not recommended even with twisted wire or low impedance cable.

	Straight, tie wrapped	Twisted Wire	Low-Impedance Cable*
240/120V Split Phase	36"	48"	48"
208/120 Wye	36"	48"	48"
240V Delta	36"	48"	48"
480/277 Wye	60"	126"	192"
480V Delta or HRG	36"	60"	108"

**Consult manufacturer documentation for exact data*
Table 4: Maximum Lead Length by voltage

REFERENCES

- Mersen TT-SPN7 – SPD Performance and Cascaded Protection
- UL 1449 – Standard for Safety Surge Protective Devices
- IEEE C62.41 – IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits
- IEEE C62.41.2 – IEEE Recommended Practice on Characterization of Surges in Low-Voltage AC Power Circuits

SURGE PROTECTION PRODUCTS FROM MERSEN

TPMOV®

Mersen's patented TPMOV (Thermally Protected Metal Oxide Varistor) eliminates common destructive failure modes associated with standard MOVs. Comprised of a voltage clamping device and a disconnecting apparatus that monitors the status of the metal oxide disk inside the TPMOV, the device is securely disconnected in the event of an overvoltage by an arc shield. Upon failure, the TPMOV is also equipped with a visual pin indicator as well as a normally open microswitch providing remote indication, if applicable.

Surge-Trap® NEMA Type 1 SPDs

Mersen's Surge-Trap NEMA Type 1 SPD line includes six surge protection products designed and manufactured by Mersen with the latest materials, layouts, and components, including the industry-leading TPMOV Technology. All are NEMA devices for ANSI/UL 1449 Type 1 and 2 applications, indoor and outdoor use, and provide UL96A lightning protection plus a variety of other features and benefits to meet clients' needs. To aid partners offering Mersen products, the company designed an intuitive cataloging system and partner portal that makes it easy to compare features and quickly find the right product for customers. For more information regarding Mersen's surge protection products, visit: ep-us.mersen.com.

Surge-Trap®
NEMA Type 1 SPDs

TPMOV

CONTACT

USA
374 Merrimac Street, Newburyport, MA 01950
T 978 462 6662 | F 978 462 0181
info.nby@mersen.com

CANADA
6200 Kestrel Road, Mississauga, ON L5T 1Z1
T 905 795 0077 | F 905 795 2508
technicalservices.mis@mersen.com

ADDITIONAL RESOURCES

Surge Protection Note 1: Introduction to Specifying Surge Protection

Surge Protection Note 2: Surge-Trap® and the Different kA Ratings

These and other Tech Topics are available on ep.mersen.com.

MERSEN
Expertise, our source of energy