DEHN, INC.

The ABC's of Lightning

TO BE SURE, USE DEHN®

Lightning represents a stunning combination of nature's beauty and awesome power

Lightning currents conducted in modern electrical circuits can cause immediate and catastrophic equipment failure. Surges from induced lightning and power switching operations are smaller but are more numerous and can result in equipment misoperation, lockup or damage.

DEHN®'s mission is "to protect life and property from the hazards of lightning and surges." Lightning cannot be prevented, but proper use of DEHN®'s Lightning and Surge protection can safely divert lightning currents away from ourselves, our homes and our businesses.

DEHN® has been providing Surge and Lightning Protection around the world for over 90 years. Currently employing a staff of over 1000 highly qualified personnel throughout the world, DEHN® is active in over 50 countries.

DEHN® invests heavily in research and development, and is active in contributing and exchanging information with others at international technical conferences.

The ABC's of Lightning and Surges

A surge is a very short burst of voltage, which if not suppressed, can cause equipment failure or lockup. The duration of a surge is less than 1/1000 of a second. Measurements of actual lightning strikes have shown that the 10/350 µs waveform is a reasonable approximation for the current waveform for the primary lightning stroke. Both the IEC and the IEEE have chosen the 10/350 µs waveform to represent the electrical and mechanical stress associated with direct conducted lightning. This waveform, along with characteristic magnitudes, is detailed in IEC 61643-1, First Edition, 1998, Surge Protective Devices Connected to Low-Voltage Power Distribution Systems, and the most recently approved edition of IEEE C62.41.2, Recommended Practice on Characterization of Surge Voltages in Low-Voltage (1000 V and less) AC Power Circuits.

Lightning occurs throughout the world, but some areas receive far more lightning than others. The United States, Mexico, Central America, and the northern part of South America are known as high lightning areas. Lightning occurs primarily in the northern hemisphere in the summer months, in the equatorial regions during the spring and fall, and in the southern hemisphere during the north's winter.

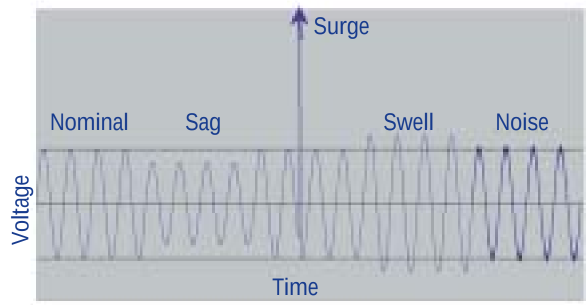
Lightning strokes can be either positive or negative. Worldwide, approximately 10% of all lightning strikes involve a positive stroke, and 90% of all lightning strikes involve a negative stroke. Although fewer in number, the positive strokes can pack a much greater punch as they have higher peak currents (I_{peak}), transfer more charge (It), and have higher specific energy (I^2t). Positive strokes occur much more often during cold front storms than warm front storms.

Within the United States, the highest incidence of lightning occurs in the southeast, with the "hot spot" being Florida. Although this area receives the highest incidence of lightning, it is predominately due to warm front storms which produce almost entirely negative lighting strokes.

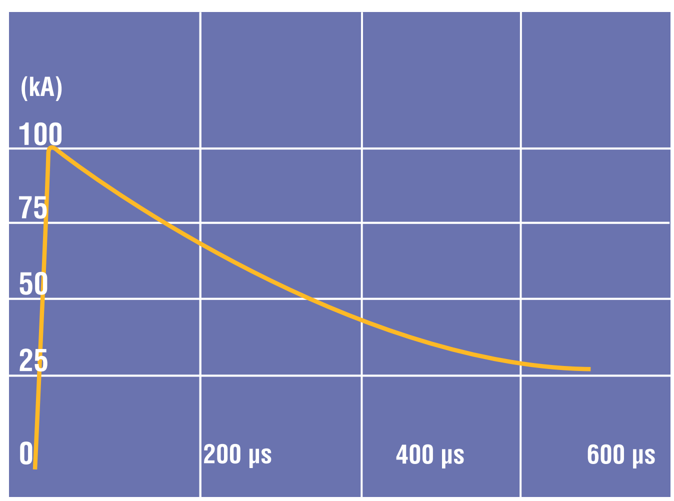
Although the mountain regions receive less lightning, they receive more of the large positive lightning strikes associated with cold front storms.

