

White Paper

Transient Surges and Suppressor Technologies

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Metal Oxide Varistor (MOV) versus Silicon Avalanche Suppressor Diode (SASD) Designs Discussion

The sole function of a quality surge suppressor is to protect sensitive electronic equipment from transient overvoltages that are present on AC power circuits. It is irrelevant whether these overvoltages are generated by lightning activity or are induced upon the AC power lines by utility grid switching, power factor correction actions, power cycling of inductive loads, or from other sources. A quality surge suppressor must limit transient overvoltages to values that do not surpass the AC sine wave peak by more than 30% as it initially absorbs intense amounts of transient energy. The suppressor must immediately respond to transients before they reach their uppermost voltage values. Suppressor performance should not deviate or degrade with use when called upon to divert extreme levels of transient current.

Transient surges are differentiated by their duration, frequency and amplitude. The surge suppression industry has adopted IEEE Power Engineering Society's IEEE C62.41-2002 document, titled IEEE RECOMMENDED PRACTICE ON SURGE VOLTAGES IN LOW-VOLTAGE AC POWER CIRCUITS, as the standard for categorizing transients and the associated waveforms used to test suppressor efficacy. This guide defines several varied voltage and current waveforms that occur in the electrical distribution environment. The most frequently referenced IEEE waveform is the combination wave. The combination wave is characterized by short duration, high-frequency short-circuit 8/20 μ s and open-circuit 1.2/50 μ s current and voltage waveforms. It is used to simulate lightning-induced transient activity. Longer duration, lower frequency, higher energy 10/1000 μ s voltage and current test impulses (also detailed within the same IEEE documentation) are recommended to simulate transient activity originating from other sources. For testing, actual voltage and current values are selected in reference to where the surge suppressor is intended for use. Surge suppressors intended for use at any location on the distribution system will be subjected to long duration waveforms and should be tested to withstand these conditions, regardless of their suppression technology. Figure 1 illustrates the combination waveforms.

When these combination waveforms are utilized to test surge suppressors, the generator voltage is adjusted to an open circuit voltage (See Figure 1). It rises to this value within 1.2 microseconds. The voltage decays to 50 percent of that value after 50 microseconds. Short circuit transient current pulses reach their maximum value in 8 microseconds and decay to their half-point after 20 microseconds.

The combination wave provides a starting point to analyze a suppressor's performance characteristics in reference to voltage protection levels (VPL) and power dissipating capabilities.

Unfortunately, short duration test pulses do not propagate far enough into an electrical distribution system to give the suppressor user a clear idea of how the suppressor will perform in the real world. Transients that are generated by grid switching

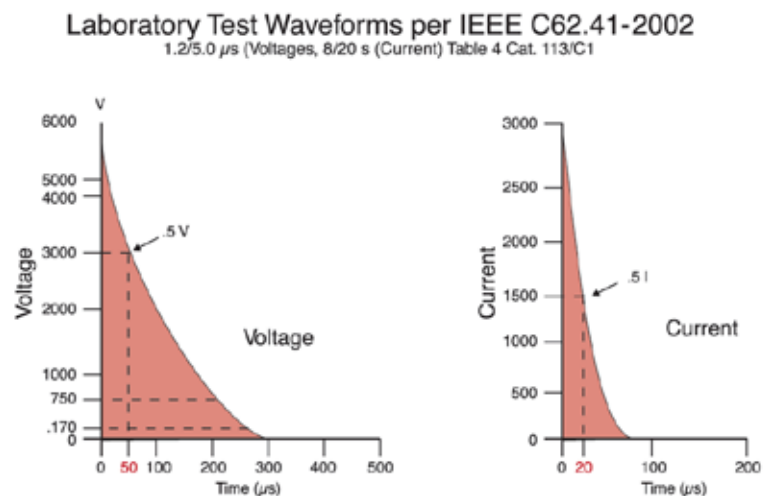


Figure 1

Because this generation has an internal impedance of 20 Ω . The peak current value will be 3000A. The suppressor is connected to the generator for testing.

power cycling of inductive and capacitive loads and other sources cause suppressors to activate. This transient activity is typically characterized by lower frequency (1 kHz) 10/1000 μ s duration waveforms. The laboratory waveforms utilized to simulate this transient activity are shown in Figure 2.

