

How to Select the Best Value Transient Voltage Surge Suppressor for Your Equipment

Abstract

A wide selection of Surge Protection Devices (SPDs) are now promoted by an even greater number of manufacturers for the protection of electrical and electronic systems from the damaging effects of electrical transients and lightning. Compounding the difficulties of selection, some manufacturers use different technologies and many manufacturers specify their SPD performance differently. Some manufacturers are known to only provide the data that will support the benefits of their product, not the weaknesses.

How does the customer without the benefit of costly test houses or years of industry experience, compare performance and value for money of these competing products and technologies?

1. STEP ONE - CONSIDER YOUR SITE

What is the risk of transients and lightning?

Site location and exposure determines the risk of transients and lightning. Typically, the probability of a structure receiving a lightning power transient in any one year can increase up to ten times or more for structures on prominent hilltops compared to metro areas. (See NFPA780 Risk Assessment.)

For sites in built-up areas the amplitude of the lightning surge current is reduced, as many parallel paths to other users exist, reducing the amplitude to each user. However, surge protection is still as critical since these sites experience the risk of transients generated from nearby electrical equipment.

The probability of lightning can be calculated using the ground flash density information (number of ground flashes/mile²/year) or Thunderday maps (Isokeraunic maps) from the meteorological bureaus or similar sources. This data can be used as a basis to predict the possible direct and induced coupling onto powerlines, allowing a surge rating required for protection to be estimated. However, Table 1 has been found to be a more simple and reliable guide to installing adequate protection.

What type of equipment is to be protected?

Electronic and electrical equipment experience different levels of susceptibility to transients. Equipment such as motors, lighting, heating and air conditioning generally are robust and do not require premium levels of protection, nor are they generally critical to the facility's core function. This type of 120V equipment can withstand impulses in the region of 300 to 600Vpk L-N (600 to 1000V for 240V equipment).

Battery chargers, rectifiers, UPSs, electronic and other electrical equipment are more sensitive to both the peak voltage they are subjected to, and the rate of that voltage rise. These pieces of equipment require a premium level of protection. Additionally, generation of revenue or provision of the core facility services is typically dependent upon the continuing operation of this type of equipment. Some rectifier manufacturers recommend a peak withstand (L-N) of 400Vpk for 120V units and 800V for 240V equipment.

What power protection concept should be followed?

Power protection at the point-of-entry to the facility should be selected to provide the first level of defense for all the site equipment. If the site has a mixture of equipment with different susceptibilities, one method is to select an SPD for the point-of-entry which provides sufficient protection for the most susceptible equipment. A more cost effective solution may be to provide "coarse" (primary) protection at the point-of-entry suitable to protect all the robust equipment, and then install "fine" (secondary) protection on the branch-circuit(s) which feed to the more susceptible equipment.

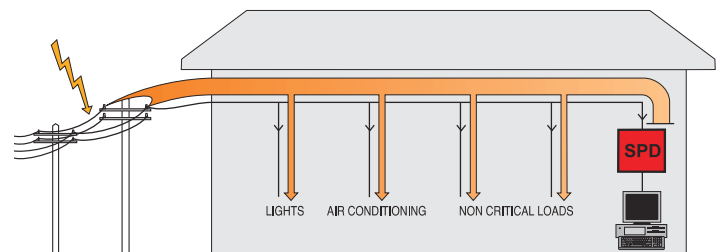


Figure 1. Poor protection layout

	Domestic	Business	Telecom	Defence/Critical
USA Region	<US\$10,000	<US\$30,000	<US\$60,000	>US\$100k
West Coast	20-40kA	40kA-60kA	100kA	100kA
East	20kA	20-40kA	65-100kA	100kA
Florida	40kA	40-65kA	100kA	100kA

Table 1. Guide to service entrance 8/20μs surge ratings

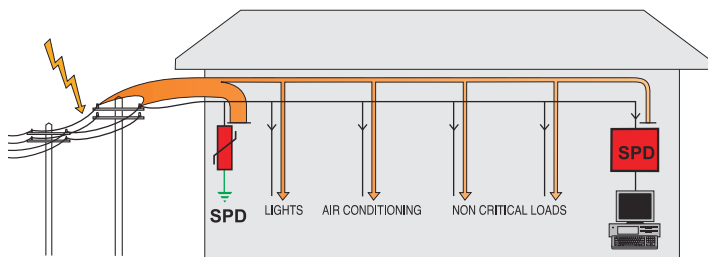


Figure 2. Preferred protection layout

Although protection is best installed as close as possible to the device(s) to be protected, it is also desirable to have protection at the service entrance to the facility to stop the bulk of the damaging energy being conducted within the building wiring and radiating into nearby data and communication circuits.