In addition, the Rocky, Appalachian, and Sierra Nevada mountain ranges have low ratio of cloud to cloud vs cloud to ground which means that a higher percentage of strikes reach the ground. As a result, even though the great plains have a higher lightning flash incidence than the Rocky Mountains, the mountain sites can often have more severe direct strike lightning problems.

A surge is a short burst of voltage.



The 10/350 µs waveform is used to represent conducted lightning currents.

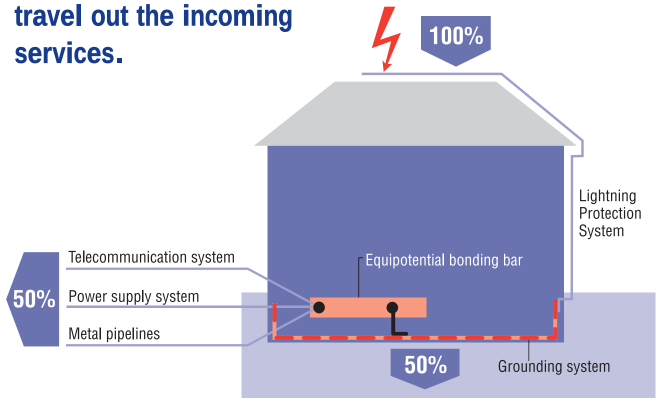


The largest surges are direct lightning strikes to either the building lightning protection system, or the secondary power conductors. Although the partial current that flows through installed surge protectors during such events is similar in magnitude to induced surges, conducted lightning currents transfer considerably more charge and specific energy than induced surges. This results in much greater electrical and mechanical stress within the surge protector, often resulting in surge protector failure. By international consensus, the 10/350 µs waveform has been chosen to represent these conducted currents as it models not only peak current, but also charge transfer and specific energy. Therefore, to ensure a surge protector will not fail under actual conducted lightning currents it must be tested with the 10/350 µs waveform.

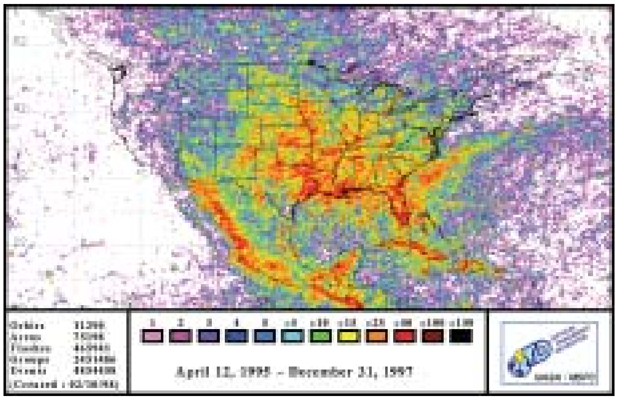
Cloud to cloud and cloud to ground strikes induce surges in nearby AC power lines. This is similar to the way a radio antenna works...imagine that the antenna, like a power line, is several miles long and that the transmitter sends out a burst of power as intense as a bolt of lightning. One can see how significant surges can be induced into long power lines from a nearby lightning strike.

In areas such as the American great plains which have between 4 and 10 cloud to cloud lightning flashes for every cloud to ground lightning flash, surge damage is more often due to a large number of induced surges rather than direct strikes.

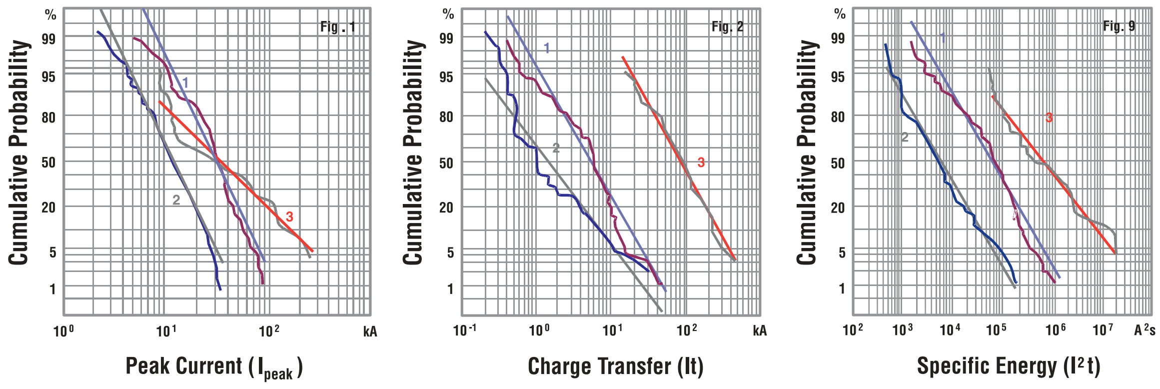
When lightning strikes a lightning protection system, a significant percentage of the lightning current will travel out the incoming services.