The physical properties of the electrical distribution system limit how far lightning-induced, or other short duration, transient surges are able to travel. Extremely high voltage transients are required to drive high voltage lightning surge current far into a facility. Transient voltages are limited (to typically 6000V because of air gap protection or insulation breakdown) at the meter base, preventing surge currents from propagating far into the building. However, most transients originate from sources other than lightning and are much more likely to travel longer distances throughout the AC power system. These transient surges are more threatening to electrical loads because they are not diminished over shorter distances, unlike lightning-induced impulses. In fact, lower level surges (below 6000V) actually force more current into a system because the transients pass under the radar of the air gap.

Suppressors intended to protect at specific points along the electrical distribution system must be selected in accordance with their physical location. Higher energy dissipating products must be used at main distribution points as compared to sub panels or electrical outlets. Suppressors intended to protect at a low exposure main or sub-panel locations inside any facility rarely need to be designed to suppress more than 3000 amps of transient current. By design, meter base gaps allow for extreme voltages to dissipate before they reach the distribution panel. Those outdoor transients might otherwise pose a threat to the facility's electrical distribution system. Figure 3 illustrates that high level voltages (in excess of 6000V) are required to drive surge currents that exceed 5000 amps a distance farther than 10 meters into an electrical distribution system.

It is very important that a surge suppressor be capable of suppressing short duration impulses, resembling and including those generated by lightning activity. It is equally, if not more important, for a suppressor to be able to sustain suppression functions and divert current effectively when called upon to suppress longer duration transients. Suppressors intended to protect at branch panels or electrical outlets will be called upon to suppress these transients more frequently than those that are lightning-induced. Surge suppressors should be tested to both long and short duration laboratory waveforms to confirm these suppression requirements.

Manufacturers utilize numerous technologies for suppressor components. These include selenium, gas tubes, metal oxide varistors (MOVs), silicon avalanche suppressor diodes (SASDs). However, most suppressors utilize MOVs or SASDs or combinations of the two. It is important to discuss the advantages and disadvantages of the two most common suppression technologies.

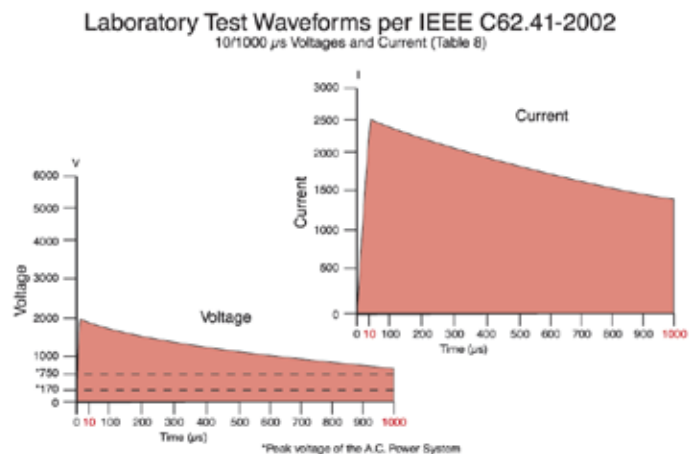


Figure 2

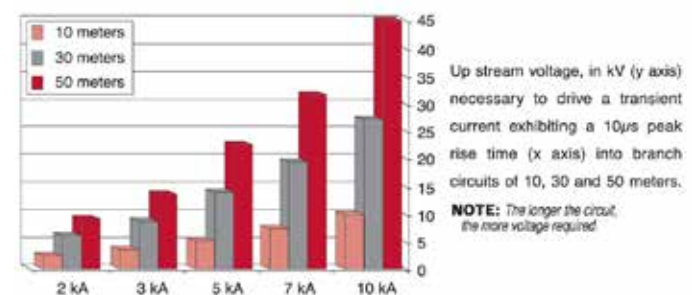


Figure 3

Metal Oxide Varistors (MOVs)

MOVs are non-linear variable resistors with semi conductor properties that were originally designed to protect electrical motor windings against wiring insulation breakdowns. There are two advantages associated with MOVs in regard to surge suppressors. They are inexpensive and they divert reasonably high values of transient current. MOVs are typically constructed with zinc oxide, which has non-linear resistive characteristics. (The term non-linear is used to define any device with resistive characteristics that change as a function of the induced current. The equation takes the form of $R=aI^{-b}$, where a and b are constants and R will be a curved line.) The zinc oxide particles are compressed under very high pressure to form various sized discs. To complete the varistor, electrical leads are bonded to the discs and covered with an insulating material.