It is not always appropriate to rely solely on point-of-entry protection, especially if the equipment to be protected is some distance from the SPD (generally more than 30 feet). Due to the capacitance and inductance in the cabling, a voltage doubling effect can occur, where the let-through voltage downstream of the SPD can be twice of that at the SPD. For such sites, secondary protection should be installed at, or near, the equipment to give additional protection.

What are the important specifications set by site layout and location?

To select applicable products, the following should be known:

- The power distribution type being used (refer to Figure 3) including the grounding method of the supply transformer and any additional grounding supplied in the distribution system.
- The nominal voltages (L-N & L-L) and frequency
- If the site has a poor voltage regulation, the maximum expected over-voltage should also be known
- The maximum load currents at the point that the SPD is to be installed
- Maximum space available, together with environmental conditions expected (maximum temperature, humidity, NEMA rating required, etc.)

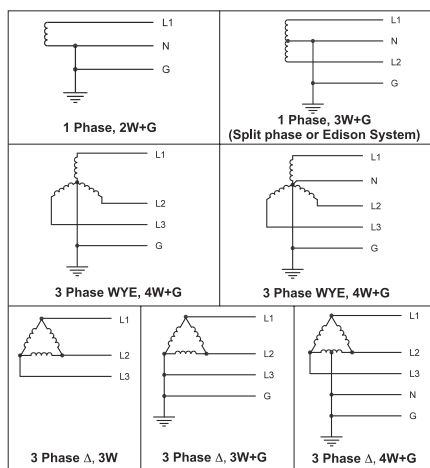


Figure 3. Common Distribution Configurations

What are the economic considerations?

The cost of lightning damage to a site is not only the cost of repairing / replacing equipment, but also the cost of:

- Operational downtime
- Opportunities foregone (lost revenue/profits)
- The risk to personnel

The use, cost and value of data, or provision of core services needs to be compared to the investment in the SPDs. It is possible that sites may not have costly capital equipment, but due to the high cost of potential lost business opportunities, they may still require high performance protection. For example, the cost of a temperature control system used in the poultry industry is reasonably low, but the cost of failure of this system is extremely expensive as a small temperature error can cause the deaths of thousands of hatchlings.

Generally, the investment in the purchase cost of the SPDs should be approximately 10% of the equipment cost, but this should be modified with the above consideration on the possible downtime and loss of opportunities forgone.

2. STEP TWO - THE SUPPLIER

The selection of the supplier can be just as critical as that of the protection.

What experience do they have?

Industry experience is critical to enable the supplier to provide professional advice and service. Qualified engineers should be on call to resolve specific issues and undertake site surveys. Typically, better technical service will be provided by those suppliers backed by comprehensive manufacturing and research and development teams.

What quality systems are in place?

Suppliers should be able to show a documented and independently audited quality assurance plan.

Do they manufacture and design their own product?

Suppliers that design and manufacture their own products are more likely to be able to offer ongoing support and prompt service, rather than those who have contracted out the design to independent engineers, or bought the rights to manufacture the technology from a third party.

What is the history of the product offered?

Can the supplier provide reference sites as to the number of clients successfully using similar equipment in similar circumstances? Equipment, although “proven” on the west coast, may not be adequate in the lightning prone regions of Florida, given the higher occurrence and intensity of the lightning.

3. STEP THREE - THE SPD

Many different types of SPDs and technology are available on the market. To enable the selection of effective protection at the best value for the money, one needs to make a selection based on the most important technical performance specifications. **Of the following parameters for selection, the first three are the most critical:**

1. Maximum Continuous Operating Voltage (MCOV)
2. Clamping voltage
3. Surge rating & protection modes
4. Indication & life
5. Physical & environmental issues
6. Standards compliance

Parameters which are not important, and can be very misleading are:

7. Speed of response
8. Energy (Joule) rating
9. Technology

NEMA Low Voltage Surge Protection Devices Standard LS1 addresses a uniform method for SPD manufacturers to specify their devices. It is recommended to request compliance with this method of specification.