United States lightning distribution.



Cumulative probability distributions for key lightning parameters.



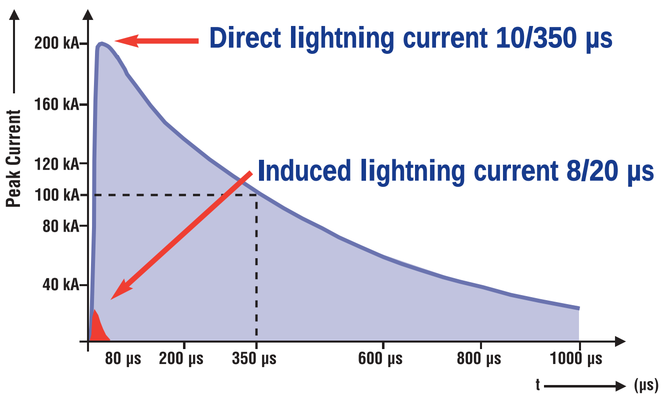
(1) Negative first strokes

(2) Negative subsequent strokes

(3) Positive strokes

K.Berger, R.B. Anderson, H. Kröninger: Parameters of Lightning Flashes, Electra, No. 41, 1975

Comparison of direct and induced lightning current wave forms.



Both the IEC and the IEEE have standardized on the 8/20 µs waveform to represent induced lightning effects. The 8/20 µs waveform, along with characteristic magnitudes, is detailed in IEC 61643-1, First Edition, 1998, Surge Protective Devices Connected to Low-Voltage Power Distribution Systems, and IEEE C62.41.2, Recommended Practice on Charactrization of Surge Voltages in Low-Voltage (1000 V and less) AC Power Circuits.

Surges are also generated due to self-inductance whenever power is switched on or off during a non-zero crossing point of the sine wave. Although smaller than lightning derived surges, these switching surges can be frequent enough to result in long term cumulative damage to solid state circuitry.

Surges that occur from the switching of electrical current include power factor correction capacitors, heavy equipment cycling, and even small swiches. The power company switches power factor correction capacitors on or off the power line to compensate for the large inductive load of industrial motors. If surge problems regularly occur in relation to industrial plant operating hours, power factor correction capacitors may be the cause.

Within the facility, surges can be caused by elevator motors, air conditioning compressors, copy machines, and other equipment. These internally generated surges are both smaller in magnitude and more numerous than externally generated surges. To protect equipment from internal surges requires that the surge protector be placed between the surge source and the equipment to be protected. A surge suppressor on the main panel, no matter how good it is, will not provide protection if the equipment to be protected and the surge source are on a subpanel, or on the same branch circuit. Total facility protection requires coordinated main panel and sub panel protection.

Detrimental Effects of Surges

The undesired consequences of surges include both equipment damage and equipment malfunction or lockup. Equipment damage occurs when excessive surge voltage flashes over or punctures semiconductor junctions. Semiconductors are also sensitive to accumulated overvoltage stress. Successive surges chip away at the insulating layers in a process referred to as “electronic rust”. When the equipment finally fails it is often not attributed to surges because there was no known major event such as a lightning storm coincident with the damage.

Surges can cause equipment malfunction or lockup without causing damage. A small surge in a digital circuit can cause a false data pulse and lock up the operating system. Although only a nuisance with a home computer, this same event with medical instrumentation, 911 emergency services equipment, or industrial processes can be very serious.

Modern equipment is much more susceptible to surge damage than equipment of the past. This is because the number of semiconductor junctions per device continues to increase, while the insulation distances between traces within a semiconductor continue to decrease.

More transistors per chip and smaller trace widths make modern equipment increasingly susceptible to surges.