When transient currents are introduced to an electrical system, the MOV shunts the current away from loads. As a varistor conducts transient current its internal resistance increases. Unfortunately, its non-linear resistive characteristics prevent symmetrical resistance shifts equal to supplied current deviations. The voltage drop across the MOV increases drastically as the varistor conducts high current values.

Numerous drawbacks become apparent as MOV based suppressors are utilized to protect sensitive electronic circuitry:

1) An MOV based suppressor device cannot maintain a stable VPL as it conducts increasing current values. As the device conducts increasing levels of transient current, it cannot limit transient overvoltages to a value of less than 30% excess of the normal AC sine wave peak.

Figure 4 illustrates this inadequacy. Note that the curve representing the MOV's suppression response climbs steeply as it conducts longer duration transient current. The curve representing the suppression response of the SASD shows that it does not suffer from the same drawbacks. Some MOV based suppressor product specifications boast extremely high surge current capacities (of up to 300,000 amps) without reporting the VPL. These large figures sound impressive; however, this practice is misleading and often meaningless. As depicted in Figure 5, the individual MOV components are frequently rated with a reasonably high peak surge current rating. If a product utilizes multiple MOVs connected in parallel, some manufacturers will add the current ratings of the individual MOV components together and report the

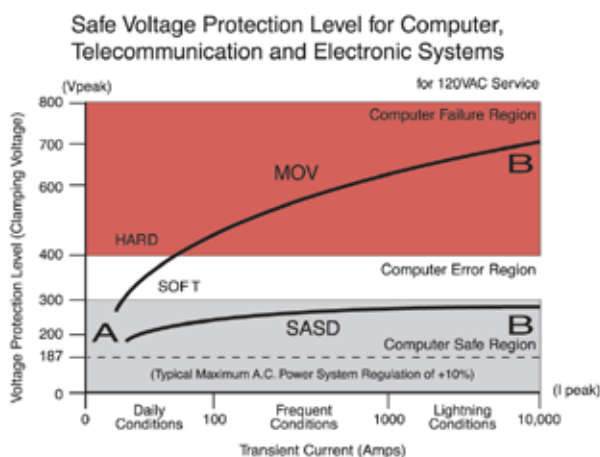


Figure 4

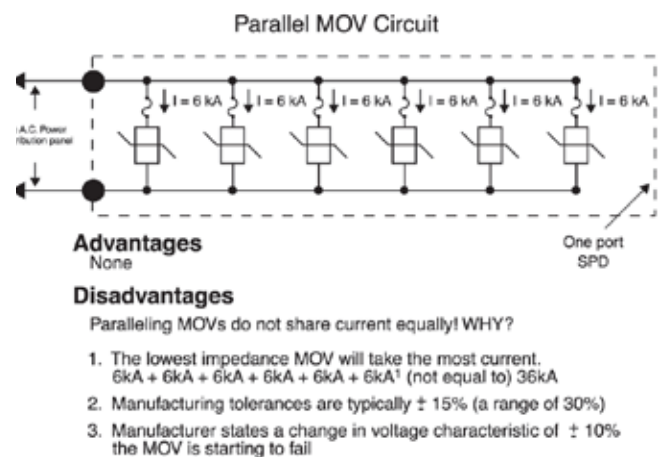


Figure 5

sum as an impressively high total value surge current capacity. This sum method is inaccurate because it is impossible to coordinate simultaneous conduction of multiple MOVs that have varying component tolerances and degradation cycles. It is like saying that a set of tires for your car will travel 200,000 miles because each of the four tires is a 50,000 mile radial.

In addition, it remains difficult to determine true VPL at the maximum rated surge current value. A device constructed with larger MOVs can be useless to protect electronic equipment. Although the component may be capable of suppressing much greater current values, it is very likely that the VPL will be too high to protect electronic equipment.

2) MOVs degrade with use. Most MOV manufacturers warn users that the component is considered failed after its initial VPL has moved $\pm 10\%$ from its original value. The MOVs conduct current through paths of zinc oxide particles. After they conduct surge current, these particles change and their resistive characteristics are weakened. This degradation cycle becomes more profound when the MOV conducts more frequently or conducts higher current values. Although larger MOVs are more robust, they are plagued by the same problems.