3.1 Maximum Continuous Operating Voltage (MCOV)

This relates to the maximum steady state voltage the SPD can withstand without becoming a fire or safety hazard. It is a very important safety issue. Traditionally, SPDs could not differentiate between slower over-voltages and the faster transient voltages. An MCOV of 20% above the normal voltage was selected to allow for normal utility regulation limits. To make this tolerance much higher would have increased the let-through voltage (under transient impulses) to a point where the equipment may not have been sufficiently protected. There are, however, many known cases where the nominal voltage has exceeded this 20%, causing the SPD to clamp on each half cycle and build up sufficient heat to become a hazard. Over-voltages can be caused by poor power regulation, wiring faults such as disconnected neutrals in unbalanced three phase WYE systems, or by mis-installation of SPDs.

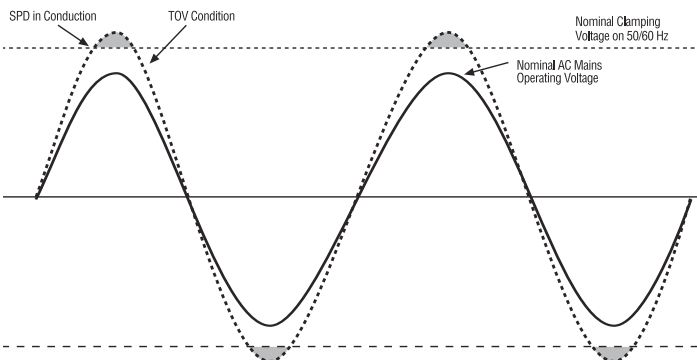


Figure 4. Over-voltage and SPD conduction

In 1998, Underwriters Laboratory issued Edition 2 of UL 1449 to address this growing problem. Now, UL 1449 first specifies that when an over-voltage of 110% of nominal voltage is applied, the device must remain functional and safe. Second, when an Abnormal Over-voltage of 125% is applied, the device is allowed to permanently stop functioning, but must not become unsafe. Finally, when the full phase voltage according to Table 2 is applied, the device is allowed to permanently stop functioning, but must not become a fire or safety hazard.

Device Rating	Phase	Test Voltage (MCOV)
110-120V	Single	240V
110-120/220-240V	Split	240V
120/208V	3-WYE	208V
220-240V	Single	415V
220-20/380-415	3-WYE	415V
240V	High leg delta	240V
254-277V	Single	480V
254-277/440-480V	3-WYE	480V
480V	High leg delta	480V
347V	Single	600V
347/600V	3-WYE	600V

Table 2. UL 1449 Full Phase Test Voltages

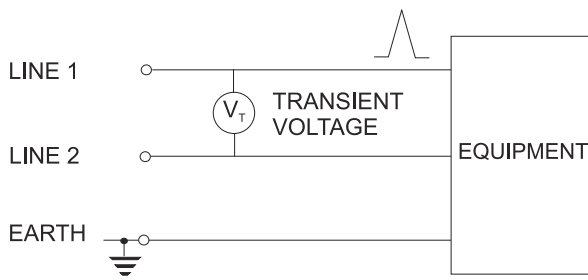
Although this full phase voltage test is an extreme over-voltage, it is recommended that only UL 1449 Edition 2 Recognized products are selected, as wiring faults and accidents can occur. For sites where poor regulation is a possibility, it is recommended that a technology be selected that is not only UL 1499 Edition 2 Recognized, but does not permanently disconnect during the full phase voltage test. This is to avoid the cost and trouble of having to replace the SPD every time the site voltage exceeds 25% of nominal. This can be an almost nightly occurrence in some remote, poorly regulated sites in developing countries.

3.2 Clamping voltage

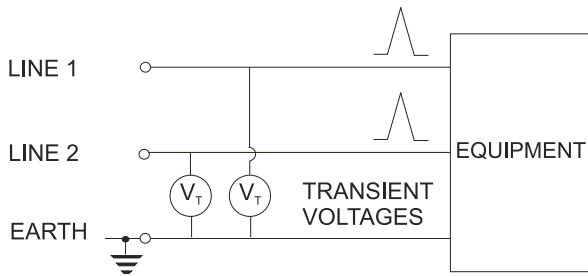
The role of the SPD is to clamp the transient to a safe level so that it will not affect the equipment. No SPD device is able to totally remove all impulses, and some small amount of transient will still reach the equipment. This is acceptable, provided that the 'let-through voltage' is within the range that the 'protected' equipment can withstand.