Year	Model	Transistors	Speed	Trace Width
1971	4004	2,300	0.1 MHz	10.00 micron
1974	8080	6,000	2.0 MHz	6.00 micron
1978	8086	29,000	5.0 MHz	3.00 micron
1982	80286	134,000	8.0 MHz	1.50 micron
1985	80386	275,000	16 MHz	1.00 micron
1989	80486DX	1,200,000	25 MHz	0.80 micron
1993	Pentium	3,100,000	60 MHz	0.60 micron
1998	Pentium II	7,500,000	400 MHz	0.25 micron
2001	Pentium IV	42,000,000	2000 MHz	0.13 micron

Surge Protector Basics

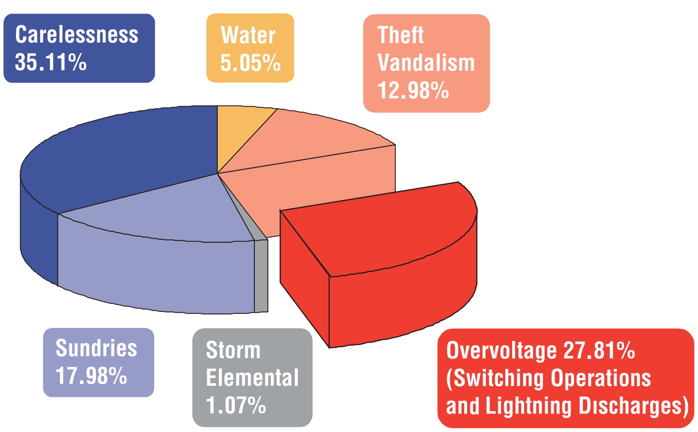
A surge protector is an overvoltage voltage pressure relief valve. At normal system voltages, the valve is closed. When a dangerous overvoltage occurs, the surge protector operates and reduces voltage to the protected equipment by allowing current to flow to ground.

To be effective, the surge protector must be placed between the source of the overvoltage surge, and the equipment to be protected.

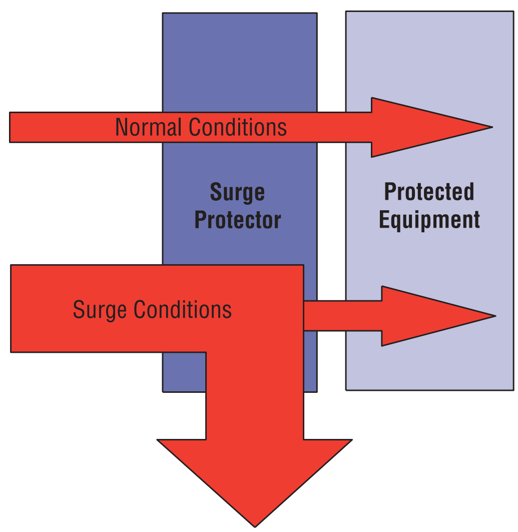
Two different types of surge protection components are used: crowbar components and clamping components. Each of these different types has unique properties and considerations.

Crowbar type components include solid state thyristors and gas tubes. A crowbar surge protection component is an on/off switch. At normal voltage it acts as an insulator. Above its turn–on point, it crowbars, creating a short circuit. Gas tubes can handle large surge currents in a very compact design with a very low capacitance, which makes them ideal for use on high density signal and data circuits.

A recent study showed that property damage was attributable to Lightning and Surges one out of three times.

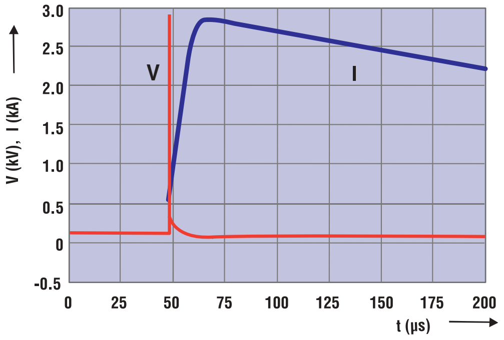


A surge protector works like an overpressure relief valve, reducing voltage at the equipment by allowing excess current to flow to ground.