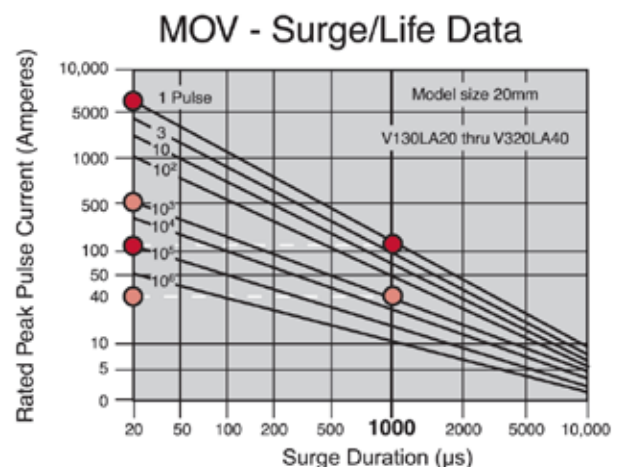
Figure 6 compares the single pulse life expectancy of 20 mm to 32 mm MOVs. Note that the 20mm MOV can withstand 1,000 500A 8/20 μ s current pulses and will self-sacrifice when it suppresses a single 6,500A 8/20 μ s transient current pulse. However, its surge current capacity decreases significantly as it is subjected to longer duration 10/1000 μ s transient current pulses. The 20mm MOV can be expected to fail when subjected to 1,000 40A 10/1000 μ s current pulses or a single 200A 10/1000 μ s transient current pulse.

The 32mm MOV is slightly more robust. It can handle one 20,000A or 1,000 900A 8/20 μ s current pulses but no more than one 450A 10/1000 μ s current pulse. Its maximum surge current capacity drops to a mere 50A value if the 32mm MOV is required to suppress 1,000 10/1000 μ s transient current pulses. At this level, the zinc oxide particles will meld together to form pools of increasingly larger surface areas. More often they will increase in resistance. As degradation continues, the MOV will either short the protected power circuit or stop conducting current.

Typical MOV degradation cycles begin as the component continues conducting current past its original VPL. The level continues to increase as the MOV degrades.

Eventually the voltage values required to activate the MOV will be at such extreme levels that it will be useless. In the case that a damaged MOV functions as a resistor rather than a varistor, it can overheat and introduce a fire hazard. In either failure event, no transient protection is provided for critical electronic loads on the affected power circuit.

3) Varistors create thermal runaway conditions when their initial clamp points or VPLs are set too close to the nominal AC line voltage. When installed across an AC power source, MOVs conduct small amounts of electrical current. They conduct more current if the VPL is set too close to the peak voltage value of the AC sine wave.



This graphic is republished from a MOV manufactures specification

Figure 6

Conduction continues over time and results in an elevation of the MOV's internal temperature. The heat causes it to conduct even higher current values and this spiral continues until it shorts. This loads electrical circuits, causes circuit breakers to clear, and can trip ground-fault interrupters. MOV based suppressors with thermal runaway disorders have been documented to ignite fires. To prevent these catastrophic failures, the initial VPL of MOV based suppressor products is typically set to a higher value. This design parameter eliminates the device's ability to provide adequate transient voltage protection.

Silicon Avalanche Suppressor Diodes (SASDs)

Compared to other suppression technologies, the advantages associated with the use of SASDs are numerous. Like the components within the sophisticated circuitry of modern electronic equipment that they are intended to protect, SASDs are true solid state semiconductors. Unlike MOVs, SASD based surge suppression components do not degrade or cause thermal runaway conditions.

SASDs turn on faster than MOVs and respond rapidly to transient overvoltages. Transient surges are characterized by their extremely rapid rise-times. A quality suppressor must respond fast enough to prevent transients from reaching a potential voltage high enough to degrade electronic components, disrupt equipment operation or damage electrical loads. A SASD based transient suppressor can be reasonably expected to illustrate an in-circuit response time of five nanoseconds or less. MOV devices are also relatively quick to respond to transient overvoltages. Realistically, their in-circuit response times fall into the 35 to 50 nanosecond range.

Quality SASD based suppressor product lines have the ready ability to maintain a stable VPL at any location upon the AC power system while conducting maximum current values. Unlike the challenges associated with MOV designs, the simultaneous conduction of SASD circuits in parallel is plausible. In addition, the non-linear behavior of the SASD resistance is more abrupt and, therefore, more effective.