Equipment voltage withstand and protection mode

For 120Vrms equipment a differential withstand of 300-600V (L-N) for electronic equipment and 1000V for electrical equipment is typical. However, the common mode (L-E & N-E) withstand for both these types of equipment is normally 4000-5000V. Thus when selecting an SPD system, consider independently the common mode and differential mode performance.



DIFFERENTIAL MODE TRANSIENT
Equipment withstand 300-600V



COMMON MODE TRANSIENT
Equipment withstand 4000-5000V

Figure 5. Typical Equipment Withstand

Clamping voltages are specified for a given impulse magnitude and waveshape. Commonly 500A 8/20 μ s (UL 1449 SVR rating), ANSI/IEEE B3 3kA 8/20 μ s and C3 10kA 8/20 μ s results are given. As the current magnitude increases, so does the clamping voltage. For a well constructed 150V MOV-based device which has a clamping voltage of 400V at 3kA 8/20 μ s, this may increase to 600V at 20kA 8/20 μ s. NEMA LS1 specifies testing to be conducted with the nominal line voltage present as this also effects let-through voltage measurement. In the absence of NEMA LS1 compliance, it should be questioned what waveshape, impulse current and (if nominal) mains voltage was applied for the provided results.

The rise in voltage at higher impulse currents is one of the reasons for the use of secondary protection devices. The primary service entrance SPD takes the bulk of the transient energy, and the secondary protection at the equipment further lowers this to below the equipment's threshold.

Effect of installation

It also needs to be considered that the method used to install the SPD will affect the let-through to the equipment. An SPD with a low let-through voltage will be ineffective in protecting the equipment if it is installed with long interconnection leads. Where possible, devices that can be connected as per the "Kelvin" connection method should be utilized.

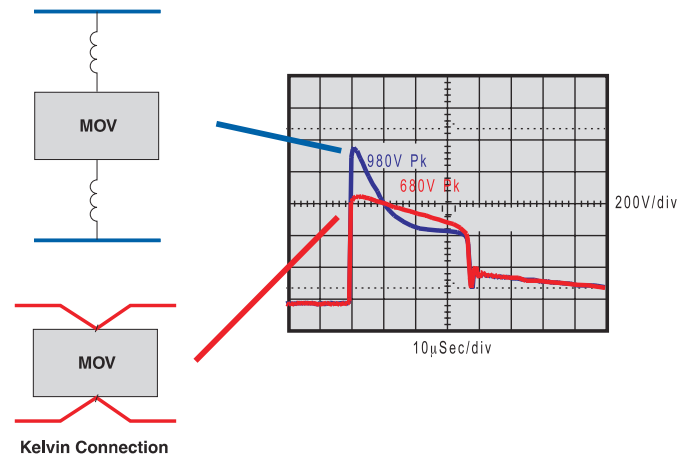


Figure 6. Connection methods

3.3 Surge Rating & Protection Modes

Method of rating modes

Some products on the market have extremely high surge ratings, such as 300kA 8/20 μ s or above. The value of this is questionable, as statistically only 1% of direct strike lightning exceeds 130kA 8/20 μ s. Most transients on power lines are induced, not galvanically (direct) connected. Thus it is extremely unlikely that 130kA 8/20 μ s would hit the line, and 100% of the energy go one direction to a single SPD. One valid reason for higher surge ratings is to provide a longer service life, but a single shot surge rating of over 100kA 8/20 μ s would not likely ever be called upon, and would give sufficient length of life.

For most distribution systems, protection is required across multiple modes, as shown in Figure 7. For built up products that have more than one protection mode, manufacturers around the world use different methods for detailing the surge rating of their products.