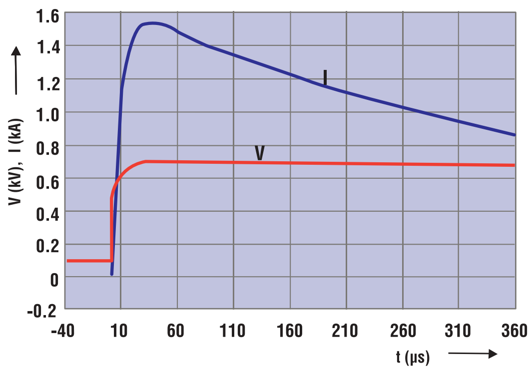


A clamping type surge protector is a variable resistor. Clamping type components include silicon avalanche diodes (SADs) and metal oxide varistors (MOVs). At normal circuit voltage a clamping component has a low leakage current and acts as an insulator. Above its turn– on point, its resistance drops dramatically. When a clamping device operates, it clamps the surge voltage to a value above the nominal operating voltage of the circuit. Unlike a crowbar protector, a clamping protector does not have an impulse voltage overshoot, and thus typically has a lower peak let-through voltage. However, clamping components have a relatively large capacitance, which limits their use on signal and data circuits.

A crowbar device crowbars the surge voltage below the circuit voltage.

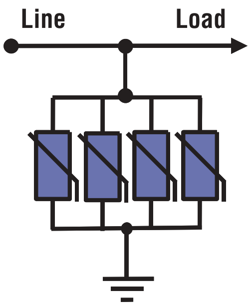


A clamping device clamps the surge voltage above the circuit voltage.



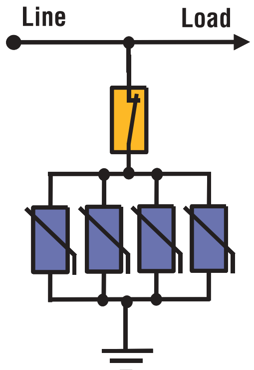
Individual surge protector components have limited surge capability and surge pulse life. In order to increase surge capability and pulse life, designers typically combine multiple surge protection components in parallel. Non-linear components such as MOVs (metal oxide varistors) and SADs (silicon avalanche diodes) share more equally at higher peak currents than at lower peak currents. For individual components, engineering scaling factors are often used between different surge current waveforms. Because non-linear components do not share as well on lower amplitude longer duration waveforms, scaling factors cannot be used for multiple component parallel designs. Parallel component designs for use against conducted lightning currents must be tested with the 10/350 µs waveform rather than relying on an 8/20 µs scaling factor.

Placing MOVs in parallel increases surge capability and pulse life.



Both MOVs and SADs fail in a low impedance or shorted state. This means that when used on power circuits, an overcurrent disconnect device must be provided within the protector. When used on a multiple component parallel design, use of a single disconnect means that the entire surge protector will be taken off line if a single component fails. Modern surge protectors often use fuses or thermal elements on each of their paralleled protection components (MOVs/SADs) so that when a single component fails the remainder still provide protection for the load. When combined with individual component monitoring, use of this paralleled disconnect scheme allows replacement of the failed component without ever losing surge and lightning protection.

Single thermal disconnect removes entire surge protection.



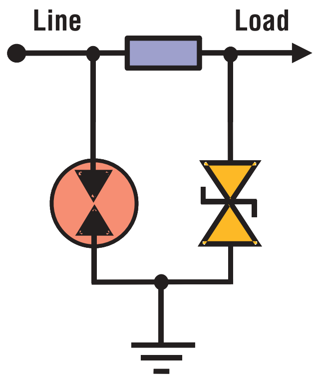
In order to reduce size and capacitance, surge protectors for signal and data circuits are based on a coordinated decoupled hybrid design.

Such a design uses one or more high capacity gas tubes to provide brute force protection. Gas tubes handle large surges, have a very low parasitic capacitance, and are very compact, however they have a slow response and relatively high sparkover voltage.

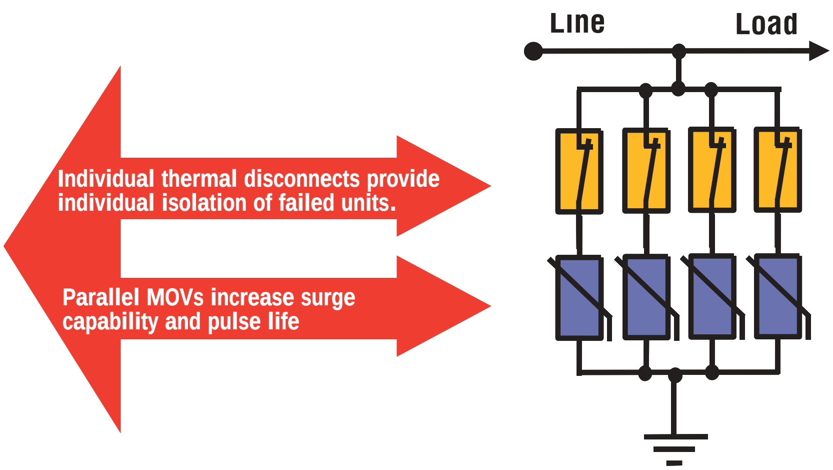
A fast acting suppression diode is added to the circuit to provide high-speed response and tight clamping voltages. Since the diode acts faster and clamps lower than the gas tube, a decoupling impedance is used between the two components. The voltage drop across the decoupling impedance ensures the gas tube will fire before the diode's surge capability is exceeded.