A surge suppressor must be designed to suppress near the peak voltage value of the AC sine wave while dissipating extremely high levels of transient energy. Here lies the basis of the cost disadvantage associated with SASD based suppressor products: individually, diodes cannot divert as much current. A properly designed SASD suppressor must incorporate numerous diodes to precisely perform their suppression responsibilities without self-sacrificing. As a result, the suppressor is often more expensive and physically larger than its MOV based alternative.

SASD based products do not degrade with use or over time. As long as their energy dissipating capabilities are not exceeded, they will function perpetually. Quality SASD suppressors should not be designed (or expected) to self-sacrifice during a typical transient surge event. It becomes apparent that a quality SASD based surge suppressor must incorporate enough diodes to handle the transient currents it will likely be subjected to under normal as well as extreme transient conditions.

It is also important to point out that non-diode based suppressor manufacturers usually test their products to short duration 8/20 μ s current impulses (intended to simulate those generated by lightning activity). They often do not test their devices with long duration 10/1000 μ s long wave pulses that the suppressor will more frequently be required to suppress. Note that high-energy pulse factories use in testing can cause degradation of non-diode based suppressor products before they reach the consumer.

Hybrid SASD/MOV Suppressors

Some suppressor manufacturers have hybrid designs that use both SASDs and MOVs. The hybrid designs attempt to take advantage of the positive performance characteristics while overcoming the negative drawbacks associated with the two suppression technologies. For cost savings, these designs generally utilize fewer SASDs as compared to pure SASD products. In a hybrid, SASD circuits are utilized to take advantage of superior response times and stable VPLs while MOV stages are introduced to handle high current dissipation.

Because of the vastly different operational characteristics of the two technologies, these hybrid designs fall short of their desired goals. There is even more difficulty coordinating simultaneous conduction between SASD and MOV components. The MOV stages cannot be coordinated to conduct reliably and simultaneously with the SASD stages. Often, premature suppressor failure is realized by the SASD stages because enough diodes to dissipate proper levels of transient energy are not incorporated. The MOV stages continue to function, but they are still plagued with the same deficiencies of the pure MOV based product. Properly designed surge suppressors utilizing 100% SASDs as their sole suppression technology are superior to hybrid designs.

Transient Surges Defined

The intensity of a transient overvoltage is determined by the rate of change in voltage or current and response of capacitors or inductors. Rapidly changing the voltage across a capacitor produces a large current. The current level is dependent upon the capacitor size and the rate of voltage change. The following formula is used to calculate transient currents associated with capacitive circuits.

$$I = C \, dv/dt$$

Where C represents capacitance, as the change in time (dt) decreases relative to the change in voltage (dv), the amplitude of the current (I) increases.

The same basic relationship applies to an inductor as well. Here, a rapid change in current results in a large voltage transient (-V) as defined by the following formula (where L = inductance and di = change in amperes):

$$-V = L \, di/dt$$

When analyzing the damaging effects of transients, it must be known where the transient is induced on the AC sine wave. Transient voltage values add instantaneously to sine wave voltages. When a transient propagates onto a line, load devices are subjected to that total overvoltage value. In some cases a transient that is induced upon the zero crossover point may be harmless, whereas that same transient induced upon the peak of the sine wave can be very disruptive. For example, the peak value of a 120 VRMS sine wave is 169.68V. A surge measuring 150V induced upon the peak of that sine wave (volts/peak) will add 150 volts to the 169.68V peak sine wave value. Therefore, a total voltage of 319.68V is passed along to load equipment in this example.

Overvoltages at these levels can disrupt sensitive equipment operation. On the other hand, that same 150 volts/peak transient occurring at the zero crossover point of the sine wave subjects load devices to a harmless 150V instantaneous voltage value that is contained well within the normal AC sine wave voltage envelope.

Numerous studies conducted during the past 30 years have identified transient activity as the most common AC power anomaly likely to disrupt or damage critical electronic equipment. G.W. Allen and D. Segall of IBM System Development Division conducted one of the most reputable studies. They monitored AC power at 200 locations, where IBM equipment was installed and operating in 25 cities across the United States. They recorded the number of various AC power anomalies that disrupted equipment operation during a two-year time span. They presented their findings to IEEE/PES. Their study was summarized in IEEE Conference Paper #C 74-199-6. This study serves as a good reference because it was very thorough and was conducted by professionals working outside of the AC power treatment industry.