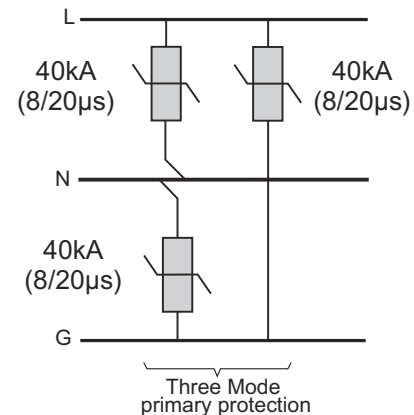


Figure 7. Three Mode SPD

For example, the above product could be claimed as either:

- An 80kA per line SPD (connected to each line is two 40kA devices)
- A 3 mode 40kA (per mode) SPD
- A 120kA SPD (the total of all the supplied surge material)

As can be seen, for exactly the same surge material three claimed ratings are possible. It is critical when comparing surge ratings for devices with multiple modes that it be fully understood how each manufacturer has arrived at their claimed ratings to allow true comparison. Some manufacturer's documentation is not clear on the method used.

Modes of protection. What is actually required?

It is common for many suppliers to offer L-N, L-G, N-G and L-L protection. The argument is, that if you do not know where the transient will occur, having all modes protected will ensure damage does not occur. However, some modes are more likely to be stressed by over-voltages, and equipment is much more sensitive to transients in some modes than others. A more reliable, less complex SPD can be made by sensibly protecting the required modes, not just all modes. In fact L-G modes can make the SPD more susceptible to over-voltage failure. L-N and N-G mode protection is an acceptable minimum, while L-L is generally not required for other than Delta connected supplies.

Impulse waveshape?

For SPDs, the 8/20 μ s is the most commonly used waveshape and is supported by organizations such as ANSI and IEEE. A 10/1000 μ s impulse is also used but predominately by manufacturers of silicon based devices. Altering the waveshape affects the energy applied and the SPD's performance. It is recommended that these suppliers be requested to provide results with the standard ANSI/IEEE C62.41-1991 A3, B3 & C3 defined impulses.

Multipulse ability

Seventy-five percent of all lightning strikes exhibit what are known as restrikes. A few hundreds of milliseconds after the first discharge, a second and subsequent discharges occur down the same channel. Four restrikes is the average, with up to 12 being recorded. Although the restrikes are of a lower amplitude, the SPD has not had time to cool from the previous impulse and can rapidly overheat. It is recommended to select a product which has been designed to withstand the thermal capacity of multipulse lightning.

Tested versus calculated ratings

NEMA LS1 specifies maximum surge rating to be determined from actual testing, where the SPD does not exhibit more than a 10% change in clamping voltage. Not all manufacturers have the test equipment to test at higher surge levels and thus have been extrapolating their results from smaller surge level tests. For example, if a 100kA product is offered, but the manufacturer can only test up to 20kA, each one-fifth of the protection circuit may be connected in turn and tested to 20kA. The reasoning is that the full device should then be able to withstand 100kA. However, the common parts of the circuit which carry the full 100kA such as main fuses, terminals and internal PCB connections, etc., have not been tested to withstand the full 100kA. It is not an uncommon occurrence to be unable to duplicate the claimed surge rating performance ratings of

some manufacturers. UL is often used as an independent proof of clamping voltage, but UL does not test whether a product meets its claimed maximum rating.

3.4 Indication & life

At some stage the SPD will reach the end of its service life. This will occur whether the SPD be MOV-silicon-spark gap-based or some other technology. It is preferable that status indication be given prior to a complete SPD failure, as it is desirable that the equipment not be left without protection. Many SPDs on the market only indicate when the entire protection capacity has been removed from service and the equipment is entirely unprotected. Audible alarms are also available.

Remote Alarms

For unmanned sites, it is preferable that the SPD provide a set of alarm contacts that can be monitored remotely to detect a reduction in SPD capacity.

Type of Alarm Circuit

To limit the fault current on high capacity supplies (typically above 100A), it is common to feed the SPDs, not directly from the main bus, but through a set of fault limiting fuses. These fuses have a secondary benefit that the power to the SPD can be removed if the SPDs require maintenance, without having to disconnect power to the entire site. One problem exists however, that some SPDs use a mechanical indicator and alarm contact system. These are unable to detect if protection to the equipment has been removed due to either a series fuse accidentally being removed, or a series fuse operating. Well-designed electronic indicator systems are more reliable as they will also set off an 'alarm' should the SPD be removed from the circuit as above.