Since the voltage drop across the decoupling impedance is dependent on peak current, lower amplitude longer duration waveforms than the protector was designed and tested for can result in diode failure. Therefore, decoupled hybrid component designs for use against conducted lightning currents must be tested with the 10/350 µs waveform rather than relying on an 8/20 µs scaling factor.

Coordinated hybrid designs such as the DEHN® Inc. BLITZDUCTOR® provide high surge capacity and low clamping voltage in a compact low capacitance design.



Modern surge protectors such as the DEHN® model S200A use paralleled MOV's in each circuit, with individual thermal disconnects and monitoring circuitry for each MOV. In the event of an individual MOV failure, the remaining MOV's continue to function, providing uninterrupted surge protection. The monitoring circuit indicates a failed MOV, which can then be replaced without ever losing surge protection.



Surge Protector Characteristics

The ideal surge protector must meet three basic goals:

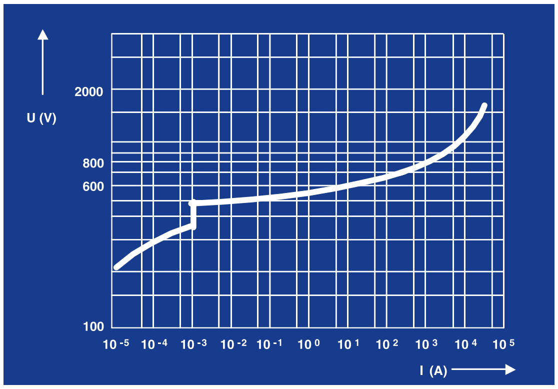
1. Do a good job
2. Last a long time
3. Be easy to use and maintain

A Surge Protector Should Do a Good Job

To do a good job the surge protector needs to protect the equipment. This means that when the surge protector is subjected to surges representative of the environment in which it will be installed, it must reduce the voltage at the protected equipment to a level the equipment can withstand without damage or upset. To verify that the surge protector will do a good job, we need to establish:

1. What surges are characteristic of the environment in which the surge arrester will be installed.
2. The maximum residual voltage the equipment can tolerate without damage or upset.

Clamping voltage as a function of peak current for a typical surge protector.



The surge environment is defined by IEEE C62.41.2, Recommended Practice on Characterization of Surges in Low Voltage (1000 V and Less) AC Power Circuits. Although this IEEE standard defines test waveforms, it does not specify the required let-through voltage necessary to protect equipment. Required values for let-through voltage are contained in Telcordia TR-TSY-0001011 Generic Requirements for Surge Protective Devices (SPDs) on AC Power Circuits. This Telcordia specification, which is widely recognized throughout the telecommunications industry, places a let-through voltage limit of 1340 volts for a 10 kA 8/20 µs surge on a 120 Vac power system.

In order to meet this limit, the surge arrester must be installed with short, straight, closely coupled connection leads to minimize the inductive voltage drops. The voltage drop across a 120 Vac surge arrester is typically around 600 V. Any additional voltage drop across the connection leads adds to this voltage. The wave front of a 10 kA 8/20 µs surge generates 1250 V/µH across the inductance of the connection leads. For leads separated by six inches, this results in a voltage drop of approximately 400 V/ft of connection leads. If the leads are closely tied together, this voltage drop can be reduced to approximately 200 V/ft. Hence for closely coupled leads, the surge arrester needs to be installed within three feet of the power bus.

Within the protector, the protection elements should be connected from line to neutral, and if the protector is not installed at the neutral to ground bond point (service entrance) protection elements should also be installed between neutral and ground. Installation of additional protection components between line and ground is unnecessary and can needlessly inject noise into the ground plane.

A Surge Protector Should Last a Long Time

In order to last a long time, we need to ensure the surge protector can withstand the extremes of its electrical environment throughout its expected service life. To accomplish this we need to ensure that it has sufficient maximum surge capability, surge pulse life, and ac overvoltage swell immunity.