Allen and Segall grouped transient activity into two categories:

Voltage spikes (impulse transients)

- Those induced by lightning activity
- Characterized by very high, short duration voltage and current levels

Oscillatory, decaying transients (Internal transient overvoltages are generated by sources such as SCR controlled light ballasts, air conditioners, furnace igniters, motor control centers and copy machines. They differ from lightning-induced transients in that they typically are lower value voltage and current pulses that last up to 50 times longer.)

- Utility grid switching activities,
- Power factor correction
- Generated by power cycling of inductive
- Loads and from numerous internal sources

Figure 7 summarizes this study's findings in pie chart form on the right.

The Allen-Segall study concludes that 88.5% of AC power problems are transient related.

Allen and Segall found that the most disruptive power problems regard oscillatory, decaying transients that (occurred 62.6 times monthly) account for 49% of the total number of AC power abnormalities. These are examples of long duration, non-lightning related transients.

Lightning-induced impulse transients (occurred 50.7 times a month) account for 39.5% of the total number of AC power hits.

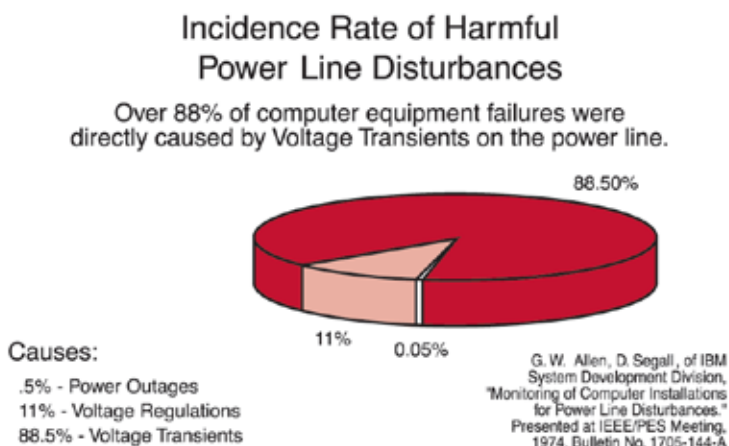


Figure 7

In contrast, sags and swells were only responsible for 11% of AC power problems and power outages accounted for a mere .5% of equipment disruptions.

Electrical distribution systems have not changed significantly from the mid-seventies, while electrical and electronic equipment has become much more sophisticated. Now, power outages are becoming more infrequent while harmonic distortion has become a major concern for equipment users. Transient activity has also become increasingly more threatening to state-of-the-art electronic load devices.

A quality transient surge suppressor limits the amplitude of transient overvoltages at all times, regardless of their points of origination, to levels that are harmless to electronic equipment.

Filter Networks Cannot Provide Ample Protection Against Transient Activity

A filter's operational characteristics, by definition, are frequency dependent. It cannot adequately protect critical electronic loads from lightning-induced transient surges, nor can the filter protect against transients generated from non-lightning sources. It is designed to attenuate noise occurring within a band of repeating frequency ranges at relatively low voltage and current amplitudes.

As it relates to an AC power distribution system, noise is a low voltage, low current signal characterized by a repeatable frequency pattern riding along the 60Hz sine wave. It typically measures less than 50 volts/peak and its current values generally do not extend beyond milliamp ranges.

The perfect filter used on AC power lines would have the capability to attenuate all noise voltages above and below the 60Hz fundamental power frequency from DC (direct current) to light frequencies. Any filter design will provide maximum attenuation at a specified frequency. Lesser attenuation levels are accorded for noise frequencies above and below that center frequency. The perfect filter would also be a series device and conduct the entire normal load current with no loss or heating.

Filter manufacturers may design their products to target and to provide maximum attenuation to specified test waveforms in order to justify marketing their devices as surge suppressors. In these cases filter networks may be designed to provide maximum attenuation to a .5 μ s-100kHz ring wave, a 1.2/50 μ s waveform, or an 8/20 μ s current pulse that are utilized by the suppression industry as test parameters.

The .5 microsecond -100kHz ring wave is defined in IEEE C62.41-2002 (IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits). It is utilized to test suppressor products that are intended to protect at electrical outlets.