3.5 Physical & environmental issues

To ensure that the SPD is suitable for the intended location, the following issues should be checked:

- Will it fit the available space?
- What wiring and additional materials are required to install the unit and how will this affect its performance?
- Does the unit have the correct water and dust proofing (NEMA rating) for the intended location?
- How easy will it be to maintain and service?

3.6 Standards Compliance

Across the globe there are many local, national and international standards. It is beneficial if the SPD device is as compliant with as many standards as possible. However, many standards are virtually duplications of others, or only test one performance factor.

It is recommended that as a minimum, the SPD be compliant with and certified by UL 1449 Edition 2. As described in Section 3.1, preference should be given to those devices that not only comply with UL 1449, but also remain fully functional after this testing.

The SPD should be specified in accordance with NEMA LS1, to ensure a true comparison of performance to be made with other products.

The SPD should comply with any mandatory local standards requirements and additionally ANSI/IEEE C62.45 Life Cycle Testing requirements, to ensure adequate length of life.

3.7 Speed of response

Speed of response is often quoted and emphasized as a performance measure. However, this is a misleading specification that should be ignored in preference to the clamping voltage result. Total unit performance under real world conditions is important, not solely the component’s speed.

Response times for shunt diverters less than 1 or 5ns are not uncommon. Generally, silicon product speeds are quoted at 1-5ns, MOVs are generally quoted at 5-25ns and Spark gaps at 100ns.

Consider that the speed of light is 3 x 10⁸ m/s, and in a conductor electrons will travel at 50-80% of this speed. At this speed 0.15 to 0.24 mm will be travelled in 1 picosecond. Thus a response time of 1ns is the time taken for electrons to flow just 6 to 10 inches.

Theoretically, speed of response will make a slight difference (10ns equating to about 43-48V) if all other specifications such as technology, layout and construction details are exactly identical. However this is never the case, and as shown by the below example, other effects are much more dominant.

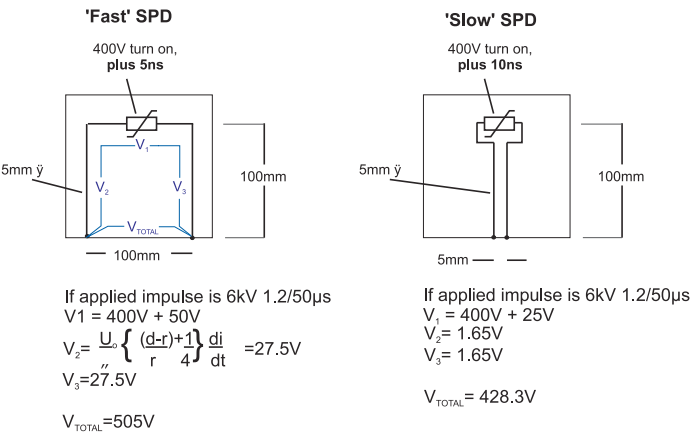


Figure 8. Speed of response is less important than let-through voltages

Figure 8 is a simplified example as it assumes that the devices start to turn on at 400V, and will be fully on by the end of the speed of response time. It only includes the effects of inductance, not resistance, etc. However, it clearly shows that speed of response is included in the let-through

voltage but is a secondary effect with regard to internal construction. It is also a second order effect in comparison to choice of technology.

It is predominantly the silicon manufacturers who promote fast response times, thereby inferring that their products are better at protecting against fast pulses. The formula in figure 8 shows as the speed of the pulse increases (i.e. dt becomes smaller) the clamping voltage across the internal leads will increase proportionally. **The effect of the leads is generally larger than the component itself.**

The British Standard BS6651 : 1992 supports this with statements such as “...let-through voltage takes into account the response time of the device, i.e. a slow response time will result in a higher voltage....the response time of a parallel connected protector will often be overshadowed by the inductive voltage drops on the connecting leads”.

3.8 Energy (Joule) rating

Another misleading specification is to attempt to compare device energy ratings. Some manufacturers will specify their product’s energy capability in Joules and perhaps as energy diverted and/or absorbed. Unless detailed information is given, it is difficult to compare just the Joule rating. The bigger number is not always better! It is better to focus on the surge rating in kA and the resultant let-through voltage.