Maximum Surge Capability:

A surge protector should withstand the maximum surge expected without damage.

For service entrance surge protectors subject to conducted lightning current it is important that the surge protector be tested to the 10/350 µs waveform. Conducted lightning current transfers more charge and specific energy than induced surges, and because of this places much greater electrical and mechanical stress on the surge protector than induced surges. The 10/350 µs waveform has been chosen by international consensus to represent conducted lightning current as it represents all the key lightning current parameters which cause electrical and mechanical stress within the surge protector. IEEE C62.41.2 recommends values of 2.5 to 10 kA 10/350 µs for modeling conducted lightning currents.

All surge protectors are subject to induced surges and should be tested using the internationally accepted 8/20 µs waveform. Typical values are 10 kA 8/20 µs (IEEE) and 20 kA 8/20 µs (Telcordia and IEC). Although many surge protectors are rated much higher, only a few manufacturers have actually tested these higher ratings, and many fail at much lower values.

Factors that limit the maximum surge capability of a surge protector include in-line fusing, electromechanical integrity, and protection components. When the maximum surge current rating is based solely on the sum of the surge current ratings of the protection components (as many are), the protector can often fail in the field when subjected to much lower surges. Common weak points which can fail include in-line fuses blowing, circuit board traces vaporizing or separating from the circuit board, and high magnetic forces ripping wiring terminals apart. These failures often occur at 1/10 the manufacturers rated surge current value.

To ensure a protector can meet its specification without blowing fuses or failure of other internal components, performance must be verified by actual testing.

- Surge protectors rated for high 8/20 µs currents must be tested to their full manufacturers specified surge current.
- Surge protectors designed for lightning currents must be tested with the 10/350 µs waveform.

Testing with the incorrect waveform for the application, testing of individual components at lower surge levels, and/or reliance on scaling factors will not ensure acceptable performance in the field.

Surge Pulse Life:

Telcordia TR-TSY-0001011 Generic Requirements for Surge Protective Devices (SPDs) on AC Power Circuits, requires a surge life of 2 operations of 20 kA 8/20 µs, plus 90 operations of 10 kA 8/20 µs, plus 2100 operations of 3 kA 8/20 µs. Experience has shown that this is sufficient for inductively coupled surges.

Overvoltage Immunity:

If a swell should exceed the turn on voltage of the MOVs, the MOVs will conduct until they overheat and fail. To minimize this, surge arresters for use in remote and industrial areas should have a maximum continuous operating voltage of 125% of the nominal service voltage.

Even with the 125% MCOV, there will be an occasional failure of the MOVs due to excessive AC overvoltage. The AC surge suppressor should be designed to disconnect the MOVs before they can overheat to point of creating a fire hazard. UL safety testing requires limited current abnormal overvoltage testing at 5 A and below. When the internal surge protector fusing is rated for over 5 A steady state (and most are), this leaves a blind spot between 5 A and the actual rating of the inline fusing. To prevent a protector operating within the blind spot from creating a safety hazard, a thermal sensing device needs to be added in addition to the current fusing. When the AC overvoltage heats the MOV above the thermal device set temperature, a soldered joint melts and a spring loaded disconnect activates, safely disconnecting the MOV from the line.

A Surge Protector Should Be Easy to Use and Maintain

Major factors which make a surge protector easy to use and maintain include self monitoring of performance capability, ease of parts replacement, and user safety.

There are two types of monitoring currently used; go/no go and reduced protection indications. By individually monitoring each individual MOV, service can be ordered if a single MOV on a single phase conductor should fail. This allows for the surge arrester to be repaired before all protection is lost.

Replacement parts, including surge protection modules and fuses, should be replaceable without tools or the need to power down the unit.

The surge protector should provide the same level of safety against accidental contact with live contacts as adjacently mounted equipment. Hinged cover surge protectors, like circuit breaker panels, should have a dead front cover to provide finger safety.

Other DEHN® Products

DEHN® manufactures a comprehensive line of Lightning & Surge protection devices. for protection of AC/DC power, signal and data lines, RF antennas, and cathodic protection systems.

For further information on other products, contact DEHN® or your local DEHN® representative.

Typical Products

S series UL listed AC protectors

BLITZDUCTOR® for protection of measurement and control circuits

Model DEHNgate for protection of RF antennas

DEHN, INC.

TO BE SURE, USE DEHN®

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