The 1.2/50 μ s and 8/20 μ s waveforms are also defined in IEEE C62-41-2002. As defined therein, the IEEE Standard 1.2/50 μ s-8/20 μ s combination wave is used to test suppressors intended to provide protection at main and branch panels. The 1.2/50 μ s waveform is an open-circuit voltage pulse that reaches its peak value in 1.2 μ s and decreases to 50 percent of the peak voltage value after 50 μ s. To properly test a surge suppressor, the device should be pulsed with that voltage waveform and the associated short-circuit 8/20 μ s current waveform.

To adequately determine how a protection product will perform in real world applications it must also be tested to 10/1000 μ s pulses. Long duration waveform parameters are also defined in IEEE C62.49-2002. These waveforms can be used as a stress test to determine how suppressors perform under worst-case scenarios. Most filter/suppressor manufacturers do not test to this long pulse nor do their products perform well when subjected to that long duration stresses.

A filter cannot provide ample protection against transient activity. This is because transients differ from noise in that they are high voltage, high current impulses that are not frequency dependent. Transients are defined as a random burst or bursts of energy that lasts for less than 1/2 cycle of AC input induced upon any portion of the AC sine wave. They exhibit extremely rapid rise times. They can reach their maximum voltage amplitude in one microsecond and typically do not display any identifiable repeating frequency pattern.

Lightning-induced transients are characterized by very short duration waveforms. However, most transients originate from other sources. Transient surges result from utility grid switching activities, power factor correction actions, and the power cycling of inductive loads. Most non-lightning-induced transient overvoltages exhibit much longer durations that last up to a full millisecond or longer. Therefore, transient overvoltages can exhibit both high and low frequency elements. Lightning-induced transients exhibit higher frequency elements than those generated by non-lightning activity.

A filter intended to protect against long and short duration transients would have to be capable of providing maximum attenuation for all frequencies falling within the kilohertz (kHz) through megahertz (mHz) ranges.

Take for example the corresponding frequencies of the previously mentioned suppressor test waveforms that simulate transient characteristics. In addition to the frequency of the 100kHz Ring Wave, repeating the 1.2/50 μ s, the 8/20 μ s, or the 10/1000 μ s pulses would correspond to 20kHz, 50kHz, and 1kHz frequency patterns. If a filter targets 50kHz as its center frequency, as is commonly done, then attenuation is provided for the lower frequency (1kHz) as well as the higher frequency (100kHz) pulses. However, filters generally advertise very low attenuation for frequencies falling below a 5kHz threshold, which translates into zero protection.

AC power lines and distribution systems tend to naturally attenuate the higher frequency surge elements while passing the longer duration transient components. The high frequency components of an 8/20 μ s transient current spike (50kHz) are reduced in number as the surge travels along the distribution system. Only a fraction of the original transient current remains as it propagates deeper into the power circuit. In contrast, the more common 10/1000 μ s (1kHz) waveform retains much more energy due to the lesser effect that line attenuation has on lower frequency transient energy. The typical filter is designed to attenuate the 50kHz pulses. It is equally, if not more, important for it to protect against the 1kHz pulses. While a filter cannot accomplish this, a suppressor utilizing “clamping” components can.

Transient overvoltages can be very high in energy content. This excessive energy can saturate the filter's inductor elements, which changes its operating characteristics and provides dramatically reduced levels of attenuation over the entire duration of the transient overvoltage.

Suppressor products must utilize clamping components in their designs that adequately protect electronic equipment from transient overvoltages. They must not load the AC circuit and they must not distort the AC sine wave as they perform their intended function. However, filter elements contained within any suppressor product can be counter-productive as they can introduce some of these problems into the protected AC power circuit.

Conclusions

The suppressor to protect a specific point upon an electrical distribution system must be selected accordingly to its physical location. Higher energy dissipating products must be used at main distribution points as compared to sub panels or at electrical outlets. IEEE C62.41-2002 is accepted as an industry standard pertaining to the transient voltage and current test waveforms to be utilized to test surge suppression devices at various physical locations throughout an electrical distribution system. It specifies that surge suppression equipment intended to protect at low exposure main or sub-panel locations inside any facility rarely need to be designed to suppress more than 3,000 amps of transient current. It explains that a quality suppressor will only be called upon to suppress from 5,000 to 10,000 amps of surge current as it protects at medium and high exposure locations. Therefore, the need for surge suppression products capable of suppressing surge currents beyond these ranges does not exist.

Please contact us for questions or further information on this topic.

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