Power = voltage x current ($P_{[watts]} = VI$)

Energy = voltage x current x time ($E_{[Joules]} = VIt$)

Thus if two devices are offered that have the same Joule rating, are they equal in performance ? The answer is yes only if the same pulse waveshape (time) **and** currents are used. If two devices have the same Joule rating, it is possible for the higher or the lower Joule rated device to be the better surge protector depending upon voltage, current and time used. More information is required to truly compare.

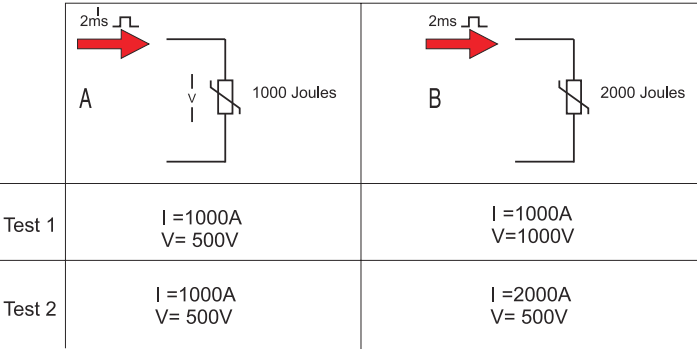


Figure 9. Confusion with Joule ratings

Given the simplified example in Figure 9, it would be expected that device “B”, would be twice as good as device “A”:

- However, should further data be given as per Test 1, this would show SPD “A” to be the better device, even though it has half the Joule rating. This is because in this test both devices were tested with the same 1000A 2ms pulse, and device “A” managed to clamp this to half the let-through of device “B”. As “A” has clamped at a (better) lower voltage, its energy dissipation rating is actually less.
- Alternatively should data be given as per Test 2, in this test the current has been altered so both devices have the same let-through voltage result. This shows “B” to be the better device as it takes twice the surge current to produce the same let-through voltage as “A”.

3.9 Technology

The type of technology used is also a misleading parameter for simple evaluation. The main reason for SPD providers attempting to get customers to specify a particular technology is to enforce a ‘non compliant’ bid by competitors who have chosen to use alternative technologies (even though under “black box” tests they may perform better). Most international standards treat the SPD device as a “black box”. By this, the standard does not care what type of technology is used within the SPD; its performance and suitability is only defined by the SPD’s ability to remain safe and to protect the downstream equipment in a given number of defined input conditions.




Device	High Energy High Current	Low let-through Voltage	No follow-on current (non crowbar)
 Silicon Devices	XX	✓✓	✓
 MOVs	✓	✓	✓
 Traditional Spark Gaps	✓✓	X	XX

Figure 10. Comparison of three common technologies

Figure 10 gives a general comparison between three different technologies while Table 3 bases this comparison on assuming the same volume (size) of protection is provided.

This is a crude approximation, and as such gives the values as a set of multiplying factors. For example, silicon devices will typically have 20% better clamping than MOVs, but five times the price, and one eighth of the surge rating.

Technology	Surge Rating (8/20µs)	Price	Let-through voltage @3kA 8/20µs
Silicon	1	5	1
MOV	8	1	1.2
Spark Gap	50	3	6

Table 3. Comparative performance for same volume of protection

Silicon Devices

The Silicon Avalanche Diode (SAD) devices include such devices as TransZorbs, Zeners, etc. They are typically characterized by a low clamping voltage, low surge rating, high speed, long life and large cost.

- Specifically ask for NEMA LS1 (tested) maximum 8/20µs surge rating of each individual protection stage and each individual mode. Do not accept just a 10/1000µs or Joule rating
- Obtain the cost of replacement of each protection mode

MOVs

MOVs are generally well accepted in the industry as the low cost, best performer. If not sufficiently rated, one of the main disadvantages of the MOV can be the length of life.

- Ask for the NEMA LS1 (tested) maximum 8/20µs surge rating of each individual mode
- Specify life cycle testing compliance to ANSI/IEEE C62.45 (1000 impulses)

Spark Gaps

Spark gaps are ventilated air gaps, not gas arresters which contain a low pressure inert gas to lower the firing voltage.

- Pay close attention to let-through voltage specifications, as most devices will be in the order of 3000-4000V.
- Specifically ask for details on follow-on currents, at the expected short circuit current rating of the supply.
- Spark gaps may also have difficulty complying with the UL 1449 requirements, unless they are supplied in a suitable enclosure.